THE CRITICAL EFFECTS OF ENVIRONMENTAL VARIATIONS ON ANAEROBIC DIGESTION OF ORGANIC FRACTION MUNICIPAL SOLID WASTE (OFMSW) TREATMENT

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ABSTRACT: *The aim of improving knowledge about the stability and reliability of anaerobic digestion of OFMSW, several researchers have studied the effects of operational or environmental variations on the performance of such reactors. In general, anaerobic digestion is affected by changes in external factors and the treatment of anaerobic digestion of OFMSW is, in many aspects of environmental variations mature. Typical topics such as process aspects (performance, two- and single-phase systems), digestion enhancement (pH, moisture, temperature, waste composition, nutrient concentration, particle size, toxicity and inhibition, mixing, granulation and biofilms, loading rates and solid retention time, bioreactor systems for OFMSW pre- and post treatments).*

Keywords*: Anaerobic digestion, OFMSW, VFA, methane; pH; temperature, pre- post treatment*

1. INTRODUCTION

Sound management systems for municipal solid waste involve source-separation scheme, whereby the organic fraction of municipal solid waste (OFMSW) can be separately treated instead of being dumped in a sanitary landfill together with other types of wastes. Local government units are now beginning to implement solid waste segregation schemes such that the biodegradable portion of the solid waste can be treated separately. As land near urban centers is limited and expensive, treatment systems for this portion must be compact. To reduce land space for composting, there must be a prior anaerobic digestion of the organic solid waste. The latter offers the potential of net energy generation. Moreover, anaerobic digesters allow for collection of methane, otherwise emitted as among the greenhouse gases from landfills. Thus, anaerobic systems that can operate at high loading rates must be developed. In the degradation of solid waste, its component polymers are firstly hydrolyzed. Under anaerobic conditions, the products of hydrolysis are fermented to mainly volatile fatty acids (VFA). The latter are further converted to acetate and hydrogen gas, which are then converted to methane. For complex organic matter, such as those present in solid waste, hydrolysis is known to be the rate-limiting step (Pavlosthathis *et, al.*, 1991; Ferreiro *et, al.*, 2003. It is therefore important to determine how to hasten this process. Since hydrolysis occurs on the surface of a solid, increasing surface area by reducing particle size may speed up hydrolysis. On the other hand when hydrolysis is accelerated, volatile fatty acids (VFAs) formed from the products of hydrolysis may accumulate to levels that are inhibitory to methanogens (Borzacconi, 1997). In addition, the second International Symposiumon Anaerobic Digestion of Solid Waste in June 1999. (II-ISAD-SW) was held in Barcelona. The first Symposium, the meeting attracted more than 350 people from 47 countries. Regarding with biological treatments, anaerobic digestion is frequently the most cost effective, due to the high energy recovery linked to the process and its limited environmental impact. Biogas production throughout Europe, could reach over 15 million m^3/d of methane. Moreover, more than 36,000 anaerobic digesters are today in operation in Europe, treating around 40 ± 50% of the sludges generated (Tilche, A., Malaspina, F.,1998). It has to be stated that this review focused on the overall publications on the topic of organic solid wastes, but some of the issues discussed may have been under implementation for some years. Thus, this paper aimed to review in the literature dealing with anaerobic digestion of OFMSW with the large number of topics related to this area. In general, the critical factor of environmental variations including process aspects (pH, moisture, temperature, waste composition, nutrient concentration, particle size, toxicity and inhibition, mixing, granulation and biofilms, loading rates and solid retention time, bioreactor systems for OFMSW pre- and post treatments)).

2. DISCUSSIONS OF THE CRITICAL FACTORS OF ENVIRONMENTAL VARIATIONS

The anaerobic digestion of complex waste, such as food waste, vegetable, comprises a series of sequential biochemical process as shown in Fig.1 (Gujer and Zehnder (1983). In batch reactors, these steps are distinct stages occurring in succession. In continuous reactors, these steps occur simultaneously for as long as there is a substrate for a particular step and the conditions in the reactor are favorable to the particular step. (Tchobanoglous *et al.,*1993). Methanogens are strict anaerobes, that is, atmospheric oxygen is inhibitory to their growth. In anaerobic reactors, facultative anaerobes present in biofilm or exterior part of the sludge particles (which are aggregates of cells), scavenge traces of dissolved oxygen, hence protecting the strict anaerobes at the interior part.

2.1.Waste composition, Volatile Solids (VS), and Total Solid (TS)

The composition of OFMSW vary from site to site and are influenced by various factors, including region, climate, methods of recycling and segregation, use of in-sink disposal, collection frequency, season, and cultural practices. Lignin is a complex organic material that is not easily degraded by anaerobic bacteria and constitutes the refractory volatile solids (RVS) in OFMSW. Waste characterized by high VS and low non-biodegradable matter, or RVS, is best suited to anaerobic digestion. Kayhanian (1995) showed that knowledge of the BVS fraction of MSW helps in better estimation of the biodegradability of waste, of biogas generation, organic loading rate and C/N ratio. The composition of waste affects the yield and biogas quality as well as the compost quality. Low solids anaerobic digestion contain less than 10% TS, Medium solids anaerobic digestion about 15-20% TS and high solids processes range from 22% to 40% (Tchobanoglous *et al.,* 1993).

2.2.Temperature

OFMSW may undergo either mesophilic or thermophilic anaerobic digestion. These two types of processes are carried out by two classes of microorganisms. Theses are (1) the mesophilic bacteria, which are active in the temperature range 30-35°C and (2) the thermophilic bacteria, which are active in the range 45-65°C. For maximum gas production, thermophilic digestion is recommended (Grasmug *et al.,* 2001). Higher temperatures in the thermophilic range reduce the required digestion time. Besides higher metabolic rates of the microorganisms carrying out the digestion processes, and thus shorter required solid retention time, digestion under thermophilic condition has many other advantages such as a high destruction of pathogens and weed seeds. On the other hand, thermophilic treatment has some drawbacks such as less stability compared to mesophilic conditions.

Rate of
the
anaerobic
process

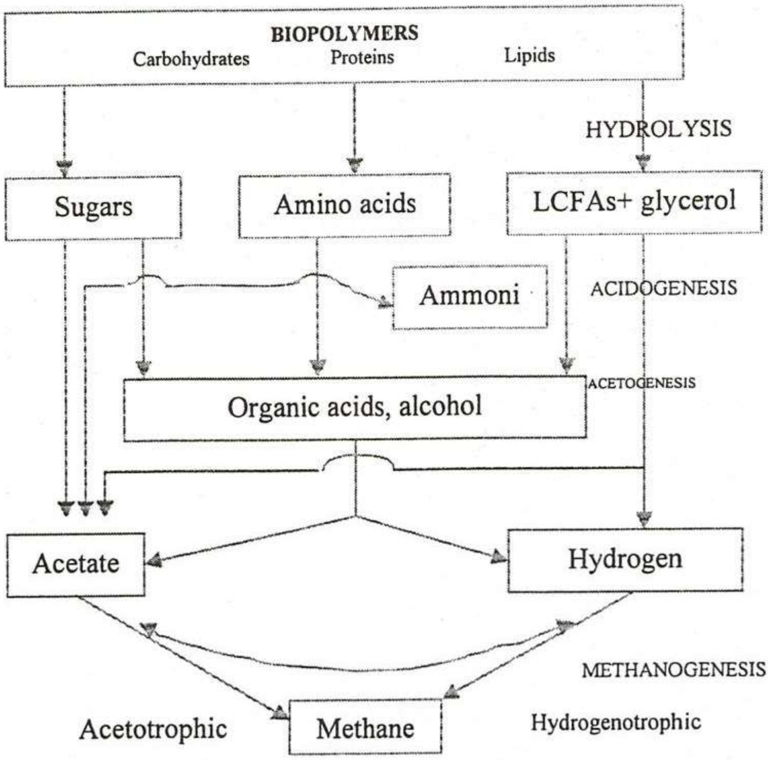

Figure 1. Conversion steps in anaerobic degradation of complex wastes (Gujer and Zehnder 1983)

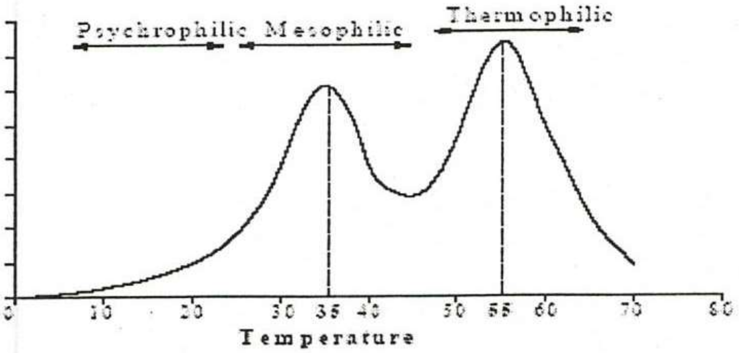

Figure 2. Temperature range for anaerobic digestion process (Grasmug *et al.*, 2001)

Furthermore, the energy requirements of thermophilic systems are higher than that of mesophilic systems (Zabranska *et al.*, 2002). The reported methane generated per unit amount of OFMSW from mesophilic and thermophilic digestion of OFMSW or co-digestion of MSW with sewage sludge is shown in Table 1.

Table 1. Effect of temperature on methane production from OFMSW

Type of waste	Temperature, °C	SRT, d	Volume of methane	Reference
OFMSW	5.5°C	120	0.045 m^3per kg SW	Smith *et al.*, (2002)
OFMSW +sewage sludge	35°C	65	0.2 - 0.35 $m^3.kg^{-1}$ SW-COD	Grasmug *et al.*, (2001)

OFMSW +sewage sludge	55°C	65	0.35 - 0.55 $m^3.kg^{-1}$ SW-COD	Grasmug *et al.*, (2001)

2.3. pH

The value and stability of pH in an anaerobic reactor is extremely important because methanogenesis only proceeds at a high rate when the pH is maintained in the neutral range. High methane gas production rates are obtained between pH 6.8 and 7.5 (Williams, 1998). At pH values below 6.3 or higher than 7.8 the rate of methanogenesis decreases. Acidogenic populations are less sensitive to low or high pH values. Hence at low pH levels acid fermentation will prevail over methane production. This may result in souring of the reactor contents (Van Haandel and Lettinga, 1994). In addition, the pH and VFA are linked to each other but their relation depends on the waste composition which may differ from the type of waste and the environmental conditions of anaerobic digestion process. The growth of anaerobic microorganisms like methanogens can be inhibited by acidic condition because they are sensitive to acid concentration. pH plays a major part in anaerobic biodegradation in which pH influences the activity of microorganisms.

2.4. Moisture

Sewage sludge, agricultural wastes and some industrial wastes may have over 90% moisture content, and municipal solid waste may have about 60% moisture content affects methane production (Williams, 1998). It also affects the rate of hydrolysis of the biodegradable solid waste (Palenzuela *et al.*, 2004). Some reactor systems have been used on pilot scale for low and high moisture content of solid waste.

2.5. Nutrient concentration

For bacterial growth, all essential nutrients should be present in the system in sufficient amounts and in available forms for the microorganisms. Nitrogen and phosphorus are the major nutrients required for anaerobic digestion. These elements are building blocks for the cell synthesis. The nutrient requirement for digestion optimum requirement is directly related to the desired microbial growth in anaerobic digesters. An average empirical formula for an anaerobic bacterium is $C_5H_7O_2NP_{0.06}$ (Speece, 1987). Thus the nitrogen and phosphorus requirements for cell growth are 12% and 2%, respectively, of the volatile solids converted to cell biomass (about 10% of the total volatile solids converted). This N and P requirement would be equivalent to 1.2% and 0.024%, respectively, of the biodegradable volatile solids. The relationship between the amount of carbon and nitrogen present in organic materials is represented by the C/N ratio. The optimum C/N ratio in anaerobic digesters is between 20 and 30 (Williams, 1998). OFMSW can have a high C: N ratio of above 50 (Williams, 1998). A high C: N ratio produces a high acid concentration and low methane production. Hence, most OFMSW need to be supplemented with N source to meet the requirement of the C: N ratio. Other nutrients needed in intermediate concentrations, include sodium, potassium, calcium, magnesium, chlorine, and sulfur. Requirements for several micronutrients have been identified, including iron, copper, manganese, zinc, nickel, and vanadium (Speece, 1987).

2.6. Particle size and shear force

Particle size and comminution were found to have important effect on the rate of anaerobic digestion of OFSWM. In a study by Palenzuela-Rollon *et al.*, (2004), they found that slurry digestion (in which the solid kitchen waste was comminuted to form the slurry) was faster than the digestion of solids cut into larger particle sizes. For the experiment on slurry digestion, the component materials were comminuted using a blender-osterizer. Moreover, longer agitation time was expected to extract more of the soluble components of the tissues of the solid waste components and cause disintegration of coarser particles. The results of the batch experiments showed that the effect of applying shear force on the solids gave a more significant improvement in the digestion rate than cutting the solids to reduce their size. Generally, the hydrolysis rate was directly related to the amount of substrate surface available and the surface of the particulate substrate was the key factor for the hydrolysis process (Sanders, *et al.*, 2000). Veeken and Hammelers (1999a, b) also reported that the rate of hydrolysis of particulate organic matter is determined by the adsorption of hydrolytic enzymes to the biodegradable surface sites and an increase in biodegradability results in an increase in adsorption sites for enzymes.

2.7. Toxicity and Inhibition

Several substances are found to inhibit both hydrolysis of complex wastes (such as proteins and lipids) and methane production. Among these are lipid, LCFA, NaCl and NH_4^+. Several ways to abate the problem caused by the presence of lipids and LCFA were studied. LCFA inhibition can be occurred via precipitation with calcium (Angelidaki and Ahring, 1990, Hanaki *et al.* 1981). The inhibitory effect of lipids is commonly attributed to the LCFAs from lipid hydrolysis. Neutral lipids are less inhibitory (Angelidaki and Ahring, 1990, Hanaki *et al.*, 1981). High amount of NH_4^+ may be generated from the degradation of proteins in solid waste. Low but sufficient NH_4^+concentration have beneficial effect on anaerobic processes as $NH_4^+$is an important nutrient source for anaerobic bacteria. On the other hand at high concentration, it inhibits methanogenesis (Palenzuela *et al.*, 1999). NaCl may also affect biochemical process via its effect on enzyme activity and the bacteria which carry out these process using intracellular and extracellular enzymes (De Baere *et al.,* 1984). For this reason, special attention is usually given to avoiding the entry of toxic substances into an anaerobic treatment system. The high concentration of propionic acid, ammonia and sulfate could inhibit the methanogenesis. Hence, seeding or inoculation with sludge and animal manure could help the onset of methanogenes. In this way, elevated biogas production and process stability could be achieved. Propionic acid is believed to be the most toxic volatile fatty acid appearing in anaerobic digestion and its oxidation to acetic acid is the slowest among all volatile organic acids (VFA) Hanaki, *et al.,* (1994). Among the VFA, propionic is the mostinhibitory and a concentration of more than 1000 mg/L is considered as toxic and can cause digester failure. Ammonia inhibition occurrs ammonia concentration of 1500 mg/L which leads to increase up pH to 8.5 is toxic to methanogens. Ammonia accumulates because there is no mechanism for its biodegradation under methanogenic conditions. In order to solve this problem, two practical methods were investigated successfully: (a) dilution of digester content with water; and (b) adjustment of feedstock C/N ratio (Mata-Alvarez, 2003).

2.8. Mixing, granulation and biofilms

The target of mixing in a digester is to blend the fresh material with digestate containing microbes. It is traditionally thought to be required for optimized digestion to enhance contact between microorganisms and their food, which is present in the solid waste. Another purpose of mixing is to remove or dilute inhibitory metabolic products from the cells (WPCF, 1987). On the other hand, mixing may expose the microorganisms to toxic substances. Mixed digesters have been referred to as "microbial torture chambers" based on research observations (Switzenbaum, 1991) that metabolism of certain compounds (e.g., benzoate) is inhibited by mixing and that efficient consortia function well in UASB digesters employing granules or attached biofilms (Switzenbaum, 1991). Chynoweth *et al.,* (1987) also demonstrated that a non-mixed solids-concentrating reactor design exhibited more rapid kinetics, lower nutrient requirements, and greater stability than a continuous stirred tank reactor (CSTR) design. This improved performance was attributed to a reduced washout of solids and critical organisms in an unmixed reactor. As excessive mixing can disrupt the microbes, slow mixing is preferred. The kind of mixing equipment and amount of mixing varies with the type of reactor and the solids content in the digester.

2.9. Loading rates and solid retention time

Anaerobic digestion systems that can operate with sufficient efficiency at high loading rates are known as high-rate systems or compact reactors. Loading rates can be expressed as follows:

Organic loading rate is a measure of biological conversion capacity of anaerobic digestion. A high organic loading will normally result in excessive volatile fatty acid production in the digester ('sour' condition) with the consequent decrease in pH, and will adversely affect the methanogens. On the other hand, an extremely low organic loading will not provide a sufficient quantity of biogas for energy uses, and will make the digester unnecessarily large. Because organic materials fed to anaerobic digesters are in semi-solid form, organic loading to a digester can be conveniently experimental in term of VS. Optimum organic loadings to dispersed-growth digesters have been reported to be 1 - 4 kg $VS.m^{-3}.d^{-1}$ and 1 - 6 kg $COD.\ m^{-3}.d^{-1}$ for anaerobic filters. For UASB digesters they are 1 - 15 kg $VS.m^{-3}.d^{-1}$ and 5 - 30 kg $COD.m^{-3}.d^{-1}$, respectively (Brown and Tata, 1985). The required retention time and thus reactor volume for anaerobic digesters is higher for slurry or feed having higher solids content. Low solids (LS) anaerobic digestion systems contain less than 10 % TS, medium solids (MS) about 15 - 20% and high solids (HS) processes range from 22% to 40% (Tchobanoglous, *et al.*, 1993). Digestion at higher TS concentration would require smaller reactor volume for the same amount of total solid content. Another index of the compactness of the system is a short solid retention time (SRT). For slurry systems, in which there is no separation of solids from the liquid phase (such as in a CSTR), the solid retention time equals the hydraulic retention time (HRT). For solid waste digesters, a shorter SRT means a smaller digester volume requirement

2.10.Bioreactor systems for OFMSW

A number of novel reactor designs have been adapted and developed allowing a significantly higher rate of reaction per unit volume of reactor (Weiland, 1993). Different anaerobic processes, such as batch reactor, continuous one-stage, and continuous two-stage systems, with a variety of methane-generating continuously stirred tank reactor (CSTR), tubular reactor, anaerobic sequencing batch reactor (ASBR), upflow anaerobic sludge blanket (UASB) and anaerobic filters have been applied lab-scale to the digestion of OFMSW. These processes differ especially in the way the microorganisms are retained in the bioreactor, and the separation of the acidogenic phase from the methanogenic phase. This separation reduces the limitations of anaerobic digestion. Methanogens may have long mass doubling times in anaerobic reactors and this makes it very difficult to obtain fast acting reactors without retaining most of the biomass normally washed out with the effluent (Verrier *et al.*, 1987).

2.11. Batch reactor

In a batch system, the waste is fed to the reactor with seeds or digested material from another reactor. The reactor is then sealed and left to digest naturally. When digestion is complete, the reactor is opened, unloaded and refilled to start the batch process again. In batch systems, digesters are filled once throughout the batch period with fresh OFMSW, with or without addition of seed materials, and the contents are allowed to go through all degradation steps sequentially. The hallmark of batch systems is the clear separation between a first phase, where acidification proceeds much faster than methanogenesis, and a second phase, where acids are transformed into biogas (De Baere, 2000). Converti *et al.*, (1999) tested the anaerobic batch digestion of OFMSW, under both mesophilic and thermophilic conditions. The results showed that, under mesophilic and thermophilic conditions, the mixture of vegetable wastes was quickly digestible, and the first-order kinetic constant was around 0.0041 h^{-1} for both mesophilic and thermophilic conditions. Anaerobic batch digestion of mixed OFMSW was also carried out successfully at 5% total solid concentration (Rajestwari *et al.*, 2001, Table 2). Digestion of the waste after 47 days resulted in 0.16m^3 biogas/kg TS added with a maximum gas production rate on day 26. Whereas, Bouallagui *et al.*, (2003) showed that the anaerobic treatment of OFMSW at 8% TS in a batch digester was inhibited by the VFA accumulation and irreversible decreasing pH problems. The specific features of batch processes, such as simple design and process control, robustness towards coarse and heavy contaminants, and lower investment costs make them particularly attractive for developing countries (De Baere, 2000).

Continuous one-stage systems

Among the continuous systems reported in literature are a continuously stirred tank reactor (CSTR) and a plug-flow reactor (PFR). The latter is applied for dry feedstock. Different experiments on fruit and vegetable wastes anaerobic digestion were carried out using different one-stage systems (Table 3). Mata-Alvarez *et al.*, (1992b) examined the performance of the mesophilic one-stage CSTR shown in Fig. 3 for the treatment of the OFMSW coming from a large food market. The maximum organic loading rate (OLR) tested was below 3 kg TVS.m^{-3}.d^{-1}. OLR of 6 kg VS.m^{-3}.d^{-1} was found to be a limiting condition for a similar waste digestion (Cecchi *et al.*, 1986). Moreover, as mentioned by Mata-Alvarez *et al.*, (1992b), this waste was presumably more biodegradable, which meant a larger and faster VFA production, which stressed the validity of this OLR limit (Mata-Alvarez *et al.*, 1990). Overloading of digesters with fresh vegetable waste above 4 TVS.m^{-3}.d^{-1} was also reported by Lane (1979) to result in a fall in pH and gas yield and an increase in the CO_2 content of gas produced using a CSTR (Lane, 1979). In one-step anaerobic digestion of OFMSW, problems may occur if the substrate is easily degradable because in solid waste digestion, there is no possibility for the accumulation or retention of biomass within the reactor. The slower growing methanogens are overfed at higher loading rates (Mata-Alvarez *et al.*, 1992a).

In a one-stage system, combining acidogens and methanogens in one vessel, any hydrogen formed by acidogenic metabolism is assimilated by the methanogens to reduce carbon dioxide to methane and water (Poggi-Varalgo *et al.*, 1997). When the the feeding rate of the substrate is increased, acidogenic activity, including mainly acetate, carbon dioxide, and hydrogen production, are all increased, whereas the methanogenic population cannot increase its activity to the same extent. At a loading rate, in which the hydrogen consuming reactions become saturated, accumulation of hydrogen partially inhibits its further formation and consequently more organic electron sink will be formed, causing imbalances and cessation of methane production (Cohen, 1983, Liu *et al.*, 2002).

Table 2. Performance of various anaerobic systems applied to the treatment of fruit and vegetable wastes

Process	Volume	Loading rates	SRT	VS	Mathane	References

	(l)	**(g VS.l^{-1}.d^{-1})**	**(day)**	**removed (%)**	**yield ($l.g^{-1}$ VS)**	
Batch system	10	1.06	47	65	0.16	Rajeshwari *et al.*, 2001
Continuously stirred tank reactor (CSTR)	3	1.6	20	88	0.37	Mata-Alvarez *et al.* 1992 a
Two- stage system: solid bed hydrolyser and UASB	100+25	6.8	2.5	94	0.35	Bouallagui *et al.*, 2003

Continuous two-stage systems

Both groups of acidogenic and methanogenic organisms are different with respect to their nutritional requirements, physiology, pH optima, growth, and nutrient uptake kinetics, and their ability to withstand environmental stress factors (Weiland, 1993). With conventional digestion processes, by combining acidogens and methanogens in one reactor, uniform conditions are imposed on both groups. However, two-phase anaerobic digestion implies a process configuration employing separate reactors for acidification and methanogenesis connected in series, allowing optimization of both processes (Llabrés-Luengo and Mata-Alvarez, 1990). The two-phase anaerobic digestion of a mixture of OFMSW was studied in different works (Table 2). The two-step technology applied by Rajeshwari *et al,* 2001, allowed the conversion of over 94% of vegetable market waste into biogas (Rajeshwari *et al.*, 2001). The raw waste was acidified in a solid bed reactor. The leachate obtained after completion of acidification phase was further treated in an UASB reactor for biogas production. In most cases, the second phase of a two-phase solid waste digester system treats the leachate coming from the first phase reactor where solid waste is hydrolyzed. In this case, the second phase reactor is similar to any anaerobic high-rate wastewater treatment system. SRT is an important factor to consider. Too short an HRT will not allow sufficient time for anaerobic microorganisms, especially the methane-forming microorganism, to metabolize the wastes.

Too long an HRT could result in an excessive accumulation of digested material in the digester, and construction of a digester that is too large. Similarly as in organic loading rates, an optimum HRT depends on the characteristics of influent feed materials and environmental conditions in the digesters. For dispersed-growth digesters the optimum HRT values are 1 - 10 for anaerobic filters and 0.5 - 6 days for UASB digesters (Brown and Tata, 1985). There are several types of two-phase systems. Most are without recycle of leachate. In some two-phase systems, the effluent from the second phase is recycled to the first phase. The first phase is in some cases a batch reactor, CSTR or tubular reactor. The second phase reactor can be UASB or upflow anaerobic filter (UAF). The system is shown in Fig.5. Tran *et al.*, 2005, 2008 the two-phase anaerobic digester system (Fig. 4) consists of a batch hydrolysis-acidogenesis reactor (phase I) and an upflow anaerobic sludge bed reactor (UASB) (phase II). The effluent from phase two (UASB) is sprinked to the first phase by pumping. In addition, the leachate from the hydrolysis reactor (first phase), which is expected to be of lower concentration, is fed to the second phase. This sprinkling with recycled effluent is expected to prevent the possible inhibition of acidogenesis by VFA at the first phase reactor (Borzacconi *et al.*, 1997). The rate of conversion of the organic solids to methane is much higher than that found in the two-phase system described in a previous study (Palenzuela-Rollon *et al.,* 2004). That system consisted of a slurry hydrolytic-acidogenic phase reactor followed by a UASB reactor. There was no recycling of effluent to the first phase reactor. Using the same simulated OFMSW as used in the present study, the methane recovery in that study was 5% and the extent of hydrolysis was 20-24%. The better performance of the present system was likely due to avoiding accumulation of volatile fatty acids (VFAs) that can inhibit methane generation in both reactors and hydrolysis in the phase I reactor. In the two phase system, the methane yield in the system used is expected to increase in time as the methanogenic capacity of the second phase reactor would increase as feeding continues. The performance of other systems used for OFMSW is presented in Table 3 (Tran *et al.,* (2008). The two-phase system in this study performed similarly to that of Sawayama *et al.* (1997). They subjected kitchen garbage to thermochemical treatment pretreatment (175 °C, 4 Mpa + acetic acid treatment for 1 h) and treated the liquid portion in a UASB reactor at 2.8 kg TOC m^{-3}.d^{-1}. The methane production of study was 0.311 m^3/kg VS. Various two-phase systems reviewed by Bouallagui *et al.,* (2004) obtained about 0.29 m^3/kg TCOD for OLR of 1 – 6.8 kg VS m^{-3}.d^{-1}. Several studies (Brummeeler *et al.*, 2003, Palenzuela Rollon *et al.*, 2004, Acosta *et al.*, 2007) have shown that two-phase systems have several advantages over the traditional single-phase systems. These are considerably longer solid retention time (SRT) higher conversion of solid organic matter to methane and higher methane concentration in the produced gas (Brummeler *et al.*, 2003).

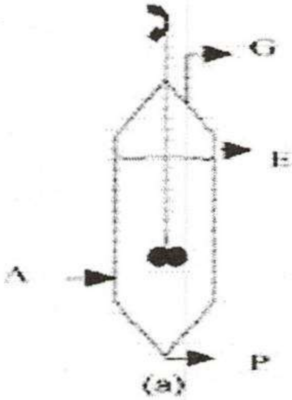

Figure. 3: Continuously stirred tank reactor (CSTR) of anaerobic OFMSW (A = feed, P = Solid reside, G = Biogas, E = Effluent).

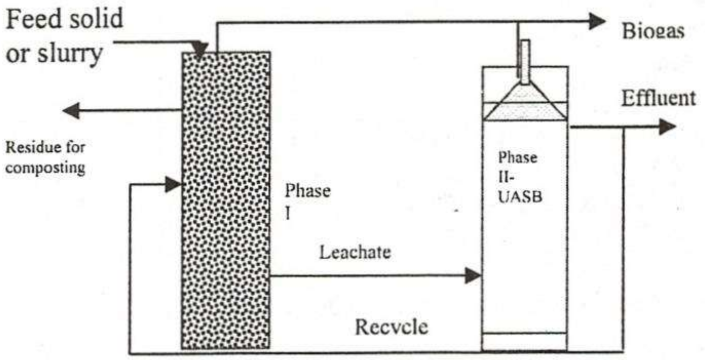

Figure 4: Two- phase system of anaerobic OFMSW, Tran et al, 2005.

Table 3. Performance of two-phase anaerobic digestion systems for OFMSW

System	Type of waste & Conditions	OLR, kg VS/m^3/d	Specific Gas Production, m^3/kg VS	Gas Production Rate, m^3/m^3/d	Digestion	Reference
Modified Indian Gobar System, 18 m^3	OFMSW and animal carcass 30 °C	0.63-0.71	0.10-0.15	0.063-0.107		Silverio et al. 2001
Semi-continuous Mesophilic, pilot	OFMSW + fats, 37° C	0.97	0.5	0.485		Fernandez et al 2005
Hybrid (HASL) semi-continuous 5.4 L	OFMSW, 35°C	1.9	0.397	0.71		Wang et al. 2005
Treatment at 170 C, 4 Mpa, 1 h acetic acid treatment + UASB	35°C	2.8	0.311	--	67%	Sawayama *et al.* 1997
Various two-phase systems (average)	Various	1-6.8	0.29	-	87%	Bouallagui *et al.* 2004 (review)
Hydrolytic 4 L + UASB 3.6 L	OFMSW 32° C	3.45	0.29	$0.34^{\#}$	$50\%^{@}$	Tran *et al.* 2005
Hydrolytic 6 L + UASB 3.6 L	OFMSW 32°C	4.59	0.18	$0.38^{\#}$	$60^{@}$	Tran *et al.* 2008

@ - Percent hydrolyzed fraction, # - volume of methane

Pre-treatment and post-treatment for anaerobic digestion of OFMSW

Municipal solid waste is composed of biodegradable and non-biodegradable materials. For the treatment of biodegradable components via anaerobic digestion, the biodegradable fraction must firstly be separated from other non-biodegradable components. Most digestion systems require pre-treatment of waste to obtain homogeneous feedstock to the digester. The preprocessing involves separation of non-digestible materials and shredding. The waste received by anaerobic digestion digester is usually source separated or mechanically sorted. The separation ensures removal of undesirable or recyclable materials such as glass, metals, stones etc. In source separation, recyclables are removed from the organic wastes at the source. Mechanical separation can be employed if source separation is not available. However, in mechanical separation, the resultant fraction is then more contaminated leading to lower compost quality (Williams, 1998; and RISE-AT, 1998). The waste is shredded before it is fed into the digester. Inside the digester, the feed is diluted to achieve desired solids content and remains in the digester for a designated retention time. For dilution, a varying range of water sources can be used such as clean water, sewage sludge, or re-circulated liquid from the digester effluent. In addition, (Forster *et al.,* 2008 a, Nakasaki *et al.,* 2009) found that anaerobic digestion of source-sorted organic fraction of municipal solid waste, which are designed to enhance the waste decomposition process. The best performance for food waste biodegradation and methane generation was the reactor with 20% of total solid and 30% of inoculum: give rise to an acclimation stage with acidogenic/acetogenic activity between 20 and 60 days and methane yield of 0.49 L CH_4/g VS. Finally, a protocol was proposed to enhance the start-up phase for dry thermophilic anaerobic digestion of food waste. Moreover, (Forster *et al.*, 2008 b) the FW reactor also showed the smallest waste biodegradation (32.4% VS removal) with high methane production (0.18 LCH4/gVS); in contrast the OFMSW showed higher waste biodegradation (73.7% VS removal) with small methane production (0.05 L CH_4/g VS). In case of post-treatment, the effluent from the digester is dewatered, and the liquid recycled for use in the dilution of incoming feed. The residual biosolids are aerobically cured to obtain a compost product. Moreover, after anaerobic digestion is completed, the remaining biodegradable solid waste residues are commonly subjected to post treatment. Such treatment includes dewatering, aeration, and leachate treatment. The objective of aeration as post treatment is to remove lingering organics, to aerobically reduce the compounds and to produce valuable products such as fertilizer and soil conditioner. Also, the possibility of terminating and optimizing the anaerobic fermentation at the organic-acid stage as part of the pre-stage of anaerobic digestion has been significantly considered.

3. CONCLUSIONS

In summary, anaerobic digestion is affected by changes in external factors and the treatment of anaerobic digestion of OFMSW is, in many aspects of environmental variations mature. This study review has also shown an opportunity to partly solve some environmental problems such as contamination of land, water and air by using a compact system in which methane is collected. It also partly addresses global energy shortage by producing energy from solid wastes by using anaerobic digestion treatment. The growth potential for this technology is very important, especially because of the important factor of the greenhouse gases emission reduction agreed at the Kyoto Summit.

CÁC YẾU TỐ ẢNH HƯỞNG ĐẾN CÁC GIÁ TRỊ THÔNG SỐ MÔI TRƯỜNG KHÁC NHAU TRONG QUÁ TRÌNH PHÂN HỦY KỴ KHÍ TRONG XỬ LÝ CÁC CHẤT HỮU CƠ CỦA CHẤT THẢI RẮN ĐÔ THỊ

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TÓM TẮT: *Mục tiêu của bài báo là tổng kết nâng cao kiến thức về việc ổn định và xử lý hiệu quả các chất hữu cơ trong chất thải rắn đô thị, các nhà nghiên cứu đã nghiên cứu các yếu tố ảnh hưởng đến quá trình vận hành hay các giá trị thông số môi trường khác nhau trên hiệu quả của nhiều loại mô hình phản ứng. Nhìn chung, phân hủy kỵ khí sẽ ảnh hưởng rất nhiều bởi sự thay đổi của các yếu tố bên ngòai và các phương pháp xử lý phân hủy kỵ khí chất hữu cơ trong chất thải rắn đô thị, trong nhiều khía cạnh thông số môi trường khác nhau. Các chủ đề điển hình như các khía cạnh về quá trình (hiệu quả, các hệ thống xử lý một giai đọan hay hai giai đọan), các yếu tố tăng cường phân hủy nhanh (pH, độ ẩm, nhiệt độ, màng, nhiên liệu sinh học, các tỷ lệ tải lượng nạp, thời gian lưu chất thải, các hệ thống bể sinh học hay các phương pháp xử lý sơ bộ hay sau xử lý)*

Từ khóa: *phân kỵ khí, OFMSW, VFA, pH, nhiệt độ, xử lý sơ bộ và sau xử lý.*

REFERENCES

[1]. Acosta, V., Rollon., Le Thi Hong Tran., Nakasaki. *Treatment of Alkali-Pretreated Slurry of Organic Fractions of Municipal Solid Waste using UASB Reactor.* Originally Article published June, Environmental exper.com, (2007).

[2]. Acosta. V. *Anaerobic digestion of alkali-pretreated kitchen waste extract. Master's Thesis, Department of Chemical and Environmental Engineering*, University of the Philippines at Diliman.

[3]. Angelidaki, I., Ahring, B. K., 1990. *Effect of lipid on thermophilic anaerobic digestion and reduction of lipid inhibition upon addition of bentonite*. Appl. Microbial. 33, 469-472, (2006).

[4]. Borzacconi, L. Lopez, I. and Anido, C. *Hydrolysis constant and VFA inhibition in acidogenic phase of MSW anaerobic degradation.* Water Science & Technology, 36(6-7), pp. 479-484 (1997).

[5]. Borzacconi, L., Lopez, I., Anido, C. *Hydrolysis constant and VFA inhibition in acidogenic phase of MSW anaerobic degradation.* Water Sci. Tech. 36, 6-7,(1997).

[6]. Bouallagui, H., Touhami, Y., Ben Cheikh, R. *Bioreactor performance in anaerobic digestion of fruit and vegetable wastes: Bioreactors performance*. Process Biochemistry, 40, 989-995(2004).

[7]. Brown, N.L., Tata, P.B.S. *Biomethanation*. ENSIC Review no. 17/18. AIT, Bangkok, Thailand (1985).

[8]. Brummeler, E. T., Aarnink, M. M. J., Koster, I. W. *Dry anaerobic digestion of solid organic waste in a biocel reactor at pilot-plant scale.* Water Sci. Tech. 25 (7), 301-310 (2003).

[9]. Chynoweth, D.P., Fannin, K.F., Srivastava, V. J. *Biological gasification of marine algae. In: K. Bird and P. Benson (ed.),* Seaweed Cultivation for Renewable Resources. Applied Sciences Ltd., New York, 285-303(1987).

[10]. De Baere, L. *Anaerobic digestion of solid waste: state-of-the-art.* Water Sci. Tech. 41, 283–90 (2000).

[11]. De Baere, L.A., Devocht, M., Van Assche, P., Verstraele, W. *Influence of high NaCl and NH4Cl salt levels on methanogenic associations.* Water Sci. Tech. 18, 543-548(1984).

[12]. Fernandez, A., Sanchez, A., and X. Font. *Anaerobic co-digestion of a simulated organic fraction of municipal solid wastes and fats of animal and vegetable origin.* Biomchemical Engineering Journal, 26, 22-28 (2005).

[13]. Ferreiro, N. and Soto, M. *Anaerobic hydrolysis of primary sludge*, (2003).

[14]. Forster-carneiro, T., Pérez, M., Romero, L.i. *Influence of total solid and inoculum contents on performance of anaerobic reactors treating food waste*. Bioresource Technology, 99: 6994–7002. (2008 a).

[15]. Forster-carneiro, T., Pérez, M., Romero, L.i. *Thermophilic anaerobic digestion of source sorted organic fraction of municipal solid waste.* Bioresource Technology, 99: 6763–6770, (2008 b).

[16]. Grasmug, W., Branun. *Anaerobic digestion of preselected biowaste municipal sewage sludge under mesophilic and thermophilic conditions*. In: Proceedings of the 9th World Congress Anaerobic Digestion. Belgium: IWA Antwerpen; 2–6 September, (2001).

[17]. Gujer, W., Zehnder, A.J.B., *Conversion process in anaerobic*. Water Sci. & Technol. 15, 127-167, (1983).

[18]. Hanaki, K., Hirunmasuwan, S., Matsuo, T. *Protection of methanogenic bacteria from low pH and toxic materials by immobilization using polyvinyl alcohol*. Water research. 28, 877-885, (1994).

[19]. Hanaki, K., Matsuo, T., Nagase, M. *Mechanism of inhibition caused by long-chain fatty acids in anaerobic digestion process.* Biotechnol.and Bioengg. 23, 1591-1610, (1981).

[20]. Kayhanian, M.. *Biodegradability of the organic fraction of municipal solid waste in a high solids anaerobic digester*, Waste Manage. Res. 13, 123-136, (1995).

[21]. Kim, M., Speece, R.E. *Reactor configuration. Environmental technology*. 23, 643-654, (2002).

[22]. Lane, A.G. *Methane from anaerobic digestion of fruit and vegetable processing waste*. Food Technol. 31, p. 201–7, (1979).

[23]. Le Thi Hong Tran , Analiza R. , Nakasaki, *Anaerobic digestion of organic fraction of municipal solid waste (OFMSW) in two-phase system,* (IJEWM), Accepted, 2008.

[24]. Le Thi Hong Tran, Rollon, Nakasaki. *Anaerobic Digestion of Organic Fraction of Municipal Solid Waste (OFMSW) In Two Phase System: Fed- Batch Hydrolysis and UASB Reactors.* Proceeding of International Conference of 12th Regional Symposium Chemical Engineering, Hanoi, Vietnam, Vol 3, pp:302-310, (2005).

[25]. Lettinga, G., Hulshoff Pol, L. *UASB process design for various types of waste water*. Water Sci Tech. 24, 87-107, (1994).

[26]. Llabrés-Luengo, P., Mata, J. *The hydrolytic step in a dry digestion system*. Biol. Wastes. 23, 25–37, (1988).

[27]. Mata-Alvarez J., Cecchi, F., Llabrés, P., Pavan, P. *Anaerobic digestion of the Barcelona central food market organic wastes: experimental study*. Bioresour. Technol. 39, 39–4, (1992 a).

[28]. Mata-Alvarez, J., Cecchi, F., Llabrés, P., Pavan, P. *Anaerobic digestion of the Barcelona central food market organic wastes: plant design and feasibility study.* Bioresour Technol. 42, 33–42. (1992b).

[29]. Mata-Alvarez, J. *Biomethanization of the OFMSW*. IWA publishing. ISBN: 1 900222 14 0, (2003).

[30]. Mata-Alvarez, J., Cecchi F., Llabrés P., Pavan P. *Performance of digesters treating the organic fraction of municipal solid waste differently sorted. Biol*. Wastes. 33, 181–99, (1990).

[31]. Nakasaki. K , Le Thi Hong Tran , Yoshito Idemoto a, Michiharu Abe , Analiza Rollon, 2009, *Comparison of organic matter degradation and microbial community during thermophilic composting of two different types of anaerobic sludge*, Bioresource Technology 100 (2009) 676–682

[32]. Palenzuela Rollon, A., Nakasaki, K., Pajarito, M. E. P., Olairez, C. D. *Effect of particle size and moisture content on the hydrolysis of kitchen solid waste in one- and two-phase digester systems.* In: Proceedings of the Regional Symposium in Chemical Engineering, Bangkok, Thailand, (2004).

[33]. Palenzuela-Rollon, A. *Anaerobic Digestion of Fish Processing Wastewater with Special Emphasis on Hydrolysis of Suspended Solids*. PhD Dissertation. Wageningen University, Balkema Publishers (1999).

[34]. Palenzuela, A., Zeeman, G. Lubberding, H. J., Lettinga, G. and Alaerts, G. J. *Effects of NaCl and NH4+ on the degradation of proteins in fish processing wastewater.* In: Proc. of the Regional Symposium in Chemical, (1999).

[35]. Pavlosthathis, S. G., Giraldo-Gomez, E. *Kinetics of anaerobic treatment.* Water Sci. Tech. 24, 35-59, (1991).

[36]. Poggi-Varalgo, H. M.; Rodriguez-Vazquez, R., Fernandez-Villagomez, G., Esparza-Garcia, F. *Inhibition of mesophilic solid-substrate anaerobic digestion by ammonia nitrogen.* Appl. Microbiol. Biotechnol. 47, 284–91(1997).

[37]. Rajeshwari, K.V., Panth, D.C., Lata K., Kishore, V.V.N. *Novel process using enhanced acidification and a UASB reactor for biomethanation of vegetable market waste.* Waste Manage. Res. 1, 292–300, (2001).

[38]. RISE-AT. *Review of current status of Anaerobic Digestion Technology for treatment of MSW,* (1998)

[39]. Sanders, W.T.M., Geerink, M., Zeeman, G., Lettinga, G. Anaerobic *hydrolysis kinetics of particulate substrates.* Water Sci. Tech. (14) 3: 17-24, (2000).

[40]. Sawayama, S., Inque., Seiichi, Minowa, T., Tsukahara, K., Ogi, T. *Thermochemical liquidization and anaerobic treatment of kitchen garbage.* Fermentation and Bioengineering. 83, 451-455, (1997).

[41]. Tchobanoglous, G., Theisen, H., Vigil, S. *Integrated Solid Waste Management,* McGraw-Hill, (1993).

[42]. Tilche, A., Malaspina, F. *Biogas production in Europe.* Paper presented at the 10th European Conference Biomass for Energy and Industry, Wurzburg, Germany, 8 ±11 June, (1998).

[43]. Veeken, A.H.M., Hamelers, B.V.M. *Effect of temperature on hydrolysis rates of selected biowaste components.* Bioresour. Technology. 69 (3): 249-254, (1999a)

[44]. Veeken, A.H.M., Hamelers, B.V.M. *Effect of substrate-seed mixing and leachate recirculation on solid state digestion of biowaste.* Proceedings of the second international symposium on anaerobic digestion of solid wastes, Barcelona, 1, 15-18. (1999b).

[45]. Verrier, D., Ray F., Albagnac, G. *Two-phase methanization of solid vegetable wastes.* Biol. Wastes. 22, 163–77(1987).

[46]. Wang, Z.J. and C.J. Banks. *Evaluation of a two stage anaerobic digester for the treatment of mixed abattoir wastes.* Process Biochemistry, 38, 1267-1273, (2003).

[47]. Weiland, P. *One and two-step anaerobic digestion from the OFMSW.* Water Sci. Tech. 27, 145-150,(1993).

[48]. Weiland, P., Rozzi A. *The start up, operation and monitoring of high rate anaerobic treatment systems: Discussers report.* Water Sci.Tech. 24, 257–277, (1991).

[49]. Williams, Paul T. *Waste Treatment and Disposal.* John Wiley & Sons Ltd., U.K, (1998).

[50]. WPCF. *Anaerobic Sludge Digestion.* Manual of Practice No. 19. Second Ed. Water Pollution Control Federation. Alexandria, VA, (1987).

[51]. Zabranska, J., Dohanyos, M., Jenicek P., Zaplatilkova, P., Kutil, J. *The contribution of thermophilic anaerobic digestion to the stable operation of wastewater sludge treatment.* Water Sci. Tech. 46, 447–452, (2002).