Chapter 5
Biogas Production from Date Palm Fruits

P. Senthil Kumar and C. Femina Carolin

Abstract In order to explore the renewable energy resources like biogas, there is a need to find the appropriate feedstock to avoid the depletion of fossil fuels and environmental deterioration. Date palm fruit is a suitable raw material with health promising features. Palm fruits also have the capability to produce biogas at a high quantity. Anaerobic digestion of palm fruit is a most valuable technique that has been evaluated as a promising feedstock to generate biogas like methane. In the event of biogas production, the anaerobic procedure assumes an essential part which gives higher help to the high amount of biogas generation. It is generally connected for the treatment of organic waste like palm natural products because of its high natural substance which helps in the generation of biogas.

This chapter features the elements which impacting or influencing the anaerobic procedure and different kind of anaerobic reactors, for example, continuous stirred tank reactors, anaerobic filtration, anaerobic fluidized bed reactors, anaerobic contact process, upflow anaerobic sludge blanket reactors and so forth used for the methane gas generation. These reactors are organic procedures that have been disclosed to upgrade the biogas generation. This chapter also depicts the potential for biogas production from date palm fruit and additionally it reveals the upsides and obstacles for anaerobic digestion technology. Procedures to additionally enhance these methodologies alongside future research are outlined in this chapter.

Keywords Renewable energy · Biogas · Palm fruits · Anaerobic digestion · Continuous stirred tank reactors · Anaerobic filtration · Anaerobic contact process

5.1 Introduction

Date palm (*Phoenix dactylifera*) is an essential antiquated monocots plant in the Saudi Arabia. It is made up of various natural products including leaves and seeds. Date palm parts are highly utilized in date creation and their primary utilization are to

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enhance organic matter of soil (Alananbeh et al. 2014). Date palm tree is an imperative tree for dry areas of the word, and it has constantly assumed an essential part in the social existences of the general population (Elluech et al. 2008). World date fruit generation achieved in excess of 7.7 million tons in 2014. An expected 12 million tons of date palm waste comprising of date palm trunk, fronds (stems and leaves), date flesh, and seeds are created on the planet consistently. The product of the date palm is one of the wealthiest natural product based wellsprings of protein. Date palm is one of the major natural products delivered in moisture free districts. It is a critical business edit in various districts of the world and is viewed as the third generally essential palm species in the worldwide farming industry, after coconut. The seeds of the date organic product, which are discarded after the date preparing, additionally contain 5–7% protein by weight. Various attempts were tried to utilize the date waste in a useful way. It produces a fruit date that is appreciated in all parts of the world. Because of this reasons the worldwide interest for dates and in addition its generation keeps on increasing. The present chapter is based on the efforts to extract energy from date palm fruit as methane-rich biogas.

5.1.1 Properties and Characteristics of Date Palm Fruit

Date palm fruit has an important part due to the upsides like agricultural, food providing, therapeutic, profitable, architectural, environmental characteristics and their various applications. As of late, this organic product has picked up noteworthy significance in worldwide business also. Amid the most recent two centuries, the world generation of dates has dramatically increased. Date organic products (*Phoenix dactylifra*) are of extraordinary significance in human sustenance attributable to their high substance of fundamental supplements, which incorporate various biomolecules (Lattieff 2016). Dates are rich in specific supplements and give a wellspring of quick vitality because of their high sugar content (70–80%). The vast majority of the sugars in dates are as fructose and glucose, which are effectively consumed by the human body. It has been built up that the date palm fruit product has different therapeutic properties like cancer prevention agent, antimutagenic, antioxidant, antimicrobial. The date organic product is recorded in society solutions for the treatment of different irresistible illnesses and cancer. Customarily they are utilized for sustenance, or to deliver desserts, sweet syrup (Dibs in Arabic), vinegar and alcoholic items. Sugars are the real substance components of the date, for the most part including glucose, fructose and little measures of cellulose and starch. The high health giving sugars of date palm squanders are great hotspots for organism maturation potential toward bio-energy creation (Gupta and Kushwaha 2011). The real parts of date palm biomass are cellulose, hemicelluloses and lignin. Additionally, date palm has high unstable solids substance and low humidity.

5.1.2 Global Production

Date palm is one of the primary rural items in the Middle East also. The date palm *Phoenix dactylifera*, a tropical and subtropical tree, having a place with the family Palmae (Arecaceae) is one of humankind's most established developed plants. It has assumed an essential part in the everyday existence of the general population throughout the previous 7000 years. Tons of dates are generating from million date palm trees per year excluding secondary products like palm midribs, leaves, stems, fronds and coir. The generation of date palm fruits has been raised from 2.3 million tons in 1974 to 7.6 million tons in 2010. The heft of this yield comes, in a specific order, from Iraq, Egypt, Saudi Arabia, Iran, United Arab Emirates, Pakistan, Algeria, Sudan, Libya, and Tunisia (Bhansali 2010). The Arab world has in excess of 84 million date palm trees with the greater part in Egypt, Iraq, Saudi Arabia, Iran, Algeria, Morocco, Tunisia and the United Arab Emirates. In Iraq, nine million trees cover the center and southern parts of the nation, bringing about a surplus generation of dates also, other optional biomass. It is created to a great extent in the hot dry locales of the world especially in Gulf Cooperation Council (GCC) nations, and Saudi Arabia is one of the world's significant maker of dates. The availability of date palm trees in Saudi Arabia is about 23 million trees, which deliver about 780,000 tons of dates for every year (Al-Abdoulhadi et al. 2011). Dates creation in Saudi Arabia incredibly expanded for the previous two centuries and is likewise paralleled by high utilization. *P. dactylifera* is the essential yield in Oman, which transfers 82% of all organic product crops creation in the nation. Algeria produces in excess of 400 distinct assortments of dates with a yearly creation of more than 400,000 tons.

5.1.3 Feedstocks of Biogas Production

The target on biogas production through better feedstock is increasing. The things like difficulties of inefficient biogas yield, high maintenance time, and high operating cost obstruct the most extreme execution of biogas creation in the anaerobic digestion process. These restrictions are profoundly reliant upon the accessibility, synthesis, and degradability of the feedstock utilized for biogas generation. The extraordinary potential lies in biogas generation from different feedstocks, for example, crop residues, livestock residues, municipal waste, landfill waste, food waste, and lignocellulosic feedstocks in light of their accessibility and plenitude. Nonetheless, the greater part of these feedstocks has moderate corruption rates and in that capacity requires longer maintenance times. Moreover, a portion of these feedstocks contains harmful intermediates or contain harmful mixes, which repress the biogas generation process. Biogas can be delivered from locally accessible natural source by anaerobic processing. Locally accessible waste items for biogas

generation include solid waste; sludge; and date palm wastes. Biogas is commonly created just from source that are effortlessly used by the microbial group in charge of changing these feedstocks into biogas. The improvement of imaginative innovations going for the usage of feedstocks that are promptly accessible however not effectively degradable would bring about an expansion in biogas creation. The real reasons why a few feedstocks are not perfect for biogas creation are: (a) they can't be processed by microbes, (b) assimilation by microbes is extremely troublesome to accomplish, (c) assimilation could be accomplished however in a moderate manner, and (d) the availability of inhibitors in the feedstock or the creation of inhibitory mixes amid microbial debasement.

5.1.4 Date Palm Fruit as a Main Source

Among the extraordinary types of inexhaustible feedstocks, biomass is without a doubt a standout amongst the most encouraging (Messineo et al. 2012). Around 16% of worldwide last vitality utilization originates from inexhaustible assets, with 10% of all vitality from customary biomass, essentially utilized for warming, and 3.4% from hydroelectricity. The biomass can be used for improving the quality of soil after proper treatment (Converti et al. 1999). The biogas quality depends on the type of waste material, characteristics of the material and also the fermenting conditions. The nature of biogas created by natural waste materials does not stay steady but rather shifts with the time of assimilation. An extensive variety of warm and biochemical innovations are available to change over the energy put away in date palm biomass to helpful types of energy. Due to the availability of moisture free in the date palm fruits, it is well appropriate for the thermal treatment like combustion, gasification and pyrolysis. Then again, the huge unpredictable solids in date palm biomass demonstrates its probability towards biogas creation in anaerobic absorption plants, conceivably by co-digestion with sludge, animal wastes and food wastes. By the fermentation process, the carbohydrate content of date palm fruits can be converted into a biofuel. Various researches have been carried out the co-digestion process of agro waste for biogas production. *Phoenix dactylifera* has assumed a critical part of the everyday existence of the general population for the last 7000 years. Today overall generation, use and industrialization of dates are consistently expanding because date natural products have acquired incredible significance in human nourishment attributable to their rich substance of fundamental supplements. The current investigation, intended to evaluate out of the biogas generation from date palm source.

5.2 Biogas Generation

In the current decades, creation and utilization of biogas have pulled in particular consideration in view of vitality deficiency and rising costs of fuel in bringing in nations. In later a long time, administrations of India and China have started far-reaching endeavors to create biogas to manage the quick increment of the imported oil value. Biogas creation from natural waste items is a good choice since it joins both energy recovery and waste administration (Radeef et al. 2016). Biogas can be used for on-location warm vitality and power. Biogas speaks to a standout amongst the most very refreshing openings to use certain classifications of biomass to satisfy in part the earth vitality needs. Biogas normally alludes to a blend of gases delivered through the natural disruption of natural matter in the nonappearance of oxygen. The resultant vitality discharge permits biogas to be utilized as a biofuel to replace ordinary fossil vitality sources (coal, oil, flammable gas) in power and warmth generation, and furthermore as an adaptable sustainable power source to fuel vehicle. It also used to replace the diesel generated and local grid power. The generated biogas can be utilized for warm age, and after that sold to the next adjacent industrial facility. The part of biogas generation and catching innovation should be considered also. The establishment and working of biogas creation frameworks can give numerous advantages to clients and the more extensive group. Focal points incorporate vitality manageability, asset protection and natural preservation. The high use of reducing petroleum derivatives is considered unsustainable in view of their fewer source and nonrenewable nature. Biogas got from different natural sources can decrease the overwhelming reliance on these draining common assets and address the vitality weakness worries because of its inexhaustible (He et al. 2012). A few reports show that anaerobic process of the natural division of strong waste gives hopeful measures of biogas. Biogas is for the most part made out of 48–65% methane, 36–41% carbon dioxide, up to 17% nitrogen, <1% oxygen, 32–169 ppm hydrogen sulfide and hints of different gases (Ward et al. 2008). Not at all like a petroleum product, does biogas not contribute much to the environmental impact, ozone consumption or corrosive rain (Nath and Das 2004). This is one of the fundamental causes that anaerobic processing is an extremely vital part in addressing vitality difficulties of the future generations. The valorization of the created biogas is that it is vitality effective because of the low outflow of risky contaminations, for instance, volatile organic compounds (VOC) (Appels et al. 2011).

5.3 Anaerobic Digestion Process

Enthusiasm for anaerobic digestion (AD) has been consistently developing in the course of the most recent decades, being increasingly as often as possible advanced by national projects for vitality generation from inexhaustible assets. Anaerobic

assimilation is an innovation confronting developing regards and expansive uses (Clarke and Alibardi 2010; Levis et al. 2010). Anaerobic assimilation is thought to be an eco-compelling innovation since it produces sustainable power source as methane, and furthermore decreases the discharge of ozone-harming substances by means of the biogas recovery (Kaewmai et al. 2013). Anaerobic Digestion (AD) is a natural procedure, which diminishes natural contamination and produces sustainable power source (biogas). This sort of bioprocess is viewed as an elective vitality source to non-renewable energy source. The capacity of anaerobic digestion process has identified newly which has the potential to convert biologically the hydrogen and carbon-di-oxide of sources into methane storage uses (Burkhardt et al. 2015). The high biodegradability and dampness substance of food waste are perfect attributes for biogas generation and digestate are utilized for conditioning the soil or as supplement feedstock. Biogas creation through anaerobic absorption innovation has progressed massively throughout the years. Because of high energy request and ecological worries as the total population expands, the drive for anaerobic digestion is inside research and the business for manageable energy. Anaerobic assimilation has been a standout amongst the most generally utilized handled for the adjustment of biosolid waste, for example, from the agro and civil waste to modern waste. In order to boost its effectiveness, anaerobic assimilation is currently generally utilized at fullscale to debase different natural feedstocks.

Anaerobic digestion is exceptionally ideal because of its ability of vitality recuperation by transformation of solids into biogas, odor decrease, and disposal of pathogens and mass decrease of solids. In anaerobic digestion, the organic biodegradable material is corrupted by microbes under conditions without oxygen, where biogas is delivered normally. Biogas is included for the most part 60–70% CH_4, 30–40% CO_2 and low measures of other trace gases. It incorporates assorted types of anaerobic microbes, which are in charge of the corruption of organic compounds and need time to adjust to the new condition before they begin to devour on organic matter to develop. To create biogas from absorbable materials by anaerobic absorption, the decay of natural squanders happens in four procedures at the same time: hydrolysis, acidogenesis, acetogenesis, and methanogenesis (Yang et al. 2015a, b). Steps associated with the anaerobic digestion process are indicated in the Fig. 5.1. Controlling these phases in an appropriate way of balance between their rates prompts the gas production to higher. Hydrolysis is a basic rate constraining procedure which corrupts insoluble natural materials, for example, lipids, polysaccharides, proteins and cellulose into its spine constituents (e.g. fatty acids furthermore, amino acids). The products from hydrolysis process are additionally separated into hydrogen (H_2, CO_2, acetic acid derivatives and volatile fatty acid (VFA) by acidogenesis process and further these products get converted in another product which is utilized for methanogenesis. In the next step, VFAs are processed to create acetic acid derivatives and H_2 by H_2 creating microbes/acetogens. In the last process where CH_4 is produced by an assortment of methanogenic microscopic organisms. The proficiency of this framework primarily relies upon the structure of the microbial group and natural variables, for instance, pH and temperature (Weiland 2010). The different gatherings of microscopic organisms taking part in the anaerobic

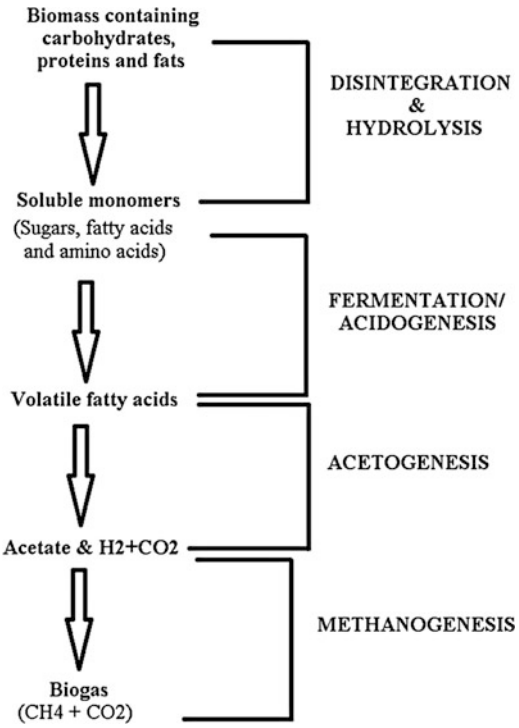

Fig. 5.1 Steps involved in the anaerobic digestion process

digestion have diverse ideal pH extents and large guarantee of effective assimilation and gas generation. The procedure of biogas age from strong natural waste is frequently completed by a few distinctive anaerobic microorganisms.

The procedure of acidogenesis also, methanogenesis need diverse pH for ideal process control. Acidogenic microbes are less delicate and just require pH over 5, while methanogenic microbes are more suitable at pH range of 6.5–7.2 (Kathirvale et al. 2004; Appels et al. 2008). Hence, the ideal pH extend is 6.8–7.4 where both the microbes gathering can coincide. The VFAs produced amid the anaerobic processing prompts the decrement in the pH. However, it can be countered by the creation of alkalinity as carbon dioxide, ammonia furthermore, bicarbonate by the methanogenesis microbes. The methane-producing process needs separate degradation phases to be executed by the bacteria fermentative bacteria, syntrophic acetogens, homoacetogens, hydrogenetrophic methanogens and aceticlastic methanogens. The relationship among the above mentioned microbes adds to proficient anaerobic digestion and biogas creation (Weiland 2010). The last stage, directed by methane forming microorganisms, is the most essential phase in biogas creation where the methanogens change over their essential substrates including acetic acid derivation, hydrogen and carbon dioxide into methane. In methane development pathway, 75% of methane generation gets from decarboxylation of acetic acid derivation and 25% begins from CO_2 and H_2.

The board utilization of this innovation originates from its potential preferences methanogenic procedure of anaerobic processing, and additionally on biodegradability. To detoxify the phenolic compounds, pretreatment was found to be necessary. A wide assortment of anaerobic frameworks has been created to particularly treat squander anaerobically. Anaerobic assimilation in this way speaks to an adaptable procedure that can be utilized as conclusive change process in a biorefinery chain for every one of those substrates furthermore, remaining streams not further convertible to high esteem items. Including, the generation of methane, a decrease of 30– half of the waste volume requiring extreme transfer, and a rate of pathogen obliteration, especially in the thermophilic procedure. The execution of the anaerobic procedures can be restricted by the inhibitory impacts of the phenolic mixes exhibit in palm effluent. Some straightforward phenolic mixes and polyphenols inhibitory affect both general anaerobic assimilation and on the

5.3.1 Factors Affecting Anaerobic Digestion Process

Anaerobic digestion, a microbial-subordinate organic process, is exceedingly subject to the presence of great environment to survive and process. Accordingly, the microbial groups will be straightforwardly influenced by the feedstock properties. This is on account of the feedstock, which assumes a part as the nourishment to be processed by the microorganisms, includes the significant living conditions inside the anaerobic assimilation framework. The microorganisms that take an interest in the process might be particular for each debasement step and in this manner could have distinctive ecological necessities. The anaerobic assimilation of natural material is a difficult process, including various diverse debasement steps. For the most part, the natural factors have a range, ideal esteem or pattern to take after for having a fruitful anaerobic assimilation process. Subsequently, the exploration techniques which had been and to be done for enhancing the biogas generation in view of the ecological variables will have a correct pathway to approach. Other than the natural factors, the cautious operational ability will be required with a specific end goal to guarantee a steady and fruitful anaerobic processing framework to work successfully and consistently. The biogas yield is influenced by numerous elements includes type and creation of substrate, microbial arrangement, temperature, pH, biodegradability and nutrient content. The factors influencing and affecting the anaerobic digestion are well explained in this chapter. Diminish in biogas generation was seen on account of fruit also, vegetable waste because of fast fermentation of these squanders, bringing about a bringing down of the pH in the bioreactor. Besides, the creation of bigger unstable unsaturated fats from such waste under anaerobic conditions restrains the action of methanogenic microbes. The expansion of co-substrates, for example, abattoir waste and sludge of fruit and vegetable waste stimulate the biogas generation under anaerobic conditions. In the meantime, these central understandings supported different of biogas generation upgrade techniques.

5.3.1.1 Temperature

Numerous analysts have announced noteworthy impacts of temperature on the microbial group, process energy and dependability also, methane yield. Temperature is an imperative parameter that significantly impacts anaerobic procedures. The working temperature is the main factor of the population of microbes' presence, particularly the assorted variety of the methanogen group in the anaerobic reactor (Leven et al. 2007). Underneath temperatures amid the procedure are known to diminish microbe development, substrate use, rates, and biogas generation (Trzcinski and Stuckey 2010). In addition, low temperatures may likewise bring about a release of cell vitality, a spillage of intracellular substances or on the other hand entire lysis Conversely, high temperatures bring down biogas yield because of the creation of unstable gases, for example, ammonia which stifles methanogenic exercises (Fezzani and Cheikh 2010). Based on the three diverse temperature ranges namely psychrophilic (0–20 °C), mesophilic (20–42 °C) and thermophilic (42–75 °C), the anaerobic digestion process delivers the biogas. There are two regular temperature levels connected in the traditional anaerobic assimilation, which are mesophilic and thermophilic temperatures. Both temperature ranges have upsides and downsides from various viewpoints. Mesophilic anaerobic digestion has higher stability than the thermophilic. This can be clarified there is more differing microbial group can be found in mesophilic (37 °C) bioreactor. It moderately lower volume of biogas and will bring down volume loading compared with thermophilic anaerobic assimilation. The task in the mesophilic extend is more steady and requires a little vitality cost (Fernandez et al. 2008). Despite the fact that thermophilic anaerobic assimilation can accomplish higher natural substance corruption, it is constantly identified with the issue of the delicate process with inclined unstable unsaturated fat gathering. Other than that, there was a contention as far as vitality discussion because of the lower methane content had been created by a thermophilic reactor. Generally speaking, a temperature extends between 35– 37 °C is viewed as reasonable for the creation of methane and a change from mesophilic to thermophilic temperatures can cause a sharp reduction in biogas creation until the fundamental population has expanded in number. Thermophilic are known to have a rate-advantage over the others because of a quicker response time and higher volumetric stacking rate, and accordingly exhibiting higher biogas efficiency. Psychrophilic are in huge consideration especially as far as creating biogas from low-quality wastewaters.

5.3.1.2 The pH

A basic parameter which impacts the methanogens and which directly affects the biogas and methane generation. Most anaerobic frameworks work at close unbiased pH since methane aging happens inside the pH 6.5 e8.5 territories with the ideal range from 7.0 to 8.0. Through neutralization process, the pH range was maintained

that need excessive utilization of chemicals, for example, sodium carbonate/bicarbonate or calcium carbonate since a few streams have outrageous pH esteems, and hydrolysis also, acidogenesis stages will diminish pH esteems. Extraordinary pH conditions amid anaerobic activity can't just furious natural execution and methane yield yet additionally influence film porousness and life expectancy. The methanogens are powerless to the encompassing pH esteem, which just can survive only under pH scope of 6.5–7.8. A scope of pH esteems appropriate for anaerobic assimilation has been revealed by different specialists, however, the ideal pH for methanogenesis has been observed to be around 7.0.

5.3.1.3 Nutrient Content

The most essential wholesome substance, for example, carbon and nitrogen are basic to help the anaerobic organic process. Nitrogen is fundamental for protein union and basically needed as a supplement by the microbes in the anaerobic reactors. Nitrogenous mixes in the natural squander are normally proteins which are changed over to ammonium by anaerobic processing (Sawayama et al. 2004). As ammonium, nitrogen adds to the adjustment of the pH esteem in the bioreactor where the procedure is occurring. The stability between carbon and nitrogen substance will be needed for a natural assimilation framework, which is usually depicted as carbon to nitrogen (C/N) proportion. The C/N proportion in the natural material assumes a vital part in anaerobic processing. The unequal supplements are viewed as a critical factor constraining anaerobic processing of natural squanders. Moderate debasement will be experienced when C/N proportion is too high, while the other way around will cause the gathering of the inhibitors, for example, alkali. For the generation of new cell mass microorganisms acclimatize ammonium. Smelling salts in high focus may prompt the hindrance of the natural procedure also, it restrains methanogenesis. For the change of nourishment and C/N proportions, co-absorption of natural blends are utilized (Cuetos et al. 2008).

5.3.1.4 Substrate Characteristics

Not a wide range of substrate is appropriate for experiencing the anaerobic assimilation, particularly when the biogas generation is the objective. For case, the poor mass exchange because of the lower water content, imbalance of nutrients and lower biodegradability. The rate of anaerobic processing is emphatically influenced by the sort, accessibility and nature of the substrate (Zhao et al. 2010). Distinctive sorts of carbon source support diverse gatherings of organisms. Before beginning an anaerobic procedure, the substrate must be portrayed for starch, lipid, protein also, fiber substance. The substrate ought to likewise be portrayed for the amount of methane that can conceivably be delivered under anaerobic conditions. Contrasted with lignocellulosic biomass, date palm fruit is substantially more desirable to be processed anaerobically due to its good characteristics. Other than of C/N

proportion, COD: N: Phosphorus (P) proportion had additionally been expected to keep up the digester activity (Annachhatre 1996). The prerequisites of different components as large-scale and micronutrient must be considered too. Sugars are viewed as the most imperative natural segment of municipal waste for biogas creation. Starch could go about as a compelling minimal effort substrate for biogas generation contrasted with sucrose and glucose (Su et al. 2009). The strong substance of the substrate in the bioreactor can essentially influence the execution of the procedure and the measure of methane delivered during the process.

5.3.1.5 Biodegradability

The biodegradability of the organic matter by the microbes is one of the major variables for a successful anaerobic assimilation process. It will specifically impact the rate of substrate use by primarily restricting the procedure of hydrolysis. This is generally portrayed as the biodegradability, which is significantly reliant on the constituents of the substrate. The water content basically restricts the mass exchange and organic matter solubilization inside the digester framework. In this way, the anaerobic assimilation of the high strong substrate will experience more difficulties and issues. Next, the unpredictability of substrate constituents, for example, the sugars, proteins, and lipids, will decide the biodegradability essentially. Moreover, the degradation of non-structural carbohydrates, lipids, proteins are more difficult to degrade due to its strong chemical bonding. Henceforth, the carbohydrate pretreatment or anaerobic digestion for a superior biogas generation. Other than that, the substrate with huge content of lipids (fat) was observed to be corrupted slower due to the availability of long-chain unsaturated fats (LCFAs).

5.3.1.6 Biomass Retention

Biomass maintenance is one of the basic observing factors for anaerobic assimilation. For this, the most widely recognized method is to decide the population of microbes in an anaerobic reactor by which it is particularly depicted as mixed liquor volatile suspended solids (MLVSS).

5.4 Anaerobic Reactors

Anaerobic bioreactors have significant use for quick processing of strong natural waste constituents to decrease the ecological stack (Agdag and Sponza 2007). Bioreactor configuration has been found to apply a strong effect on the execution of a digester. an assortment of new bioreactor plans has been produced lately, which encourage a fundamentally higher rate of response for the treatment of food waste. Favorable position of anaerobic waste treatment frameworks as means for the

recuperation of non-regular vitality is progressively being perceived around the world. Anaerobic deterioration is an organically intervened process, indigenous to nature, and fit for treating squanders radiating from civil, agriculture, and modern exercises. These prompted improvement of different reactors, which are equipped for holding a considerably higher biomass focus than customary digesters. It is hard to assess the focal points and weaknesses of every framework in connection with other ideas. The most well-known anaerobic reactors are Anaerobic sequencing batch bioreactor, Anaerobic filtration, Plug flow reactor, Continuous stirred tank reactors, Lagoon system, Anaerobic fluidized bed reactor, up-flow anaerobic sludge blanket reactor, Anaerobic contact digester. This chapter discuss the anaerobic digestion strategy for the improvement of production biogas through date palm fruit waste. The methodology must be applicable and possible, and this will require a solid comprehension of the compelling elements of biogas generation by anaerobic digestion.

5.4.1 Anaerobic Filtration

The primary showing of this treatment framework originated from Young and McCarty, who productively worked an up-flow anaerobic channel to treat the rum refinery wastewater. It is widely in scale studies for the treatment of palm waste materials. Channel clogging is a noteworthy issue in the activity of anaerobic channels. Anaerobic filtration contains a channel medium where anaerobic microbial population—life forms that live without oxygen—can build up themselves. Such channels are generally used in the wastewater treatment. Such channels are generally utilized in the treatment of wastewater. An anaerobic channel is an anaerobic reactor with at least one filtration chambers in the arrangement. The principal anaerobic channels outlined utilized characteristic materials as help media, for example, stone and rock. These had a low voidage and obstructed with biomass and solids quickly. Plastic raschig rings were used in which the increase the time interval between blockages yet did not defeat the issue completely. As wastewater courses through the channel, particles are caught and the natural issue is corrupted by the dynamic biomass that is connected to the surface of the channel material. The channels can be worked under either an up-stream or on the other hand down-stream condition. The up-stream condition contains a high convergence of suspended biomass shaping a biofilm in the structure of the settled bed. The downstream bed contains a huge concentration of inorganic sulfur between the BOD and inorganic compounds. Upflow anaerobic channels (UAF) can be worked at either mesophilic or thermophilic temperature ranges. Thermophilic anaerobic filters are highly suitable for the treatment for high concentrated wastewaters particularly for the palm oil effluent (Mustapha et al. 2003). The anaerobic filtration has been effectively utilized in the treatment of date palm effluent on account of the advantages credited to it, which incorporates little reactor volume with low water powered maintenance time, capacity to withstand stun loadings, no strong partition/reusing and reasonableness of the

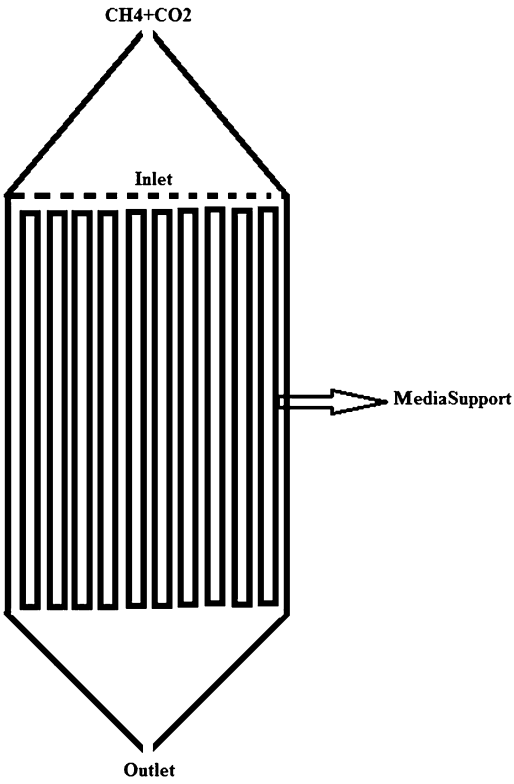

Fig. 5.2 Anaerobic filtration

reactor (Poh and Chong 2009). Anaerobic channels are utilized as an auxiliary treatment in family level or decentralized wastewater treatment frameworks. With respect to any anaerobic assimilation process, biogas can be recouped and changed to vitality or light. It is highly utilized for the personal contact between the inflow and microbial biomass, in this way taking into account a biomass maintenance time longer than the HRT. Reusing can be connected for high-quality wastewaters. In this manner, the AF shows incredible versatility for biomass to another carbon source and to natural load vacillations. Contrasted with an anaerobic contact process, the AF shown better sludge settlement. Accordingly, the AF could be more reasonable to treat wastewaters with bringing down suspended solids. The higher speculation cost ought to likewise be considered in applications. Figure 5.2 represents the diagram of anaerobic filtration.

5.4.2 Plug Flow Reactor

Anaerobic plug flow reactors have been accounted for to be proficient for dry anaerobic assimilation forms. This reactor is economical what's more, simple to

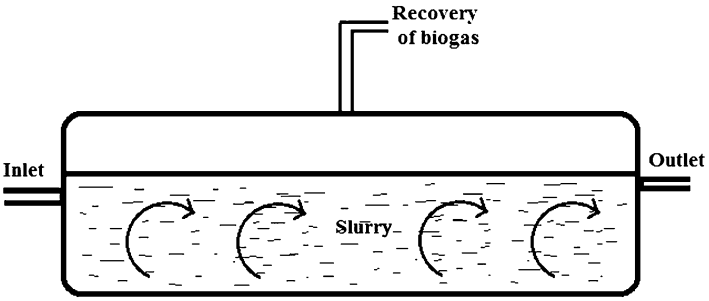

Fig. 5.3 Plug flow reactor

assemble which make them an appropriate innovation to enhance the occupations of the farmers (Lansing et al. 2010). The schematic representation of plug flow reactor is depicted in Fig. 5.3. The execution of biogas generation relies upon biomass substance creation and also process factors, for example, sustain focus, water driven maintenance time, pH, and temperature. The anaerobic plug flow reactor (APFR) is another customary process giving low groupings of VFA in the effluent, a high level of sludge maintenance and stable reactor execution. Plug flow reactors are long, direct troughs normally arranged over the ground. This kind of reactor is effective regarding productivity and conversion when compared with the ordinary single-phase CSTR. The APFR includes no inside disturbance and is stacked with the thick fertilizer of 11–14% aggregate solids and functions admirably at mesophilic or thermophilic temperature. The maintenance time is generally 15–20 days (Rajeshwari et al. 2000). This type of reactor has been accounted for to have the most noteworthy achievement rate in the United States, where 42% out of the 242 anaerobic digesters working at domesticated animals cultivates in 2015. This sort of reactor was used to give low beginning venture cost, high productivity and moderately simple activity and support in case of semi-solid waste (Sharma et al. 2000). Subsequently, in both industrialized and creating nations, the reactor has huge tendency to deliver biogas. Additionally, the reactor has been tried tentatively utilizing substrates, for example, pig manure, cattle deposits and urban natural squander, and so forth.

A plug flow reactor, a sort of reactor which is isolated into acidogenic and methanogenic stages along the stream way of the reactor, could enhance the reactor stability and treatment proficiency. By and by, a few deficiencies, for example, bring down mass exchange because of the absence of blending, warm stratification and strong sedimentation issues have been accounted in certain studies (Lansing et al. 2010). These issues can be controlled by the usage of compressors in plug stream reactors. The impellers permit insignificant blending for higher execution in the reactors. Plug flow reactor is constrained to cases in which the substrate contains low measures of sand, soil, coarseness that these polluting influences settle at the base of the reactor and prompt stratification of the reactor substance, requiring unavoidable release and cleaning of the digester. In addition, light coasting particles amass at the

highest point of the reactor and cause crusting issues. Nowadays, a mixed plug flow reactor was utilized to maintain a strategic distance from the settlement of particles at the base and to make an inflexible layer on the reactor substance.

5.4.3 Continuous Stirred Tank Reactors

The traditional continuous stirred tank reactor (CSTR) is the most regular suspended microbial development framework and has been generally used to create hydrogen (Fang and Liu 2002). CSTRs (Continuous Stirred Tank Reactors) are in round and hollow or rectangular shapes and utilize mechanical turbines for blending. Continuous stirred tank reactors are also known as closed tank digesters. The potential for natural transformation from the substrate to methane can be incredibly expanded because of the overall high shear pressure and serious blending (Ozgun et al. 2013). CSTR works at a persistent stream of reactants and items with a steady makeup in the reactor including exit stream having an indistinguishable synthesis from the tank. The mechanical instigator of the CSTR gives more zone of contact with the biomass in this way upgrading gas generation. CSTR utilizes microorganisms to process the natural substances in the wastewater under anaerobic condition. Amid this procedure, the BOD of the profluent is diminished in the meantime delivering biogas. To heighten this innovation and keep up a reasonable populace of the moderate developing methanogens, the CSTRs are generally joined with an inside or then again outer biomass division and reusing framework (Reungsang et al. 2013) A CSTR coupled film framework can accomplish a promising methane yield up to hypothetical esteem. Also, CSTR, for the most part, works at a lower biomass fixation (e.g. 5 g/L MLSS) contrasted with other high rate anaerobic reactors because of deposition of waste control issues, which comes about in a lower OLR (Organic Loading Rate) connected to the framework, constraining the biomethane potential from high stacking wastewater. Various digesters are being connected for AD process in both laboratory usage and in industrial use, continuous stirred tank reactor (CSTR) is one of most generally utilized for the anaerobic processing of high-strong food waste like date palm waste. A solitary CSTR is easy to work yet less effective in feedstock processing and biogas generation due to the “short circuit”. The short circuit in CSTR is found to be a major downside in the generation of biogas. Associating two reactors in arrangement (serial assimilation) is a suitable method to defeat the issues from single CSTR to build the biodegradation rate and also acquire more biogas generation. A few investigations have stressed the attainability of serial arrangement of CSTR. Blending yields better collaboration amongst microorganisms and substrates diminishes impediment to mass transmission and reduces the gathering of safe intermediates (Chong et al. 2013). Due to continuous blending in the reactor, the microorganisms get suspended. Application of biogas distribution expanded the COD evacuation proficiency, bio-methane age effectiveness, biomass maintenance capacity and the solids retention time (SRT) of CSTR. CSTR is simple to work and minimal effort without immobilization transporter. Besides, it normally

takes shorter start-up time compared with the anaerobic sludge blanket reactor and biofilm frameworks. Good mixing stimulates the contact between the organisms and food waste by consuming more energy. The activity of a traditional single CSTR is straightforward yet less proficient in based on the effluent quality. Therefore, a two-stage framework was found to have the more typical sort of framework. The two-stage CSTR framework is well known because of the effortlessness of the framework inactivity and its low capital when compared with the one stage CSTR. Also, the downsides related to the framework's structure and activity mode make it difficult to hold a high microbial population in the reactor. Because of blending and ceaseless blending, fast fermentation occurs, resulting in substantial VFA creation, which could prompt AD process. Recently, advances have concentrated on CSTR variations to make reactor execution through reactor volume enhancement.

5.4.4 Lagoon System

Anaerobic ponds or lagoons is most useable palm fruit anaerobic treatment around 85% of the plant implemented this technique inferable from just its low capital and operational cost This approach viably empowers about 100% catch of the biogas created in all the lagoon ponds to decrease smell and GHGs (Green House Gas) outflows to the environment. Lake framework is one of the commonest treatment innovation because of its cost adequacy. An alternative to lessen digester cost is utilizing more affordable digester plans and lower cost development materials. This line of thinking can prompt be considering a persistent stream 'earthen digester', worked at encompassing temperatures, which is like present anaerobic ponds. This framework depends principally on microbial action to decrease natural material and supplements. Anaerobic lagoons are working as digesters where microbes break down the natural issue. Anaerobic tidal ponds are regularly used to treat modern wastewater or creature squanders from dairy or then again swine cultivates, or to fill in as the primary treatment advance in frameworks utilizing at least two lagoons in an arrangement. The anaerobic ponds digesters are intended for a generally low stacking rate worked with a long maintenance time and work well under warm climatic conditions and intensely subject to the surrounding temperature.

5.4.5 Anaerobic Fluidized Bed Reactor

Over the most recent two decades, anaerobic fluidized-bed reactors (AFBRs) started to be utilized as a part of food waste because of their ability for keeping high biomass fixations furthermore, thin biofilm thickness. In anaerobic fluidized bed reactor, the

barrier for bacterial connection and development is little dormant particles, for example, fine sand or alumina, kept in suspension by a quick upward stream of approaching wastewater. The design considerations provide more prominent protection from inhibitors and higher OLR. Moreover, execution of a thin biofilm on these medium particles and a great connection to biomass take into consideration great mass move effectiveness in the AFBR. AFBR depends on worthy fluidization attributes, for example, bed-extension tallness also, gas, fluid, and strong hold-ups. In any case, gas generation in AFBRs may acquire a bed-compression impact, bringing about the decrease of contact time between mass fluid and bioparticles, particularly for a huge scale AFBR. Anaerobic fluidized bed reactor (AFBR) is the treatment techniques for low-quality wastewater and it provides the excellent mass conversion between the substrate and the medium like a solid particle. FBR is a progressed stuffed bed framework, which allows the development of the bed amid activity (Alade et al. 2011). AFBR setup has pulled in an expanding consideration due to the maintenance of biomass onto a strong inactive biofilm bearer material with a huge particular surface region (Karadag et al. 2015). The reactors have been broadly utilized for the treatment of numerous food waste since the most recent two decades. The bearer materials are fluidized by the influent stream as well as through distribution of the supernatant fluid (Barca et al. 2015). FBR is a sort of anaerobic reactor gadget that has the limit of doing a few multiphase synthetic responses. The high up-flow fluid speeds give a bed development of just about 100%. The effectiveness of the fluidized bed reactor relies upon the idea of help material (Sowmeyan and Swaminathan 2008). The opposite stream fluidized reactor indicated high stability when over-burden is connected (Alvarado-Lassman et al. 2008). Little permeable fluidized media hold high biomass focuses in the reactor and in this way diminished HRT. Lower HRT (High Retention Time) and more prominent CH_4 generation demonstrated an advantage of fluidized bed over an anaerobic process.

Figure 5.4 shows the pictorial diagram of anaerobic fluidized bed reactor. In any case, gas generation in AFBRs may bring about a bed-compression impact, bringing about the diminishment of contact time between mass fluid and bioparticles, particularly for a substantial scale AFBR. The FBR can withstand high OLRs and a superior methane gas creation. Moreover, the capacity to evacuate surface strong particles of local wastewater utilizing the AFBR is superior to that of the UASB. This kind of reactor is more compelling for the treatment of soluble, or surface material nourish that is effectively biodegradable, for example, whey, whey permeates, black liquor condensate, etc. However, membrane fouling is a limitation for anaerobic fluidized bed reactors. It has been accounted for that proteins are the prevailing supporters of layer fouling at low temperature (Gao et al. 2014). To wipe out or diminish layer fouling, analysts have exhibited that a small amount of strong media such as granular activated carbon (GAC) or powder activated carbon (PAC) can be included, in light of the fact that they can successfully adsorb microbial metabolic items (Akram and Stuckey 2008).

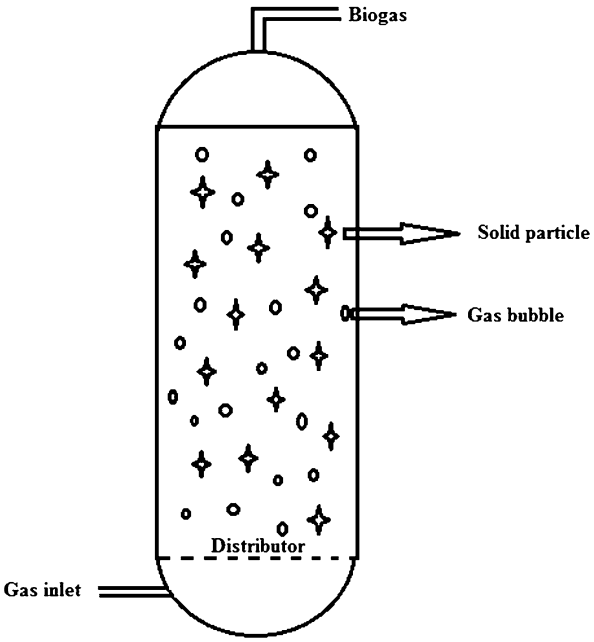

Fig. 5.4 Anaerobic fluidized bed reactor

5.4.6 Upflow Anaerobic Sludge Blanket Reactor

The UASB idea was produced by Lettinga et al. in the 1970s for methane creation. The up-flow anaerobic sludge blanket (UASB) reactor is the noticeable extensions in anaerobic processing framework for wastewater treatment and in excess of 1000 such sort of reactors is utilized as a part of worldwide (Tiwari et al. 2006; Chong et al. 2012). UASB reactor (Fig. 5.5) is very simple, compact and widely applied for the treatment of waste for the production of gas. The principle structure of the reactor is a thick slime bed situated in the base, which ensures great wastewater and biomass contact. This procedure has been successfully used to treat the extensive variety of modern profluent. The mystery of such a novel reactor configuration lies in its capacity to hold a high centralization of biomass as well settable methanogenic slop granules in a thick slop bed at the base of the reactor; furthermore, besides, catch the created biogas through a gas-liquid separator (GLS) at the top. This reactor demonstrates a great execution for high-suspended strong wastewater and produces a huge volume of methane. The creation of fermentative hydrogen relies upon the impacts of HRT (High Retention Time) and OLR (Organic Loading Rate). The biomass and sludge from the organic waste settle in UASB reactor and the sludge gets digested by this reactor when the organic waste be in contact with the sludge. UASB reactor has been effectively been utilized for the treatment of various modern effluents incorporating those with high natural substance fit for restraining assimilation (Demirel and Scherer 2008). The suspended natural solids of date palm effluent have a high biogas potential which makes the transformation innovation

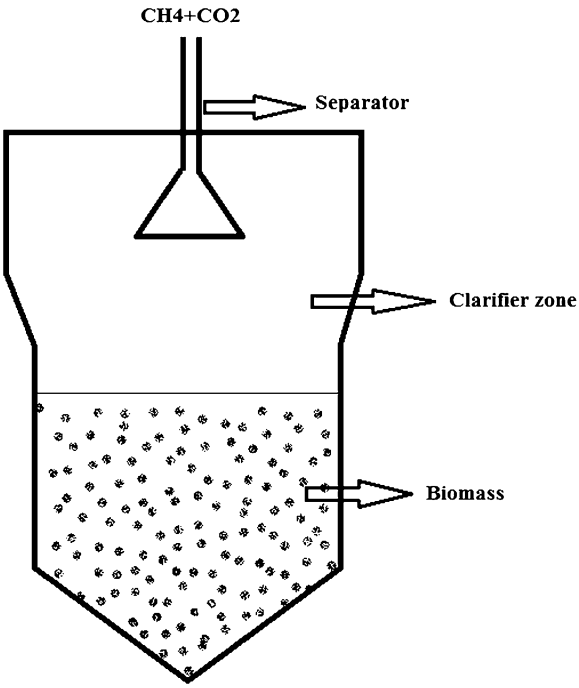

Fig. 5.5 Up flow anaerobic sludge blanket reactor

practical, which are the main thrust of UASB. Among the remarkable preferences, UASB requires low volume and space, highlights higher stream speed and biogas generation and fundamentally higher natural load rates. Moreover, the accessibility of granular permits treatment of higher COD stacking rates and providing satisfactory treatment at bringing down HRTs than is conceivable with the anaerobic filters (AF). UASB reactors can utilize thick bacterial granules, which fill in as a channel to counteract bacterial washout and which additionally give a bigger surface territory for speedier biofilm advancement and enhanced methanogenesis.

5.4.7 Anaerobic Contact Reactor

The anaerobic contact reactor is comprised of digester and sedimentation tank. The anaerobic contact reactor (ACR) is widely utilized for wastewater with high quantity of surface solids In a few cases, high-rate mesophilic ACRs have been shown to be a manageable innovation for an extensive variety of modern wastewater, for example, food industry wastewater (Senturk et al. 2012) and pulp and paper mills (Capela et al. 2009). These reactors introduce comparative highlights to their oxygen-consuming partners like activated sludge reactors. Anaerobic contact assimilation includes the utilization of digester and sedimentation tank whereby the processed wastewater is left to coagulate and the wastewater is reused once more into the

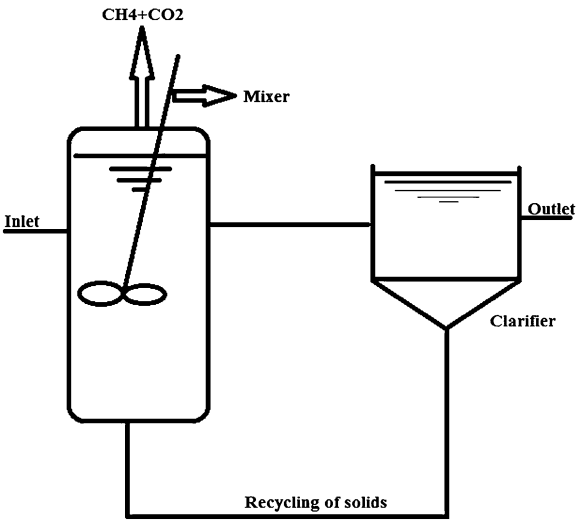

Fig. 5.6 Anaerobic contact reactor

digester. ACR is more invaluable than regular anaerobic reactors, for example, up-flow anaerobic sludge blanket reactors (UASB). Figure 5.6 Schematic representation of anaerobic contact reactor.

Revealed focal points incorporate the contact procedure, quickly accomplished consistent state times because of blending, adequately short water powered maintenance times and moderately high gushing quality, less affected by stun stacking, ideal pH and constrained biomass washout. In order to maintain the organisms' quantity, the settled solids are move towards the reactor. The clarifier or pilgrim may have gravity settling or vacuum buoyancy. Settlement must be helped by degassing, cooling, filtration, or slanted plates. This approach was fruitful for the treatment of processed solids and enabled one to acquire fantastic effluents. Gas-lift blending is well known in these sorts of digesters. Great blending is likewise fundamental in this sort of reactor to guarantee uniform substrate and biomass concentration. Traditionally blending has been by paddles in a draft tube. Much of the system of the paddle type is submerged in the digester and maintenance is exceptionally troublesome. Another strategy for mixing is directed distribution of the digesters contents. Present day digesters are a large portion of the size and blending is significantly simpler.

5.5 Conclusions and Recommendations

Date palm natural product, a standout amongst the most nutritive and complete organic products regarding medical advantages is a perfect substrate for inferring a scope of significant worth included items in sustenance and nutraceutical businesses in the upcoming future utilizing bioprocessing innovations which will have a massive extension for the biogas production. For supporting the future manageable

palm fruit advancement, more exhaustive research on improving the biogas creation from date palm by anaerobic assimilation is basically required. Keeping in mind the end goal to guarantee the execution of anaerobic assimilation, RSM improvement of the manipulable elements (temperature, pH) by utilizing the specific bioreactor is very encouraged. The present chapter plainly shows that anaerobic assimilation is a standout amongst the best organic procedures to treat a wide assortment of date palm fruit. Additionally, this chapter demonstrates that anaerobic digestion is a standout amongst the best natural procedures to treat a date palm fruit for biogas generation. In any case, unique variables for example, substrate and co-substrate structure and quality, natural components (temperature, pH), microbial elements add to the proficiency of the anaerobic assimilation process and should be improved to accomplish the greatest advantage from this innovation as far as both vitality creation furthermore, natural waste administration. The examined reactors can be further investigated by taking into consideration of different measures, for example, extraordinary co-substrates, pre-treatment advances, added substances etc. the major elements of anaerobic assimilation and cost adequacy must be considered for the future activities. By working the anaerobic digester effectively, the used techniques had a positive reaction to the biogas creation. The prime preferences of this innovation incorporate that the procedure at the same time prompts minimal effort generation of biogas, which could be indispensable for meeting future vitality needs. In any case, unique components, for example, substrate and co-substrate structure and quality, ecological components (temperature, pH), furthermore, microbial flow add to the productivity of the anaerobic assimilation process and should be enhanced to accomplish most extreme advantage from this innovation. This innovation has enormous application later on for maintainability of both condition and horticulture, with the generation of energy as an additional advantage.

This chapter focuses the way that there is an extraordinary research movement around the globe, both in nations that deliver date palm and those in nations where the production is low yet the consumption is high. The anaerobic assimilation is a perplexing procedure, which the execution came about will be effectively affected by alternate variables, for example, organic loaded, start-up effectiveness, operation conditions, bioreactor design etc. The cooperation impacts of these diverse components might be amplified and turned out to be more imperative than its individual impact. The efforts were made to basically upgrade the biogas volumetric creation, yet not underlined to enhance the biogas quality. The basic examination of newer literature shows that much advance has been made in the innovative work of anaerobic systems for biogas creation. The green points of view of anaerobic reactors are biogas creation, high profluent quality, squander minimization, high limit, and impression proficiency (diminishing capital expenses) and bring down vitality prerequisites. Most research on reactors has concentrated on researching customary setups, for example, up-flow anaerobic sludge blanket reactor anaerobic fluidized bed reactor, continuous stirred tank reactors and so forth. The anaerobic pond is the basic strategy to produce biogas because of its minimal effort. The most suitable reactor for the generation of biogas from the date palm fruit is Upflow anaerobic sludge blanket reactor (UASB) as it produces higher measures of biogas,

for example, biomethane and biohydrogen. Be that as it may, it can't release completely clear profluent. For the further improvement of biogas AD that consideration be given to the blend of at least two of the previously mentioned factors influencing proficiency and to advance anaerobic digestion efficiency.

References

Agdag ON, Sponza DT (2007) Co-digestion of mixed industrial sludge with municipal solid wastes in anaerobic simulated landfilling bioreactors. J Hazard Mater 140:75–85. https://doi.org/10.1016/j.jhazmat.2006.06.059

Akram A, Stuckey DC (2008) Flux and performance improvement in a submerged anaerobic membrane bioreactor (SAMBR) using powdered activated carbon (PAC). Process Biochem 43:93–102. https://doi.org/10.1016/j.procbio.2007.10.020

Al-Abdoulhadi IA, Dinar HA, Ebert G, Buttner C (2011) Effect of salinity on leaf growth, leaf injury and biomass production in date palm cultivators. Indian J Sci Technol 4:1542–1546. https://doi.org/10.17485/ijst/2011/v4i11/30283

Alade AO, Jameel AT, Muyibi SA, Karim MA, Alam MZ (2011) Application of semi fluidized bed bioreactor as novel bioreactor system for the treatment of palm oil mill effluent (POME). Afr J Biotechnol 10(81):18642–18648. https://doi.org/10.5897/AJB11.2767

Alananbeh KM, Bouqellah NA, Al Kaff NS (2014) Cultivation of oyster mushroom *Pleurotus ostreatus* on date-palm leaves mixed with other agro-wastes in Saudi Arabia. Saudi J Biol Sci 21(6):616–625. https://doi.org/10.1016/j.sjbs.2014.08.001

Alvarado-Lassman A, Rustrian E, Garcia-Alvarado MA, Rodriguez-Jimenez GC, Houbron E (2008) Brewery wastewater treatment using anaerobic inverse fluidized bed reactors. Bioresour Technol 99:3009–3015. https://doi.org/10.1016/j.biortech.2007.06.022

Annachhatre AP (1996) Anaerobic treatment of industrial wastewaters. Resour Conserv Recycl 16:161–166. https://doi.org/10.1016/0921-3449(95)00053-4

Appels L, Baeyens J, Degreve J, Dewil R (2008) Principles and potential of the anaerobic digestion of waste-activated sludge. Prog Energy Combust Sci 34(6):755–781. https://doi.org/10.1016/j.pecs.2008.06.002

Appels L, Lauwers J, Degr_eve J, Helsen L, Lievens B, Willems K, Impe JV, Dewil R (2011) Anaerobic digestion in global bio-energy production: potential and research challenges. Renew Sustain Energy Rev 15:4295–4301. https://doi.org/10.1016/j.rser.2011.07.121

Barca C, Soric A, Ranava D, Giudici-Orticoni MT, Ferrasse JH (2015) Anaerobic biofilm reactors for dark fermentative hydrogen production from wastewater: review. Bioresour Technol 185:386–398. https://doi.org/10.1016/j.biortech.2015.02.063

Bhansali RR (2010) Date palm cultivation in the changing scenario of Indian arid zones: challenges and prospects. In: Ramawat KG (ed) Desert plants: biology and biotechnology. Springer, Berlin/Heidelberg, pp 423–459. https://doi.org/10.1007/978-3-642-02550-1_20

Burkhardt M, Koschack T, Busch G (2015) Biocatalytic methanation of hydrogen and carbon dioxide in an anaerobic three-phase system. Bioresour Technol 178:330–333. https://doi.org/10.1016/j.biortech.2014.08.023

Capela I, Bile MJ, Silva F, Nadais H, Prates A, Arroja L (2009) Hydrodynamic behavior of a full-scale anaerobic contact reactor using residence time distribution technique. J Chem Technol Biotechnol 84:716–724. https://doi.org/10.1002/jctb.2104

Chong S, Sen TK, Kayaalp A, Ang HM (2012) The performance enhancements of upflow anaerobic sludge blanket (UASB) reactors for domestic sludge treatment – a state-of-the-art review. Water Res 46:3434–3470. https://doi.org/10.1016/j.watres.2012.03.066

Chong MF, Chen J, Oh PP, Chen ZS (2013) Modeling study of chemical phase equilibrium of canola oil transesterification in a CSTR. Chem Eng Sci 87:371–380. https://doi.org/10.1016/j.ces.2012.11.002

Clarke WP, Alibardi L (2010) Anaerobic digestion for the treatment of solid organic waste: what's hot and what's not. Waste Manag 30:1761–1762. https://doi.org/10.1016/j.wasman.2011.03.021

Converti A, Del Borghi A, Zilli M, Arni S, Del Borghi M (1999) Anaerobic digestion of the vegetable fraction of municipal refuses: mesophilic versus thermophilic conditions. Bioprocess Eng 21:371–376. https://doi.org/10.1007/s004490050

Cuetos MJ, Gomez X, Otero M, Moran A (2008) Anaerobic digestion of solid slaughterhouse waste (SHW) at laboratory scale: influence of co-digestion with the organic fraction of municipal solid waste (OFMSW). Biochem Eng J 40:99–106. https://doi.org/10.1016/j.bej.2007.11.019

Demirel B, Scherer P (2008) The roles of acetotrophic and hydrogenotrophic methanogens during anaerobic conversion of biomass to methane: a review. Rev Environ Sci Biotechnol 7:173–190. https://doi.org/10.1007/s11157-008-9131-1

Elleuch M, Besbes S, Roiseux O, Blecker C, Deroanne C, Drira NE, Attia H (2008) Date flesh: chemical composition and characteristics of the dietary fibre. Food Chem 111:676–682. https://doi.org/10.1016/j.foodchem.2008.04.036

Fang HHP, Liu H (2002) Effect of pH on hydrogen production from glucose by a mixed culture. Bioresour Technol 82:87–93. https://doi.org/10.1016/S0960-8524(01)00110-9

Fernandez J, Perez M, Romero LI (2008) Effect of substrate concentration on dry mesophilic anaerobic digestion of organic fraction of municipal solid waste (OFMSW). Bioresour Technol 99:6075–6080. https://doi.org/10.1016/j.biortech.2007.12.048

Fezzani B, Cheikh RB (2010) Two-phase anaerobic co-digestion of olive millwastes in semi-continuous digesters at mesophilic temperature. Bioresour Technol 101:1628–1634. https://doi.org/10.1016/j.biortech.2009.09.067

Gao D-W, Hu Q, Yao C, Ren N-Q (2014) Treatment of domestic wastewater by an integrated anaerobic fluidized-bed membrane bioreactor under moderate to low temperature conditions. Bioresour Technol 159:193–198. https://doi.org/10.1016/j.biortech.2014.02.086

Gupta N, Kushwaha H (2011) Date Palm as a Source of Bioethanol Producing Microorganisms. In: Date Palm Biotechnology. Springer, Berlin/Germany, pp 711–727. https://doi.org/10.1007/978-94-007-1318-5_33

He Y, Bagley DM, Leung KT, Liss SN, Liao BQ (2012) Recent advances in membrane technologies for biorefining and bioenergy production. Biotechnol Adv 30:817–858. https://doi.org/10.1016/j.biotechadv.2012.01.015

Kaewmai R, H-Kittikun A, Suksaroj C, Musikavong C (2013) Alternative technologies for the reduction of greenhouse gas emissions from palm oil mills in Thailand. Environ Sci Technol 47:12417–12425. https://doi.org/10.1021/es4020585

Karadag D, Koroglu OE, Ozkaya B, Cakmakci M (2015) A review on anaerobic biofilm reactors for the treatment of dairy industry wastewater. Process Biochem 50(2):262–271. https://doi.org/10.1016/j.procbio.2014.11.005

Kathirvale S, Muhdyunus M, Sopian K, Samsuddin A (2004) Energy potential from municipal solid waste in malaysia. Renew Energy 29(4):559–567. https://doi.org/10.1016/j.renene.2003.09.003

Lansing S, Martin JF, Botero RB, da Silva TN, da Silva ED (2010) Methane production in low-cost, unheated, plug-flow digesters treating swine manure and used cooking grease. Bioresour Technol 101(12):4362–4370. https://doi.org/10.1016/j.biortech.2010.01.100

Lattieff FA (2016) A study of biogas production from date palm fruit wastes. J Clean Prod 139:1191–1195. https://doi.org/10.1016/j.jclepro.2016.08.139

Leven L, Eriksson ARB, Schnürer A (2007) Effect of process temperature on bacterial and archaeal communities in two methanogenic bioreactors treating organic household waste. FEMS Microbiol Ecol 59:683–693. https://doi.org/10.1111/j.1574-6941.2006.00263.x

Levis JW, Barlaz MA, Themelis NJ, Ulloa P (2010) Assessment of the state of food waste treatment in the United States and Canada. Waste Manag 30(8–9):1486–1494. https://doi.org/10.1016/j.wasman.2010.01.031

Messineo A, Volpe R, Marvuglia A (2012) Ligno-cellulosic biomass exploitation for power generation: A case study in Sicily. Energy 45:613–625. https://doi.org/10.1016/j.energy.2012.07.036

Mustapha S, Ashhuby B, Rashid M, Azni I (2003) Start-up strategy of a thermophilic upflow anaerobic filter for treating palm oil mill effluent. Process Saf Environ Prot:Trans Inst Chem Eng Part B 81:262–266. https://doi.org/10.1205/095758203322299798

Nath K, Das D (2004) Improvement of fermentative hydrogen production: various approaches. Appl Microbiol Biotechnol 65:520–529. https://doi.org/10.1007/s00253-004-1644-0

Ozgun H, Dereli RK, Ersahin ME, Kinaci C, Spanjers H, Van Lier JB (2013) A review of anaerobic membrane bioreactors for municipal wastewater treatment: integration options, limitations and expectations. Sep Purif Technol 118:89–104. https://doi.org/10.1016/j.seppur.2013.06.036

Poh PE, Chong MF (2009) Development of anaerobic digestion methods for palm oil mill effluent (POME) treatment. Bioresour Technol 100:1–9. https://doi.org/10.1016/j.biortech.2008.06.022

Radeef W, Shanableh A, Merabtene T (2016) Impact of date palm seed size on biogas production from date seeds/wastewater treatment sludge mixtures. Int J of Thermal Environ Eng 13(1):1–6. https://doi.org/10.5383/ijtee.13.01.001

Rajeshwari K, Balakrishnan M, Kansal A, Lata K, Kishore V (2000) State-of-the-art of anaerobic digestion technology for industrial wastewater treatment. Renew Sust Energ Rev 4:135–156. https://doi.org/10.1016/S1364-0321(99)00014-3

Reungsang A, Sreela-or C, Plangklang P (2013) Non-sterile bio-hydrogen fermentation from food waste in a continuous stirred tank reactor (CSTR): performance and population analysis. Int J Hydrog Energy 38:15630–15637. https://doi.org/10.1016/j.ijhydene.2013.03.138

Sawayama S, Tada C, Tsukahar K, Yagishita T (2004) Effect of ammonium addition on methanogenic community in a fluidized bed anaerobic digestion. J Biosci Bioeng 9:65–70. https://doi.org/10.1016/S1389-1723(04)70167-X

Senturk E, İnce M, Engin GO (2012) The effect of transient loading on the performance of a mesophilic anaerobic contact reactor at constant feed strength. J Biotechnol 164:232–237. https://doi.org/10.1016/j.jbiotec.2012.08.016

Sharma V, Testa C, Lastella G, Cornacchia G, Comparato M (2000) Inclined-plug- flow type reactor or anaerobic digestion of semi-solid waste. Appl Energy 65:173–185. https://doi.org/10.1016/S0306-2619(99)00084-7

Sowmeyan R, Swaminathan G (2008) Evaluation of inverse anaerobic fluidized bed reactor for treating high strength organic wastewater. Bioresour Technol 99:3877–3880. https://doi.org/10.1016/j.biortech.2007.08.021

Su H, Cheng J, Zhou J, Song W, Cen K (2009) Improving hydrogen production from cassava starch by combination of dark and photo fermentation. Int J Hydrog Energy 34:1780–1786. https://doi.org/10.1016/j.ijhydene.2008.12.045

Tiwari M, Guha S, Harendranath CS, Tripathi S (2006) Influence of extrinsic factors on granulation in UASB reactor. Appl Microbiol Biotechnol 71:145–154. https://doi.org/10.1007/s00253-006-0397-3

Trzcinski AP, Stuckey DC (2010) Treatment of municipal solid waste leachate using a submerged anaerobic membrane bioreactor at mesophilic and psychrophilic temperatures: analysis of recalcitrants in the permeate using GC-MS. Water Res 44:671–680. https://doi.org/10.1016/j.watres.2009.09.043

Ward AJ, Hobbs PJ, Holliman PJ, Jones DL (2008) Optimization of the anaerobic digestion of agricultural resources. Bioresour Technol 99:7928–7940. https://doi.org/10.1016/j.biortech.2008.02.044

Weiland P (2010) Biogas production: current state and perspectives. Appl Microbiol Biotechnol 85:849–860. https://doi.org/10.1007/s00253-009-2246-7

Yang L, Huang Y, Zhao M, Huang Z, Miao H, Xu Z, Ruan W (2015a) Enhancing biogas generation performance from food wastes by high solids thermophilic anaerobic digestion: effect of pH adjustment. Int Biodeterior Biodegrad 105:153–159. https://doi.org/10.1016/j.ibiod.2015.09.005

Yang L, Xu F, Ge X, Li Y (2015b) Challenges and strategies for solid-state anaerobic digestion of lignocellulosic biomass. Renew Sust Energ Rev 44:824–834. https://doi.org/10.1016/j.rser.2015.01.002

Zhao Y, Wang A, Ren N (2010) Effect of carbon sources on sulfidogenic bacterial communities during the starting-up of acidogenic sulfate-reducing bioreactors. Bioresour Technol 101:2952–2959. https://doi.org/10.1016/j.biortech.2009.11.098