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Design considerations and operational performance of anaerobic digester: A review

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Abstract: Due to the decline in fossil fuel reservoirs, the researchers emphasized more on the production of biogas from organic waste. Producing the renewable energy from biodegradable waste helps to overcome the energy crisis and solid waste management, which is done by anaerobic digestion. Anaerobic digestion is the controlled breakdown of organic matter into methane gas (60%), carbon dioxide (40%), trace components along with digested used as soil conditioner. However, there is vast dearth of literature regarding the design considerations. The batch digestion system yields a cost-effective and economically viable means for conversion of the food waste to useful energy. It is therefore recommended that such process can be increasingly employed in order to get and simultaneously protect the environment. This paper aims to draw key analysis and concern about the design considerations, analysis of gas production, substrates and inoculua utilization, uses and impacts of biogas.

Subjects: Chemical Engineering; Civil, Environmental and Geotechnical Engineering; Engineering & Technology

Keywords: biogas; anaerobic digestion; food waste; landfill; digester; municipal solid waste

1. Introduction

Tropical regions have very high biomass productivity compared to other regions. Large amount of biomass waste is generating every year from agricultural, forestry, food, and other industries. As a result, there is an opportunity to improve the sustainability of energy production in tropical regions by converting this locally abundant biomass waste into bioenergy products using anaerobic digestion (Ge, Matsumoto, Keith, & Li, 2014). Presently, due to increasing demand and shortage of fossil fuels, the interest of people all over the world has shifted to biogas energy source (Krishna, Devi, Viswnath, Deepak, & Sarada, 1991).

Being third largest component of municipal solid waste, 30 million tons of food waste is produced annually. Less than 3% is treated and rest is disposed in land fillings (Igoni, Ayotamuno, Eze, Ogagi,

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Muzaffar Ahmad Mir and Athar Hussain are affiliated to the Environmental Engineering Division, School of Engineering Gautam Buddha University, Greater Noida, India. Our research focus is in sustainability of the environment and energy derivation from waste. This work is part of the several research works in the focus subject.

PUBLIC INTEREST STATEMENT

This review article highlighted the possibility of introducing alternative technologies for waste management. It promotes sustainability in environment and waste management. It highlights all modern advancements in the management of food waste. It also gives positive impacts in the economy by converting waste into useful gas. As an additional advantage, it has introduced an economical and environmentally friendly way to manage food waste.

& Probart, 2007). The most promising method for the generation of methane gas from organic matter is high rate anaerobic digesters (Bouallagui, Touhami, Ben Cheikh, & Hamdi, 2005). For the best results, the anaerobic digester must be monitored regularly with the passage of time (Hansen et al., 2004). It is a controlled process that effectively produces 60% methane, 40% carbon dioxide, and highly nutritive digestate. Generally three main reactions, hydrolysis, acetogenesis, and methanogenesis complete this process (Igoni et al., 2007).

The most prominent method to determine the preposition of food waste is to carry out house hold composition analysis. There is no international standard method yet established for household waste composition analysis (Lebersorger & Schneider, 2011). Currently, food waste either goes to animal farms as feedstock or to land filling in most cities. Serious health threat associated with food waste as animal food stock has attracted great public attention. Food waste landfills have created serious environmental problems.

Anaerobic digestion is extensively acceptable as an efficient process to treat and utilize food waste because it has proven to be promising method for waste reduction and energy recycling. (Zhou et al., 2014). Landfilling is a dangerous process because the leachate containing organic and inorganic contaminants poses a risk of ground water contamination. This leachate problems calls for leachate management and treatment facility. Green house gasses must be collected. Facing this problem, many countries all over the world started recycling the waste and developed management infrastructure programs. According to reports, 50% waste is recycled in Canada by this program (Adhikari, Barrington, Martinez, & King, 2008).

Biochemical methane potential (BMP) assay was developed to show the ultimate conversion and methane yield of organic substrate for various feedstocks (Chynoweth, Turick, Owens, Jerger, & Peck, 1993). According to the literature, co-digestion of food waste with manure can increase methane production up to 67 to 294%. It is induced because co-digestion of manure with food waste increases the buffering capacity and maintains the pH (Maria & Lansing, 2013). Various studies are available regarding source selection of food waste and sludge for anaerobic digestion process. Biodegradability and biomethane potential are determined by molecular analysis and BMP test. By such pretreatment process, it was concluded that canteen and restaurant waste showed very high methane potential. The methane yield for restaurant and canteen waste was reported as 675 $NmlCH_4$/g VS and 571–645 $NmlCH_4$/g VS, respectively. The methane percentage has increased to 47% (Cabbai, Ballico, Aneggi, & Goi, 2013).

Excess high loading rate of sludge with low organic waste always cause failure in anaerobic process with low methane yield. To sort out this problem, mild thermal pretreatment is used (Yan, Chen, Xu, He, & Zhou, 2011). To reduce the use of chemicals for maintaining the pH, manure and meat-based products or other nutrient-rich materials can be used (Chen et al., 2010). The most complex problem about landfilling of any waste is fate and transport of organic containments. Such effect can be predicted by modeling approach (Saquing, Knappe, & Barlaz, 2012). Food waste leachate can be easily handled by biological process to get economical and environmental benefit by increasing methane yield up to 70% (Dae, Shishir, Kim, & Hung-Suck, 2009). The treatment period entirely depends upon HRT, OLR, and other design consideration (Cho & Park, 1995).

2. Anaerobic digestion

Food waste not only contains molecular organic matter, but also contains various trace elements. Currently, anaerobic digestion process has become an intensive field of research, since the organic matter in the food waste is suited for anaerobic microbial growth (Zhang & Jahng, 2012). During anaerobic digestion process, organic waste is biologically degraded and converted into clean gas (Appels et al., 2011). In most of the studies, anaerobic digestion process is mainly divided into four steps: hydrolysis, acidogenesis, acetogenesis, and methanogenesis (Figure 1). However, according to (Molino, Nanna, Ding, Bikson, & Braccio, 2013), anaerobic process is divided into three steps: hydrolysis, acidogenesis, and methanogenesis but both the approaches work on the same principle.

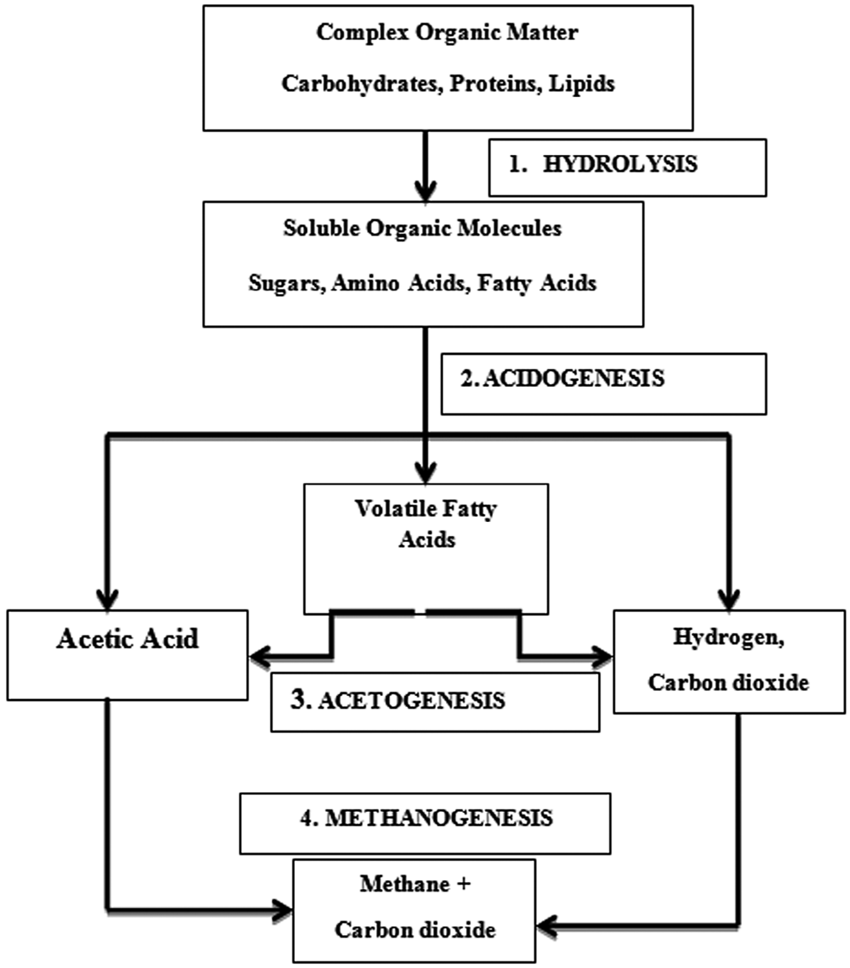

Figure 1. Anaerobic degradation process (Bouallagui et al., 2004; Madigan, Martin, & Porter, 1997; Ray et al., 2013).

Anaerobic digestion is historically used by humans for waste management and wastewater treatment (Palmisano & Barlz, 1996). Anaerobic digestion is the biological process in which the biodegradation and stabilization of complex organic matter in the absence of oxygen with a consortium of microbes lead to the formation of energy-rich biogas. It is used to replace fossil fuel. The residues of anaerobic digestion process are nutrient-rich, used as soil amendment (Maria & Lansing, 2013). Anaerobic digestion is carried out at different temperature conditions, called as mesophilic, thermophilic, and psyrcophilic. Many factors affect the anaerobic digestion. Acetogens and mathanogens produce methane gas through hydrolysis, acidogenesis, acetogenesis, and methanogenesis (Charles, Walker, & Cord-Ruwisch, 2009; Park, Lee, Kim, Chen, & Chase, 2005).

2.1. Hydrolysis

Complex organic molecules like proteins, polysaccharides, and fat are converted into simpler ones like peptides, saccharides, and fatty acids (Figure 1, stage-1) by exoenzymes like cellulase, protease, and lipase produced by hydrolytic and fermentative bacteria (Noike, Endo, Chang, Yaguchi, & Matsumoto, 1985). End products are soluble sugars, amino acids, and glycerol and long-chain carboxylic acids (Ostrem & Themelis, 2004; Ralph & Dong, 2010). Overall reactions (1) are represented by the following equations:

$$C_6H_{10}O_4 \rightarrow C_6H_{12}O_6 + H_2O \qquad (1)$$

Hydrolysis is a relatively slow process and generally limits overall reaction. The overall conversion of polymers into soluble monomers is catalyzed by enzymes known as hydrolases or lyase like esterase, glycosidase, or peptidase (Noike et al., 1985). The major classes of anaerobic bacteria that degrade the cellulose include *Bacterioides succinogenes, Clostridium lochhadii, Clostridium celobioporus, Ruminococcus flavefaciens, Ruminococcus albus, Butyrivibrio fibrosolvens, Clostridium thermoculum, Clostridium stercorarium*, and *Micromonospora bispora* (Noike et al., 1985). Hydrolysis is carried out by a group of relative anaerobes bacteria of genera like Streptococcus and Enterobacterium (Ali Shah, Mahmood, Maroof Shah, Pervez, & Ahmad Asad, 2014).

2.2. Acidogenesis

In acidogenesis, the product of hydrolysis peptides, saccharides, and fatty acids are converted into simpler molecules having low molecular weight like organic acids alcohols, carbon dioxide, hydrogen, and ammonium. The existence of oxygen and nitrates is considered toxic and inhibits the anaerobic process. So, the presence of oxygen removing bacteria is vital to remove the oxygen and facilitate anaerobic conditions. During acidifation process, pH reduces to 4 (Dhamodharan & Ajay, 2014). Byproducts like ammonia and hydrogen sulfide are also produced (Figure 1, stage-2). Overall reaction is represented by the following Equations (2 and 3) (Mata-alvarez, Mace, & Llabres, 2002):

$$C_6H_{12}O_6 \rightarrow 2CH_3CH_2OH + 2CO_2 \tag{2}$$

$$C_6H_{12}O_6 \rightarrow 2CH_3CHOHCOOH \tag{3}$$

The acid-phase bacteria belonging to facultative anaerobes use oxygen accidentally introduced into the process, creating favorable conditions for the development of obligatory anaerobes of the following genera: Pseudomonas, Bacillus, clostridium, Micrococcus, or Flavobacterium (Ali Shah et al., 2014).

2.3. Acetogenesis

In acetogenesis, the product of acidogenesis is converted into acetic acid, hydrogen, and carbon dioxide by acetate bacteria (Figure 1 stage-3). Before methanogenesis acetic acid is formed. Homoautotrophic acetogenesis is produced by acetate from hydrogen and carbon dioxide. Overall reactions (4), (5), and (6) (Ostrem & Themelis, 2004; Ralph & Dong, 2010) are shown as:

$$CH_3CH_2COOH + 2\,H_2O \rightarrow CH_3COOH + CO_2 + 3H_2 \tag{4}$$

$$CH_3CH_2\,CH_2COOH + 2H \rightarrow 2CH_3COOH + 2H_2 \tag{5}$$

$$CH_3CH_2OH \rightarrow CH_3COOH + 2H_2 \tag{6}$$

The first three steps are together known as acid fermentation. In this process, no organic matter is removed from liquid phase but converted to as substrate for further process of methanogenesis (Dhamodharan & Ajay, 2014). In this process, the acetate bacteria including those of the genera of Syntrophomonas and Syntrophobacter convert the acid-phase products into acetates and hydrogen which may be used by methanogenic bacteria. Bacteria like *Methanobacterium suboxydans* account for the decomposition of pentanoic acid to propionic acid, whereas *Methanobacterium propionicum* accounts for the decomposition of propionic acid to acetic acid (Ali Shah et al., 2014).

2.4. Methanogenesis

In this final step of anaerobic digestion, the products of the acetogenesis are converted into methane gas by two groups of microbes known as acetoclastic and hydrogen-utilizing methanogens (Figure 1, stage-4). The acetoclastic methanogens convert acetate into carbon dioxide and methane. Hydrogen-utilizing methanogens reduce hydrogen and carbon dioxide into methane. The former process is dominant producing about 70% of methane in anaerobic digestion because hydrogen is limited in anaerobic process (Chu, Wang, & Huang, 2007).

The overall reaction (7), (8), and (9); (Kossmann et al., 2007) of methane production is described by the following chemical reactions:

$$CH_3COOH \rightarrow CH_4 + CO_2 \quad (7)$$

$$2CH_3CH_2OH \rightarrow CH_4 + 2CH_3COOH \quad (8)$$

$$4H_2 + CO_2 \rightarrow CH_4 + 2H_2O \quad (9)$$

During CH_4 formation process, the co-enzyme M and F_{420} play important role. They convert CO and formate into CH_4. Further co-enzyme M also helps in acetate and carbonyl transformation during the metabolic process of methane formation (Appels et al., 2011). The examples of methanogens found in all anaerobic digestion processes are *Methano bacterium, Methano thermobacter, Methano brevibacter, Methano sarcina, and Methano saeta* (Liu, Zhang, El-Mashad, & Dong, 2009). Conversions of complex organic compounds to CH_4 and CO_2 are possible owing to the cooperation of four different groups of micro-organisms and are presented in Table 1. These micro-organisms may be counted among primary fermentation bacteria, secondary fermentation bacteria (syntrophic and acetogenic bacteria), and two types of methanogens belonging to domain Archaea. These micro-organisms occur in natural environment and fulfill various roles during the process of anaerobic degradation of wastes.

Syntrophy is a form of symbiosis of two metabolically different groups of bacteria, which enables degradation of various substrates. Among methanogenic micro-organisms, we can distinguish psychro, meso, and thermophilic micro-organisms. Mesophilic and thermophilic bacteria described in the literature exhibit high activity within temperatures, respectively, 28–42°C and 55–72°C. So far, no anaerobic psychrophilic bacterium has been found which would exhibit activity at a temperature lower than 25°C. Temperature is very important for methanogenic bacteria, due to limited temperature resistance of their enzymatic structures. Methanogenic bacteria usually develop under inert conditions, with environmental pH from 6.8 to 7.2.

This, however, does not mean that methanogenesis does not occur in environments of acid or alkaline reaction. Methanogens which decompose acetates (*Methanosarcina barkeri* and *Methanosarcina* sp.) were isolated from environments of approximately pH 5, while methylotrophic and hydrogen-oxidizing methanogens were found in strongly alkaline ecosystems. Methanogenic bacteria belong to chemolithotrophs, because they are capable to use CO as a source of carbon (Ali Shah et al., 2014).

Table 1. Conversions of complex organic compounds to CH_4 and CO_2 by four different groups of microorganisms

S. No.	Microorganisms	Electron donor	Electron acceptor	Product	Reaction type
1	Methanogenic bacteria	Organic carbon	Organic carbon	CO_2	Fermentation
2	Syntrophic bacteria	Organic carbon	Organic carbon	H_2	Acidogenesis
3	Acetogenic bacteria	Organic carbon/H_2	CO_2	CH_3COOH	Acidogenesis
4	Methanogenic bacteria	Organic carbon/H_2	CO_2	CH_4	Methanogenesis

Table 2. Characterization of substrates and inoculums by different researchers study

Parameters	Sheng et al. (2013)		Wang et al. (2014)		Yong, Dong, Zhang, and Tan (2015)		Sun, Wang, Qiao, Wang, and Zhu (2013)		Zhou et al. (2014)		Wang, Wang, Cai, and Sun (2012)		Zhou, Elbeshbishy, and Nakhla (2013)		Cho et al. (2013)		Sreela-or, Plangklang, Imai, and Reungsang (2011)		Shen et al. (2013)	
	F	S	F	S	F	S	F	S	F	S	F	S	F	S	F	S	F	S	F	S
TS (%,w.b)	27.59	16.52	7.94	5.43	20.05	4.26	197.12	145.83	22.71	11.3	–	–	66900	33500	211	27	–	–	9.51	6.75
VS (%,w.b)	25.91	8.73	6.74	2.29	19.21	2.39	170.43	106.31	20.72	5.36	–	–	47000	26400	174	24	–	–	7.93	3.03
VS/TS (%,w.b)	93.90	52.83	84.89	42.17	95.81	56.10	83.46	72.90	–	–	–	–	–		–	–	–	–	79.17	44.89
pH	4.51	7.75	5.28	7.74	–	–	–	–	5.05	7.44	–	–	6	6	3.90	7.5	–	–	–	–
$C_nH_nO_n$(%,d.b)	–	–	11.80	–	33.22	–	100.54	42.28	–	–	45.01	68.15	36500	3,200	–	–	–	–	–	–
Protein (%,d.b)	–	–	13.80	19.12	14.03	–	28.61	49.30	–	–	14.82	14.50	–		–	–	–	–	13.57	20.03
Fat (%,d.b)	–	–	3.78	2.73	25.25	–	–	–	30.40	2.92	32.10	–	–		–	–	–	–	–	–
TCOD (g/kg)		–	–	–	–	–	106.01	124.72	198951.70	17841.30	–	–	106700	33900	320	–	116000	147000	–	–
C (%,d.b)	46.28	27.25	28.05	18.80	–	26.22	–	–	48.30	19.09	43.21	27.53	–		–	–	–	–	29.65	17.5
N (%,d.b)	2.23	3.64	1.63	3.06	–	4.68	35.15	51.27	–	–	2.37	2.40	34	2700	–	–	840	22790	1.57	2.97
C/N	–	–	17.21	6.14	–	–	–	–	18.90	8.90	18.20	11.40	–		24.60	–	–	–	18.88	5.89
SCOD (g/kg)	–	–	–	–	–	–	97.50	2.75	–	–	–	–	39300	3300	148	–	–	–	–	–
P (ppm,w.b)	–	–	–	–	–	–	3.94	17.23	–	–	–	–	21	450	13	–	1.98	2.62	–	–
Na (%,d.b)	–	–	–	–	–	–	–	–	–	–	–	–	–		–	–	36.00	32.44	–	–

3. Characteristics of substrate (F) and inoculua (S) reported in literatures

The composition of food waste depends upon eating habitats, cultivation, and availability. The food waste mainly comprises rice, vegetables, meat, egg, bread, roti, meat, etc. The presence of high moisture content in food waste (Table 2) indicates the high biodegradability (Zhang, Su, Baeyens, & Tan, 2014). The characterization of substrate and inoculua is vital before feeding the digester. TS (total solid) and VS (volatile solid) are mostly measured according to the Standard Methods (APHA, 2005). pH is determined using a pH meter (Orion, Model 370). Chemical oxygen demand (COD) is measured using COD ampoules (Hach Chemical) and a spectrophotometer (DR/2010, Hach). Total Kjeldahl nitrogen (TKN) is analyzed using a Kjeldahl apparatus (Kjeltec 2100, Foss, Sweden), and total ammonia (free ammonia and ionized ammonia) content is determined by the Kjeldahl method without the destruction step.

Protein content is estimated by multiplying the organic nitrogen value (TKN subtracted by total ammonia nitrogen) by 6.25 (Ahn, Do, Kim, & Hwang, 2006). Lipid is measured gravimetrically (Bligh & Dyer, 1959). Biogas composition (N_2, CH_4 and CO_2) is determined using gas chromatograph (GC) (Hewlett Packard 6890, PA, USA) equipped with a thermal conductivity detector and an HP-PLOT Q (Agilent Technologies, USA) capillary column (30 m _ 0.32 mm _ 20 lm). A gas standard consisting of 60% (v/v) CH_4 and 40% (v/v) CO_2 is used for calibrating gas chromatographic results.

The measurement of biogas generation is described by Zhang and Jahng (2010). Concentrations of volatile fatty acids (including acetate, propionate, n-butyrate, iso-butyrate, and n-valerateand iso-valerate) are determined using another GC (M600D, Younglin, Korea) equipped with a flame ionization detector and an HP-INNOWAX (Agilent Technologies, USA) capillary column (30 m _ 0.25 mm _ 0.25 lm). The sample preparation procedures and GC operational conditions are described by Zhang and Jahng (2010). Elements are assayed using an element analysis instrument (Flash EA1112, Thermo Electron SPA). Nitrogen, carbon, hydrogen, sulfur, and oxygen are the target elements. Metal analysis is performed using an ion-coupled plasma-atomic emission spectrometer (ICP-AES) (OPTIMA 4300DV, Perkin–Elmer, USA) or inductively coupled plasma-mass spectrometer (ICP-MS) (ELAN6100, Perkin–Elmer SCIEX, USA). Most studies show use of sludge from anaerobic digester as inoculua or seed (Zhang & Jahng, 2010).

Inocula play an important role in anaerobic reactor startup by balancing the populations of syntrobacter and methanogens. This balance makes syntrophic metabolism thermodynamically feasible in anaerobic digestion. The source of inocula not only affects the amount of biogas production but also influences the kinetics of the process of anaerobic digestion. The composition of a substrate is very important for the micro-organisms in the biogas process and thus also for process stability and gas production. When it comes to the decomposition of organic material in the anaerobic digestion process, the ratio of carbon to nitrogen (C/N ratio) is also regarded to be of great importance; therefore, the performance of the anaerobic digestion process is shown to be enhanced using substrates from different sources and with the right proportions. Investigations show that co-digestion of substrates from different sources produces more gas than predicted compared to gas production from the individual substrate. It is hard to say exactly what ratio is optimal because it varies with different substrates and also with the process conditions (Ali Shah et al., 2014).

4. Uses of gas and impacts

The gas generated from different sources is becoming the priority of energy throughout world. The gas generated is used to run vehicles or used as lighting and cooking source. According to Xuereb report, the production of electricity from biogas accounts for 0.5% of the total electricity output; the digester gas is used as fuel for boilers, internal combustion engines and pumping water in treatment plants. Further, the residues obtained after biogas production are used as manure for enrichment of soil nutrients (Igoni et al., 2007). In addition to gas production, anaerobic digestion of different wastes may be helpful in solid waste management as it reduces the volume of waste and stabilize it (Stroot, McMahon, Mackie, & Raskin, 2001). The positive impact of anaerobic digestion is gas production and solid waste management. Million tons of solid waste is produced from agriculture, industries and municipal sources. It is nowadays problem as rate of generation is greater than rate of degradation under natural conditions. According to Yu, Tay, and Fang (2001), 1MT of grass waste may release 50–110 carbon dioxide and 50–140 of methane. It will increase the global temperature up to 1–2% per year (IPCC, 2007). The biogas production by anaerobic process is on focus throughout world as it is used in development for many decades (Braber, 1995). Organic friction of municipal solid waste produce green house gas must be collected to reduce impacts like global warming and nuisance (Adhikari et al., 2008).

5. Comperative properties and composition of biogas

Before loading the digester, food waste must undergo pretreatment (Fabien, 2003; Igoni et al., 2007). After this the digester is fed with substrate and gas is produced by systematic reactions (Figure 1). The gas produced is known as gobar gas (Mattocks, 1984), or digestion gas (Oregon State Department of Energy, 2002), or natural gas (Harris, 2003) sewage gas (Xuereb, 1997), depending upon the existing condition. The gas is colorless, odorless, and flammable having calorific value between 4500–5000 kcal/m^3 and burns with blue flame if methane content is present. The comparative properties and composition are given in (Tables 3 and 4).

Table 3. Properties of biogas, landfill gas and natural gas

Properties	Landfill gas	Biogas	Natural gas
Lower calorific value	16 MJ/Nm^3, 4.4 kWh/Nm^3, 12.3 MJ/kg	MJ/Nm^3, 6.5 kWh/Nm^3, 20 MJ/kg	MJ/Nm^3, 11kWh/ Nm^3, 48 MJ/kg
Density	1.3 kg/Nm^3	1.1 kg/Nm^3	0.82 kg/Nm^3
Relative density	1.1	0.9	0.63
Wobbe index, upper	18 MJ/Nm^3	27 MJ/Nm^3	55 MJ/Nm^3
Methane number	>130	>135	73
Methane	45 Vol.%	65 Vol.%	90 Vol.%
Methane, range	35–65 Vol.%	60–70 Vol.%	85–92 Vol.%
Heavy hydrocarbons	0 Vol.%	0 Vol.%	9 Vol.%
Hydrogen	0–3 Vol.%	0 Vol.%	–
Carbon dioxide	40 Vol.%	35 Vol.%	0.7 Vol.%
Carbon dioxide, range	15–40 Vol.%	30–40 Vol.%	0.2–1.5 Vol.%
Nitrogen	15 Vol.%	0.2 Vol.%	0.3 Vol.%
Nitrogen, range	5–40 Vol.%	–	0.3–1.0 Vol.%
Oxygen	1 Vol.%	0 Vol.%	–
Oxygen, range	0–5 Vol.%	–	–
Hydrogen sulfide	>100 ppm	>500 ppm	3.1 ppm
Hydrogen sulfide, range	5 ppm	100 ppm	–
Total chlorine as Cl^-	20–200 Mg/Nm^3	0–5 Mg/Nm^3	–

Source: Fabien (2003) and Ray et al. (2013).

Table 4. Approximate biogas composition in anaerobic digestion

Gas	CH_4	CO_2	N_2	H_2	H_2S	O_2	C_xH_y	NH_3	R_2SiO
Concentration (%)	50–70	25–30	0–10	0–5	0–3	0–3	0–1	0–0.5	0–50

Source: Ray et al. (2013) and Igoni et al. (2007).

6. Design consideration

While designing any treatment plant for treatment of organic waste, factors like characteristics of waste, environmental and economic conditions are considered.

6.1. Nature of digester

According to Hessami, Christensen, and Gani (1996), production of biogas from household waste is almost negligible because present digesters are not capable for small-scale applications. This needs research. As per the nature of feedstock, the digester may be “lowtech” natural digester, modern digester, or low-cost community-based digesters (Hessami et al., 1996). However, according to (Igoni et al.) large number of digesters is available depending upon the nature of solids and operational factors. The digester may be covered lagoon, complex mixed digester (feedstock stock contains < 2–10% solids), and plug flow digester (suitable for feedstock stock contains < 11–13% solids). Many investigators used other digesters like high solid, batch system, continuous one-stage system or continuous two stage (Bouallagui, Haouari, Touhami, Ben Cheikh, & Hamdi, 2004), or anaerobic sequencing batch reactor (Rosenkranz et al., 2013).

6.2. Temperature

Operating temperature is very essential for survival, optimum thriving of the microbial consortia, and performance of anaerobic digestion. Anaerobic digestion can occur under the two temperature ranges defined as mesophilic (25–40°C) and thermophilic (50–65°C). Thermophilic conditions allows higher loading, yield, substrate digestion, methane production, and pathogen destruction but gas-producing bacteria die due to toxin and small environmental changes (Arsova, 2010). The above said conditions reduce the retention time when bacteria need higher retention time over 28 days to develop redox potential. So they are harder to maintain, reducing its commercial importance. Anaerobic digestion process is temperature-sensitive. Higher temperature affects the activity of hydrogenotropic methanogens, causes higher production of hydrogen and spore-forming bacteria (Speece, 1996). Mesophilic conditions, on other hand, operate with robust microbial consortia that tolerate environmental changes. Such digesters are stable, easier to operate and maintain, and lower investment cost allows their attraction in commercial scale. Disadvantages are retention time is high and lower biogas production (Van Haandel & Lettinga, 1994).

6.3. Hydrogen ion concentration or pH value

pH value of food waste is very important factor as methanogenic bacteria are sensitive to acidic environment by which growth and gas production is inhabited. The pH value varies along the different stages of anaerobic digestion (Zhang, Lee, & Jahng, 2011). The pH variation is caused by volatile fatty acids, bicarbonates, alkalinity and CO_2. Chemicals like NaOH and $NaHCO_3$ are used to maintain the pH value (Goel, Tokutomi, & Yasui, 2003). During the acetogenesis, the pH value declines below 5 causing mass death of methogens. This would lead to acid accumulation and digester failure. Constant pH is vital for starting the digestion, which is maintained by buffers like calcium carbonate or lime (Ray, Mohanty, & Mohanty, 2013). The methane-producing bacteria require neutral to slightly alkaline environment (pH 6.8–8.5). The hydrolysis and acetogenesis occur at pH between 5.5 and 6.5, respectively (Xiaojiao, Yang, Feng, Ren, & Han, 2012). The pH value for anaerobic digestion waste was discussed by various researchers but optimal range was found around 7.0 (Sosnowski, Wieczorek, & Ledakowicz, 2002).

6.4. Composition of food waste

The knowledge regarding the food waste is a vital design consideration in order to predict efficient design and biomethanization potential. The biomethanization of food waste depends upon four main components like proteins, lipids, carbohydrates, and cellulose. Highest methane yield associated reactor having excess of lipids but require higher retention time. The methonization is fast in the system with excess of protein followed by cellulose and carbohydrates (Neves, Goncalo, Oliveira & Alves, 2008). The active sources of food waste include residential, commercial, and institutional establishments or others like cafeterias, canteens, or lunch rooms (Lacovidou, Dieudonné-Guy, & Nikolaos, 2012). Food waste is highly variable in nature based on component (carbohydrates, protein, and lipids) and elemental (C, H, N, O) assessment. The value of protein and lipids are high in meat, egg, cheese, and fish as compared to bread, flour and potatoes which are rich in carbohydrates (Table 5). According to Belitz, Grosch, and Schieberle (2009) vegetables are generally rich in carbohydrates except mushroom and spinach that are rich in proteins. Similar trend is shown by fruits. Fresh fruits are rich in carbohydrates but dry fruits are rich in proteins. According to research, milk powder and legumes show wide range of variation among various components. Generally, legumes show higher content of carbohydrates and milk show higher lipid content. Based on the origin, it is evident that food waste shows numerous variability among different sources (Table 6). According to (Lesteur et al., 2008), two methods are widely used for component composition analysis or overall assessment of food waste. One is based on elemental (C, H, N, O) analysis and another on component (carbohydrates, protein, and lipids) composition (Table 7).

6.5. Organic loading rate

It is the biological conversion of capability of a reactor. It determines the amount of volatile solids that is feasible as the input to the anaerobic digester. Over loading may cause accumulation of fatty acids, acts as inhibitor, and results in low biogas yield. It would cause proliferation of acidogenesis, decrease pH, and mass death of methogenic bacteria (Igoni et al., 2007; Ray et al., 2013). According to the existing literature (Nagao et al., 2012), optimal OLR and SRT were reported as 22.65 kg VS/m^{3}d (160 h) for hydrogen fermentation and 4.61 kg VS/m^{3}d (26.67 d) for methane fermentation digester.

6.6. Retention time

It is defined as the time during which feedstock remain in the reactor. It is the measurement of chemical oxygen demand and biological oxygen demand of interfluent and the effluent material. There is optimal retention time for complete biological conversion, 12–24 days for thermophilic and 15–30 days mesophilic digester. It depends upon the type of substrate, environmental conditions, and intends use of digested material (Ostrem & Themelis, 2004). Parameters like Organic loading rate, hydraulic retention time and temperature must be monitorited to reduce instability of digester (Mechichi & Sayadi, 2005).

Table 5. Component composition assessment of food waste from different origin according % of dry weight/matter

Food waste origin	Carbohydrates	Proteins	Lipids	References
Household	60.70	14.40	14.40	Hansen, Cour Jansen, Spliid, Davidsson, and Christensen (2007)
Urban (Market, household)	78.20	16.90	4.90	Redondas et al. (2012)
University dining hall	64.5	14.90	17.50	Ferris, Flores, Shanklin, and Whitworth (1995)
Military facilities	56.79	17.50	22.00	Ferris et al. (1995)
Institutional restaurant	63.90	21.30	12.40	Yan et al. (2011)

Table 6. Elemental composition assessment of food waste (on %Dry weight/matter) reported in the literature (Straka, Jenicek, Zabranska, Dohanyos, & Kuncarova, 2007)

Name	C	H	N	O	S
Carbohydrate	40.00	7.00	–	53.00	–
Protein	46.00	5.00	18.50	30.00	0.50
Lipid	76.00	12.00	–	12.00	–

Table 7. Composition of food waste reported in existing literature based on (on %Dry weight/matter)

Waste	Carbohydrates	Proteins	Lipids	References
Meat and bone	<1	70–75	23–30	Straka et al. (2007)
Egg (Inc. shell)	2	35	32	Belitz et al. (2009)
Fish meat	–	75.6	20.2	Lu, Gavala, Skiadas, Mladenovska, and Ahring (2008)
Whole milk powder	37.7	26.5	27.4	Belitz et al. (2009)
Skim milk	53	36	–	Belitz et al. (2009)
Cheese	–	25–35	20–45	Belitz et al. (2009)
Legumes	46–74	23–29	1.3–5	Belitz et al. (2009)
Fresh vegetables	27.1	26.9	1.4	Carucci, Carrasco, Trifoni, Majone, and Beccari (2005)
Fruit	83	4	2	Christ, Wilderer, Angerhofer, and Faulstich (2000)
Bread	84	14	2	Straka et al. (2007)
Potato	99	1	< 1	Straka et al. (2007)
Rice	76.3	7.4	0.8–2.4	Belitz et al. (2009)
Flour	70	12	< 1	Straka et al. (2007)

6.7. Mixing
It is an important operating factor for achieving digestion of organic matter (Tchobanoglous & Burton, 1991). Mixing is vital for achieving uniformity among the substrate concentration, temperature, and environmental conditions to reduce the chance of scum formation and solid deposition (Agunwamba, 2001). Mixing is done by mechanical stirrers or by gas recirculation depending upon the total solid concentration within the digester. However, excessive mixing can disrupt microbes, so slow mixing is preferred (Khalid, Arshad, Anjum, Mahmood, & Dawson, 2011).

6.8. Waste particle size
Particle size directly effects the decomposition, calls for particle reduction by crushing, gridding, and shredding (Kiely, 1998). It increases surface area action for microbes, ultimately improves the efficiency of digester (Agunwamba, 2001). The most widely used methods of disintegration were mechanical grinding (NahI, Kang, Hwang, & Song, 2000), ultrasound (Marañón et al., 2012), microwave (Shahriari, Warith, Hamoda, & Kennedy, 2013), thermal, chemical (Ma, Duong, Smits, Verstraete, & Carballa, 2011) or their combination (Vavouraki, Angelis, & Kornaros, 2013), and biological pretreatment (Gonzales et al., 2005).

6.9. C/N ratio
The ratio of C and N plays a crucial role in anaerobic digestion. The carbon acts as energy source and nitrogen serves to enhance the microbial growth. These two nutrients often act as limiting factor (Richard, 1998). Optimum ratio is between 20 and 30 (Vandevivere et al., 2000). The gas production is low due to high C/N ratio by rapid consumption of nitrogen. On the other hand, low C/N ratio causes ammonia accumulation. pH value exceeds 8.5 that is toxic to methanogenesis. Optimum C/N ratio can be achieved by mixing substrate of low and high C/N ratio (Khalid et al., 2011). It has been found that conversion of carbon to nitrogen in digestion process is 30–35 times faster, so ratio of C/N should be 30:1 in raw substrate. Nitrogen is considered as limiting factor and nitrogen sources like urea, bio-solids, and manure could be used as supplements' (Richard, 1998). C/N ratio between 20 and 30 provide sufficient nitrogen for anaerobic process (Weiland, 2006). C/N between 22 and 25 is best for anaerobic digestion of fruit and vegetable wastes (Ghosh & Pohland, 1974).

6.10. Cost

Cost consideration includes cost of waste processing, construction and maintenance, obtaining substrate, and capital and operating costs, which are very important in the selection of type and size of the digester (Tchobanoglous & Burton, 1991). The digester may be modern operating or simple batch one affect cost (Steadman, 1975). According to Oregon State Department of Energy, among three main types of digesters, batch, complete mix, and plug flow digester batch digester was the least expensive one (Oregon State Department of Energy, 2002). To build the digester having capacity of 8.0 m^3/day, approximately around 8000$ is required (Hessami et al., 1996).

6.11. Moisture content

High moisture contents usually facilitate the anaerobic digestion; however, it is difficult to maintain the same availability of water throughout the digestion cycle (Hernandez-Berriel, Benavides, Perez, & Delgado, 2008). Initially water added at a high rate is dropped to a certain lower level as the process of anaerobic digestion proceeds. High water contents are likely to affect the process performance by dissolving readily degradable organic matter. Moisture content has profound effect on anaerobic digestion. An anaerobic process was carried out at different moisture levels i.e. 70 and 80%. It was found that bioreactor operated at 70% moisture content produces more methane than the bioreactor operated at 80% moisture content. However, the ratio of BOD and COD remained the same (Hernandez-Berriel et al., 2008).

7. Pretreatment of food waste

The process to prepare the food waste as feedstock for anaerobic digestion is known as pretreatment. Usually, waste is found as mixture of organic and inorganic components. So, it would be positive to segregate the organic friction for digestion process (Igoni et al., 2007). The pretreatment of feedstock involves the removal of non-biodegradable materials, providing effective size and uniform feedstock material and removal of such material decreases the quality of digestate (Fabien, 2003). In order shred and mix the food waste, mechanical methods are used. It lowered the quality of digestate (Fabien, 2003). Mechanical biological treatment can theoretically reduce methane yield up to 40–60% (Ray et al., 2013). Sometimes sterilization of substrate is also done (Fabien, 2003). Nowadays, trace elements are added as supplement to food waste for stable and successful digestion at a particular loading rate per day with high biogas yield. Selenium and cobalt are key trace elements found effective in stabilizing digestion mainly during ammonia formation. According to research, the recommended concentration of Selenium and Cobalt for kitchen waste is around 0.16 and 0.22 mg /liter, respectively, for moderate organic loading rate. It must be noted that the concentration of Selenium greater than 1.5 mg/liter is found to be toxic to microbes that are busy in digestion (Ray et al., 2013).

8. Operational and performance of anaerobic digestion of food waste

Linke (2006), used the potato waste as substrate to produce gas anaerobically in CSTR at temperature 55°C. upon increasing the OLR up to 3.4 kg VS m^{-1} day^{-1}, the biogas yield declined. It was found between 0.85 and 0.65 m^3 kg^{-1}VS with 58% methane content. They conclude that on increasing OLR, accumulation of fatty acids can act as inhibitor. So, special attention must be kept on it to reduce the chance of reactor failure.

Bouallagui, Cheikh, Marouani, and Hamdi (2003), used tubular digester for the digestion of fruit and vegetable wastes with maximum OLR rate of 6% TS for 20 days of retention time at mesophilic temperature, and high yield of 0.707 m^3 kg^{-1} with efficiency of 75.9% were reported. Bouallagui et al. (2004), experimentally investigated the biodegradability of fruit and vegetable wastes by using two-phase anaerobic digestion system at mesophilic and thermophilic temperature. The OLR was reported as 7 kg at HRT of 20 days. The efficiency was reported as 96% with biomass yield of 0.705 and 0.997, with ultimate methane content as 64.61. In another study, Bouallagui, Rachdi, Gannoun, and Hamdi (2009) experimentally studied the performance of sequencing anaerobic batch reactor by varying HRT and temperature to digest the mixture of abattoir waste and food and vegetable waste. As per result, VS removal varies between 73 and 86%, biogas yield of 0.3–0.73 m^3 kg^{-1}VS added on

OLR of 2.56 kgTVS m^{-3} day^{-1}. They conclude that biogas yield at 20 days HRT was significantly increased by increasing temperature to thermophilic range from mesophilic range. It was reported that by increasing temperature HRT was reduced fallowed by digestion failure possibly by increase in pH and alkalinity with increasing OLR and temperature. Again, Bouallagui et al. (2009), conduct anaerobic digestion of food waste using sequencing batch rector at thermophilic conditions by HRT of 15 days. They reported biogas yield of 0.48 m^3 kg^{-1}VS added with 60% of methane content and 79% of VS reduction.

Zhang et al. (2007) investigated the biodegrebility of food waste using batch rector at HRT of 10 and 20 days. Methane yield of 0.435 m^3 kg^{-1}VS and 0.348 m^3 kg^{-1}VS was reported the end of 10 and 28th day of digestion at 50°C respectively. In first case, VS removal was 81% indicating that food waste could be used as substrate in anaerobic digestion. The methane yield was reported as 73%. Kim, Oh, Chun, and Kim (2006) carried out the digestion of food waste using the three-stage semi-continuous digester at thermophilic conditions. As per the result, they reported 67% methane content at HRT of 12.4 days.

Forster-Carneiro, Pérez, and Romero (2008c) conducted a study to compare the biodegradability of shredded organic friction of MSW and food waste separately using batch digesters. According to them, for shredded organic friction of MSW showed VS removal of 74% with methane yield 0.05 m^3 kg^{-1}VS added and VS removal for food waste was 32% with methane yield of 0.18 m^3 kg^{-1}VS added. The methane percentage was reported as 68.5 and 76.7, respectively. Again Forster-Carneiro, Pérez, and Romero (2008a) evaluated the performancer of different reactors by carrying out digestion of different forms of municipal solid waste According to the result, the digester which carried out digestion of source separated municipal solid waste showed VS reduction of 45% with biogas production as 0.120 m^3. However, for MS of municipal solid waste showed the VS reduction as 46% with biogas yield of 0.082 m^3. In both the cases HRT was 6 days and temperature was noted as of thermophilic range. In first case, the start was faster than second case. Similarly Forster et al. (Forster-Carneiro, Pérez, Romero, & Sahes, 2007) conducted another study to determine the effect of different inoculua for treating the separately collected organic friction of municipal solid waste. The result showed that the performance of sludge inoculum reactor was highest followed by swine/sludge inoculum reactor. The result showed sludge is the best inoculum for anaerobic digestion of separately collected organic fraction of municipal solid waste produces green house gas, it must be collected and used in anerobic digestion to produce energy and reduce impacts like global warming and nuisance. In another study Forster-Carneiro, Pérez, and Romero (2008b) investigated the biomethane production by varying total solid percentage and different inoculua at mesophilic temperature. The best result was obtained at 20% total solid and 30% inoculua.

Lastella et al. (2002) carried out an experimental investigation to show the impact of a bacteria in columns on the anaerobic digestion of semisolid organic waste of ortho fruit market using plug flow rector at 37˚c with HRT 22.5 day. According to result efficiency is 72% and methane content is 68%. Prema et al. (1991) studied the effect of varied OLR using fruit and vegetable wastes as substrate on the performance of semi-continuous digester. They reported that methane yield was 0.5–0.6 m^3 kg^{-1}VS added with methane content of 53% at mesophilic conditions with HRT of 25 days and OLR as 40m^3 kg^{-1}VS Krishna et al. (1991), in their study, used canteen and mess waste as substrate for biogas production in a floating dome-type reactor. The OLR was reported as 40 kg VS m^{-1} day^{-1} with biogas yield of 0.98 m^3 kg^{-1}VS at 20 day HRT. The substrate utilization was reported as 65% with methane content as 50%. They concluded that canteen and mess waste is a promising substrate for biogas production under mesophilic condition. If sufficient care is maintained, the digester can withstand loading rate up to 100 kg TS m^{-3} day^{-1}.

Elango, Pulikesi, Baskaralingam, Ramamurthi, and Sivanesan (2007) carried out an experimental investigation using domestic and municipal solid waste as substrate for anaerobic digester. The batch reactor was operated at mesophilic temperature with HRT 26 days and OLR between 0.52 and 4.3 VS m^3 kg^{-1}. The efficiency was reported as 87% with biogas production of 0.3 m^3 kg^{-1}VS added

Table 8. Operational and performance data for different digesters used in food waste study

Researcher	Reactor type and volume	Feed	Tem (°C)	OLR (kg VS m^{-1} $days^{-1)}$	HRT (Days)	Efficiency VSred (%)	CH_4 yield (m^3 kg^{-1}VS added)	Biomass yield (kg^{-1}VS)	%CH_4
Linke et al. (2006)	CSTR	PPW	55	0.8–3.4	NR	NR	NR	0.65–0.85	58
Bouallagui et al. (2003)	Tabular reactor (18L)	FVW	35	6	20	75.9	NR	0.707	57
Zhang et al. (2007)	Batch system	FW	50	NA	10, 28	81	0.348, 0.435	NR	73
Bouallagui et al. (2009)	ASBR (2L)	FVW	55	1.24	15	79	NR	0.48	60
Kim et al. (2006)	3-Stagesemi continuous	FW	50	NR	12.4	NR	NR	NR	67.4
Forster et al. (2008b)	Batch (1.1L)	FW	55	NA	90	74, 32	0.18, 0.05	NR	68.5–76.7
Lastella et al. (2006)	PFR (1350)	SSW	37	NR	22.5	68, 72	NR	NR	68
Prema et al. (1991)	Semin Continuous (60L)	FEW	37	40	25	NR	0.5–0.6	NR	53
Krishna et al. (1991)	Floating dome type (200L)	FW	33	40	20	65	NA	0.98	50
Ortega, Barrington, and Guiot (2008)	Batch scale (5L)	FW	36–55	0.12–5.32	21–60	NR	0.84	0.2–1.4	60–65
Berlian, Sukandar, and Seo (2013)	Batch (200L)	FVW	28–46	NR	98	NR	0.387	5.3–6.8	65
Kim et al. (2006)	3-Stage semi continuous	FW	35–55	8	12	78	3.3	5.60	58.9
Bouallagui et al. (2009)	ASBR (2L)	AW, FVW	55	2.56	20	73, 86	NR	0.3–0.73	NR
Elengo et al. (2007)	Batch	DW, MSW	35	0.52–4.3	26	87	0.3	NR	NR
Alvarez and Lidén (2008)	Semi continuous	SHW, FWS,M	35	0.3–1.3	20	NR	0.3	NR	56
Zupančič et al. (2008)	Full Scale (2,000 m^3)	DW, MSW	50	1	20	80	0.39	NR	NR
Bouallagui et al.(2004)	2-phase system (18L)	FVW	35, 55	7.5	20	96	NR	0.705, 0.997	64.61
Chen et al. (2010)	Batch and cont. (20 and 18L)	FW	35, 50	0.5, 1.0	28	80–97, 78–91	0.25–0.55, 0.35–0.78	0.53–0.83, 0.60–1.10	47–68, 48–74

Notes: PPF = Processed Potato Waste, FVW = Food and vegetable waste, FW = Food waste, SSW = Semi solid waste, FEW = Fruit and Vegetable waste, AW = Activated sludge waste, DW = Domestic waste, MSW = Municipal solid waste, SHW = Slaughter house waste, FWS = Fruit and slaughter house waste, M = Manure, CSTR = Continuous stirred tank reactor, ASBR = Anaerobic sequential batch reactor, PFR = Plug flow reactor, HRT = Hydraulic retention time, OLR = Organic loading rate, NR = Not reported, Cont. = Continuous.

Alvarez and Lidén (2008), experimentally carried out aerobic digestion of slaughterhouse waste, fruit and vegetable waste, and manure in co-digestion process using semi-continuous digester at mesophilic temperature. The result revealed that methane yield was 0.3 m^3 kg^{-1}VS added with methane as 56% at OLR rate at 0.3–1.3 kg VS m^3 kg^{-1}. According to them, biogas production was decreasing with increasing OLR. It was found that the methane content was reduced due to overloading and reduction in pH value. They concluded that it is possible to carry out co-digestion of mixed waste comprised of slaughter waste, manure, and fruit and vegetable waste by semi-contin-ues digester at mesophilic temperature Zupančič, Uranjek-Ževart, and Roš (2008) experimentally carried out the co-digestion of domestic and municipal sludge at HRT of 20 days with OLR of 1 kg VS^{-3} day^{-1}. The efficiency was reported as 80% with methane yield of 0.39 m^3 kg^{-1}VS added. They concluded that high efficiency of degradation was achieved and whole organic waste was degraded.

Kim et al. (2006) developed biomethenation system for food waste to study the effect of temperature and hydraulic retention time during digestion. They used modified three-stage reactor with varying temperature between 35 and 55°C and hydraulic retention time was set between 8 and 12 days, respectively. According to them maximum methane yield was reported on day 12th day at the temperature of 55°C. The methane yield was reported as 3.3 m^3 kg^{-1}VS added with biomass as 5.60.52–4.3 VS m^3 kg^{-1}. At the maximum temperature, the efficiency was reported as 78% with methane content of 58%. Ortega, Barrington, and Guiot (2007) investigated the effect of food waste digestion with sludge under mesophilic to thermophilic conditions. The retention time was reported to vary up to 21–61 days. Organic loading was reported as 8 kgVS m^{-3} day^{-1}. The methane and biomass yield were reported as 0.84 m^3 kg^{-1}VS added and 0.2–8.16 m^3 kg^{-1}. The percentage of methane was reported as 60–65%. They concluded that mesophilic wastewater for treating anaerobic sludge can be used to digest food waste under thermophilic conditions.

Berlian et al. (2013) carried out the anaerobic digestion of mixed fruit and vegetable waste in a batch reactor with capacity of 200 liters. The objective was carried out at temperature between 28 and 46°C. The waste sampling method was used as grab sampling done at traditional market of Pontianak. According to their result, the methane yield was reported as 0.38 m^3 kg^{-1} VS added with methane content of 65%. The biomass yield varied between 5.3–6.8 m^3 kg^{-1}VS. Chen, Romano, and Zhang (2010), conducted a study to determine the biodegradability of five kinds of food waste individually and as mixture under thermophilic and mesophilic conditions. The digestibility was shown in term of biogas yield, methane yield, and volatile solid reduction. They also reported that pH was maintained by NaOH. OLR was reported as 0.5–1.0 VS/L/day. They revealed the biogas yield as 0.53–0.83, methane yield as 0.25–0.55, VS reduction 82–97% with methane content as 47–68% respectively at mesophilic temperature with HRT of 28 days. However, at thermophilic temperature the biogas yield was reported as 0.60–1.10, methane yield as 0.35–0.78, VS reduction as 78–91% with methane content as 48–74%.

Nagao et al. (2012) experimentally carried out anaerobic digestion of food waste for HRT of 222 days with varied OLR from 3.37 to 12.9 kg VS m^{-3} day^{-1} in a semi-continuous mode at mesophilic temperature. As per results, the efficiency, CH_4 and methane percentage was reported as 9.18, 0.45, and 68.70%, respectively. They concluded that maximum CH_4 yield and VS reduction was reported as 10.5 kg VS in single-stage wet anaerobic digestion at mesophilic conditions with high rate of stability.

The whole operational performance data according to above discussion research work are summarized in Table 8.

9. Conclusion

The various factors involved in design of anaerobic digester for the production of biogas from food waste have been reviewed. The anaerobic digestion is proven superior to landfilling and aerobic digestion of waste. The design considerations like nature of digester, hydrogen ion concentration, temperature, composition of waste, organic loading rate, retention time, mixing, waste particle size, C/N ratio, cost, and moisture content were discussed and analyzed to achieve optimal, cost-effective and environment-friendly designed digesters. According to this review, further advanced research is necessary for data collection, performing the experiments, and designing environmentally feasible digester for food waste. Many types of reactors like conventional batch, single, and two-stage processes were employed for various substrates. The two phase system showed good ability and efficiency for the biodegradation of food waste. Thus, more attention should be directed toward the development of such systems for food waste. However, single phase should not be neglected as it is very effective for ruler energy recovery.

From the overall review, it is concluded that the failure of digester due to accumulation of fatty acid by decreasing pH could be overcome by co-digestion of food waste along with organic manure and other natural organic product. This will ultimately reduce the use of chemical in anaerobic digestion. The batch digestion system yields a cost-effective and economically viable means for conversion of the food waste to useful energy. It is therefore recommended that such process be increasingly employed in order to get and simultaneously protect the environment. Anaerobic digestion is a complicated reduction process involving a number of biochemical reactions under anaerobic conditions. This digestion processes convert biomass to energy used in recycling of organic wastes and reduction of hazardous effects on the environment. Hydrolysis, acidogenesis, acetogenesis, and methanogenesis are different stages of anaerobic digestion. Biogas is possible due to the different groups of micro-organisms, namely, fermentative, syntrophic, acetogenic, and methanogenic bacteria.

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