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ORIGINAL RESEARCH PAPER

Application of anaerobic digestion of municipal solid food wastes in treating wastewaters

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ABSTRACT: Anaerobic digestion is the breakdown of biodegradable organic material by microorganisms in the absence of oxygen or in an oxygen-starved environment. This technology is superior to the landfilling and also the aerobic composting. The aim of the present study was to examine whether the effluent Volatile Fatty Acids from the anaerobic acidogenesis of the urban food waste can be used, due to its high value in organic elements, as an external carbon source for the denitrificationin waste water treatment plants. The results showed that Volatile Fatty Acids concentration in mgCOD/L in the fermentation was in the range between 3,300 mg COD/L and 6,560 mg COD/L. The n-butiric acids had the highest concentration in mg COD/L followed by the propionic and acetic acid, while the valeric acid had the lowest concentration,also the concentration of the acetic and valeric acid were stable over the time. Opposite to these, the propionic and n-butyric acid showed high variability in the concentration, especially the n-butyric acid. The specific denitrification rate tests showed that the ethanol cultivated biomass was more successful in using the effluent of the urban food waste digestion as carbon source than methanol cultivated biomass. The specific denitrification rate tests results of the experiment showed that the average of 0.15 an 0.51 mg N/mg for methanol and ethanol cultivated biomass respectively.

KEYWORDS: *Acidogenesis; Anaerobic digestion (AD); Chemical oxygen demand (COD); Denitrification; Food waste*

INTRODUCTION

Organic materials are currently landfilled and putting this material to a more beneficial use as feedstock for composting and anaerobic digestion (AD) (Fleming *et al.*, 2006; Smidt *et al.*, 2011; ISWM-Tinos Life, 2011) solid. Composting is the biological decomposition of biodegradable municipal solid waste under controlled, predominantly aerobic conditions (Atiyeh *et al.*, 2000). Compost facilities have traditionally utilized open windrows to process compostable organics (mostly agricultural and green material) into finished compost (EA, 2011). End products of the compost products include: soil amendment, fertilizer, mulch, boiler fuel, and a small amount used as alternative daily cover at landfills (Atiyeh *et al.*, 2000; Karki, 2006). More recently, there has been considerable world-wide interest and significant technological progress, such as in Iran, on the production and optimal uses of vermicomposts (Mainoo *et al.*, 2009; Kiefer, 2012; Yadav, 2013). Vermicomposts can be processed from most organic wastes such as animal manures, and particularly, paper and food wastes (Singh *et al.*, 2013). Composting and vermicomposting are two of the best-known processes for the biological stabilization of solid organic wastes. The combination of composting and vermicomposting has recently been considered as a way of achieving stabilized substrates (Lazcano *et al.*, 2008; Yadav, 2013).

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AD is an alternative method of organic matter decomposition to aerobic composting (Torbert *et al.*, 2010; Smidt *et al.*, 2011; ISWM-Tinos Life, 2011). Indeed AD is the breakdown of biodegradable organic material by microorganisms in the absence of oxygen or in an oxygen-starved environment. It occurs extensively or at instance in landfills and the stomachs of cows (Chynoweth *et al.*, 2002). This process as the biological decomposition is historically one of the oldest processing technologies used by mankind. AD is a technology of choice converting food waste to bioenergy and other co-products (Dennis and Burke, 2001). By controlling the process, two useful products are obtained: biogas and the remaining material from the digestion (a nutrient-rich fertilizer). It produces mainly 55 % methane and 45 % carbon dioxide gas and a compost product suitable as a soil conditioner (Chen *et al.*, 2014). The biogas produced by AD can be combusted directly to produce electricity and heat, or purified for injection into the gas network or for use as a transport fuel (Arsova, 2010). Biogas is a mixture of methane (50-70%), carbon dioxide (25-45%) and minor impurities. The aims for energy production are maximize the amount of methane produced, which partly depends on the raw material used, also it can be efficiently convert this methane into electricity, heat or transport fuels (Gray *et al.*, 2008). One of the efficient suggested methods in this field is High solid anaerobic digestion (HSAD) that is a proper technology for organic waste treatment as allows for harvesting energy and nutrients while stabilizing the organic materials (Chen *et al.*, 2014). Digestion of wastes is regulated by the Environment Agency. Permits are required for the digester, biogas combustion and the remaining digestion material storage, transport and use. Although the regulations can be complex and are developing, the industry has praised the Environment Agency for responding to its needs (EA, 2011). The main sources of waste feedstocks for AD are food and drink waste (municipal waste), sewage sludge, animal slurries and solid manures. Municipal solid waste (MSW) is the waste generated in a community with the exception of industrial and agricultural wastes (Verma, 2002). Hence MSW includes residential waste (e.g., households), commercial (e.g., from stores, markets, shops, hotels etc.), and institutional waste (e.g., schools, hospitals etc.). Paper, paperboard, garden and food waste can be classified in a broad category known as organic or biodegradable waste (Rapport *et al.*, 2008). AD has been recognized as the best option for the treatment of the organic fraction of the MSW and superior to the landfilling and aerobic composting (Kelleher, 2007; Hogg *et al.*, 2010). However despite the success of many AD plants and the production of green energy and compost, this technology has also some problems (Monnet, 2003; Rapport *et al.*, 2008; Arsova, 2010). As an alternative to methane generation, food waste can be bio reacted to yield Volatile Fatty Acids (VFA); these acids may be used to promote denitrification in carbon limited wastewater streams, in place of using supplemental carbon sources such as methanol. Typically, the wastewater treatment utilities add external organic electron donors to enhance the denitrification rates (Grady *et al.*, 1999). Most commonly used among the external electron donors is methanol, mainly due to its lower cost as compared to ethanol and acetate (Louzeiro *et al.*, 2003). The anaerobic acidogenesis process comprises the reactions of hydrolysis, fermentation and acetogenesis. These reactions precede the methanogenesis step in the AD process (Arsova, 2010).

The present study designed to examine whether the effluent VFA from the anaerobic acidogenesis of the food waste can be used as an external carbon source for the denitrification Waste Water Treatment Plants (WWTP). The specific objectives of this experimental study were to demonstrate the potential of recovering VFA by means of acidogenesis of municipal food waste in bench-scale experiments. Moreover quantify the bio kinetics of denitrification by means of VFA contained in the effluent of acidogenesis, under laboratory conditions.

This study has been performed in Tehran-Iran in 2015.

MATERIALS AND METHODS

Anaerobic acidogenesis of the municipal food waste

A bench scale experimental study was conducted in a 6-liters glass reactor equipped with a water jacket for maintaining a constant temperature of 37°C (mesophilic bacteria reaction). The pH was continuously controlled and maintained at pH=6.5, by injection of a buffer solution of 1 Mg sodium bicarbonate and 1 Mg sodium hydroxide. A Teflon stirrer blade provided continuous mixing of the material in the reactor. The reactor was

operated in -batch mode for four weeks (results are not shown here) and in chemostat mode for three months (November 2013- January 2014). Retention Time (RT) during the chemostat mode was 4 days. The seed biomass was provided by Recycling organization of Tehran municipality (Region 11, Tehran, Iran) and originated from their AD plant treating organic waste.

The feedstock to the reactor was municipal food waste from the campus restaurant, consisting of mixed cooked and fresh food leftovers. Fresh feed material was prepared once a week and was stored at 4°C. The preparation included homogenization in a kitchen blender, diluting with water and sampling for further analyses. The average organic loading rate was 13000 mg total COD/L/day and 3200 mg soluble COD/L/day of food waste. Both, the feed material and the digests from the reactor, were sampled three times per week for measuring the parameters shown in Table 1.

All laboratory analyses were conducted according to the Standard Methods for Examination of water and waste water (Eaton *et al.*, 2005). VFA speciation and the concentration were analyzed in a Metrohm 861 Advanced Compact Ion Chromatographer. Samples for testing, the soluble COD were filtered through0.45 µm filter paper.

Biokinetics of the denitrification

Denitrification biokinetics were determined via extant batch assays (Chandran and Smets, 2001) using nitrate as electron acceptor. Denitrification rates were determined via influent and effluent nitrate (ion-selective electrode) and influent total COD measurements. Also, the pH and ORP values were measured.

The methanol and ethanol microbial consortia were cultivated in Sequenced Batch Reactor (SBR) as reported by Bayshtok *et al.* (2009). These denitrification consortia were tested for their affinity to use VFA from the food waste digester as supplemental carbon source instead of methanol/ethanol. For these denitrification rate assays the biomass was withdrawn from the SBR just prior to the start of the "settle" phase and washed by centrifugation at 10,000 rpm for 5 min at room temperature and resuspended in COD and nitrate free feed medium bubbled with N2 gas. The digested material from the food waste reactor was centrifuged at 10,000 rpm for 10 min at room temperature and filtered through 0.45 µm filter paper, in order to remove any biomass, prior to being used as carbon source for specific denitrification rate test (sDNR). Initial carbon source and nitrate concentrations in the batch biokinetics assays were 250 mg COD/L and 100 mg NO3- -N/L respectively. This initial COD: N ratio of 2.5:1, lower than based on stoichiometric COD: N requirements of 5:1 for nitrate rendered the organic carbon as limiting nutrient (Grady *et al.*, 1999). The sDNR was computed by linear regression of the nitrate depletion profiles normalized to the tCOD of the batch test beaker (Bayshtok *et al.*, 2009).

RESULTS AND DISCUSSION

Anaerobic acidogenesis of food waste

The concentration of the fermentation was between 43,000 mg COD/L and 111,000 mg COD/L consisted on average of 50% of sCOD. The average concentration of the volatile fatty acids (VFAs) in the sCOD was 17.5 %. Results of the measurements performed on the key parameters are given in Table 2.

Measured parameters were used to calculate the performance ratios of the anaerobic acidogenesis. Following ratios were monitored: sCOD/ NH4+, sCOD sKN and sKN/ NH4+. The results are shown in Table 3.

Table 1: The studied monitored parameters

Parameters
Total Chemical Oxygen Demand- tCOD (mg COD/L)
Soluble Chemical Oxygen Demand- sCOD (mg COD/L)
Total Kjeldahl Nitrogen- TKN (mg/L)
Soluble Kjeldahl Nitrogen- sKN (mg/L)
Ammonia (mg/L)
Total Volatile Fatty Acids COD- VFA COD (mgCOD/L)
Volatile Fatty Acids speciation

The conversion rates were calculated based on the direct measurement of the total feed COD (tCODf), the soluble and VFA COD in the feed material (sCODf, VFA CODf) and the digested material (sCODd, VFA CODd). The conversion rates were calculated using the following equations:

Feed tCOD-to-digestate sCOD conversion rate =
(sCODd- sCODf) /tCODf

Feed tCOD-to-digestate VFA COD conversion rate =
VFA CODd - VFA CODf / VFA CODf

The minimum, maximum as well as the average and the standard deviation of the results for these conversion rates are provided in Table 4.

The VFA concentration in mg COD/L in the fermentation was in the range between 3,300 mg COD/ L and 6,560 mgCOD/L. The most common VFA in the sCOD were acetic, propionic, n-butiric and valeric acid. The n-butiric acid had the highest concentration in mgCOD/L followed by the propionic and acetic acid, while the valeric acid had the lowest concentration. The concentration of different species of the VFAs changed with time and the evolution of each of them is illustrated in Fig. 1. From the Fig. 1 it can be noticed that the concentration of the acetic and valeric acid were stable over the time. Opposite to these, the propionic and n-butyric acid showed high variability in the concentration, especially the n-butyric acid.

During the operating time of the reactor there was production of small amounts of gas. This happened occasionally and there was no continuous production. In total, during the operation of the reactor there were ten samples of gas. In eight samples methane was found in average concentration of 0.6%, seven of the samples contained nitrogen in concentration of 2.2% on average, and in all ten samples the concentration of the CO2 was on average 26.5%. Therefore, selective acidogenesis with almost complete elimination of methanogenesis of food waste was successfully demonstrated Specific denitrification rate tests (SDNR).Many researchers have studied the suitability of the VFAs for denitrification. Among the others, Arsova (2010) has reported that the denitrification rates for acetate, propionate and butyrate were as much as four times higher than for methanol and ethanol. Achieved conversion rate of the feed tCOD to digestated COD in our reactor was higher than reported for biomass destruction, 22% on average (Ezenekwe *et al.*, 2002). Also the concentration of the sCOD in the tCOD of the digested material was higher than reported 17% for mesospheric plug-flow anaerobic fermenter using mechanically-sorted organic waste (Sans *et al.*, 1995). However the acetogenesis rate was not that

Table 2: Values of the monitored parameters in the fermentation (mg/L)

	Parameter	Min.	Max.	Average	SD*
1	tCOD	42,872.92	111,182.50	61,610.43	14,491.76
2	sCOD	20,981.46	46,116.88	30,389.81	7,030.42
3	TKN	563.08	2,775.93	1,410.77	516.22
4	Skn	0.56	1,388.24	548.26	375.28
5	NH4	9.69	523.08	179.31	160.7

*Standard Deviation

Table 3: Performance ratios

	Ratio	Min.	Max.	Average	SD*
1	$sCOD/NH_4^+$	65.14	2,733.24	567.84	656.73
2	sCOD/sKN	27.29	1,224.49	157.39	279.09
3	sKN/ NH_4^+	0.03	1.14	0.33	0.22

*Standard Deviation

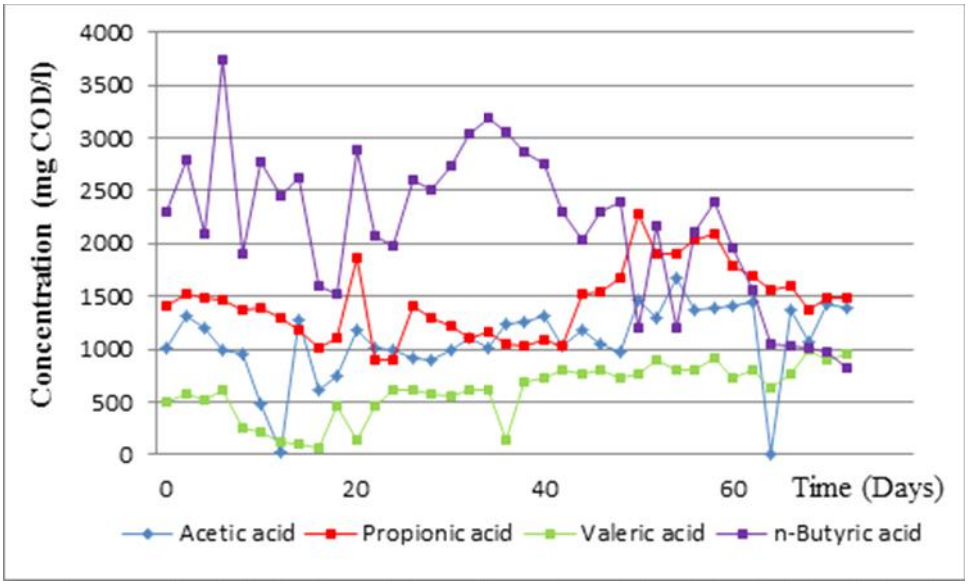

Fig. 1: Evolution of the concentrations of the VFAs in the fermented material

successful and the concentration of VFA in the sCOD was lower than previously reported (85-90%) for primary sludge fermentation (Elefsiniotis& Wareham, 2006), around 50% for effluent from anaerobically treated 1:1 mixture of starch- rich industrial and municipal wastewater (Katehis *et al.*, 2003), and 80% reported for anaerobic acidogenesis of food waste (Llabres *et al.*, 1999; Lim *et al.*, 2008). These numbers are not directly comparable because the experimental conditions differ but can give an overall idea of range of the results that have been reported. Main reasons for the big difference between previously reported and the results from this experiment may be due to the different retention time or the composition of the feed material. The performance ratios sCOD/NH3, sCOD/sKN, sKN/NH3 obtained in the reactor were much better than average reported values of 65, 9 and 0.7 respectively (Ezenekwe *et al.*, 2002).

Among the analysis VFA, the acetic had the most constant concentration while the biggest fluctuations were noticed in the concentration of the n-butyric acid. It can also be noticed that after the 50th day of operation the trends of the concentration of the VFA were constant, except for the n-butyric acid, and very similar values at the very end of the concentrations. Unfortunately, it was not possible to determine any relation between the concentration of the different VFA in the carbon source and the SDNR results.

Specific denitrification rate tests (SDNR)

The SDNR tests showed that the ethanol cultivated biomass was more successful in using the effluent of the food waste digestion as carbon source than methanol cultivated biomass. The results of these tests are shown in Table 5.

There was a slight difference in the concentration of different VFAs in the carbon source illustrated in the Fig. 2.

The results of the SDNR tests performed with the fermentation from the reactor were showed that the VFA naturally produced in the anaerobic acidogenesis

Table 4: Conversion rates

	Conversion rates (%)	Min.	Max.	Average	SD*
1	Feed tCOD to fementates COD	7.22	65.10	34.75	17.70
2	Feed tCOD to fermentation VFA COD	2.25	13.05	8.93	2.92

*Standard Deviation

of municipal food waste are suitable supplemental carbon source for denitrification. The biomass cultivated on ethanol showed higher SDNR that the biomass cultivated on methanol.However the SDNR results for both, ethanol and methanol cultivated biomass, were comparable to the previously reported denitrification rates achieved using VFA produced from different organic materials. Reported SDNR values are shown in Table 6. The SDNR results of the experiment, showed that the average of 0.15 an 0.51 mg N/mg VSS-d for methanol and ethanol cultivated biomass respectively, are better than previously reported values. Compared to the results of the same sDNR tests conducted with methanol as carbon source and methanol cultivated biomass the results with our carbon source were lower (Bayshtok *et al.*, 2009). The reason for this might be the acclimatization period that bacteria used for conducting the sDNR tests need to get used to new carbon source (Elefsiniotis *et al.*, 2004). In this case the methyl trophic bacteria showed lower affinity to the new carbon source then the ethanol degrading bacteria.

CONCLUSION

Anaerobic digestion (AD) is a proven technology for processing source-separated organic wastes and has experienced significant growth during the last 15 years. This technology is superior to the landfilling and also the aerobic composting. In fact, the AD technology has been widely applied in the world.
This study has elaborated the AD technology, its application in the treatment of the organic fraction of the MSW as well as the difficulties and the challenges that the AD plants management and the technology

Table 5: Results of the specific denitrification rate tests

	Specific Denitrification Rate tests (mg NO3-N/ mg VSS-d)	
	Methanol biomass	Ethanol biomass
1	0.13	0.44
2	0.07	0.56
3	0.23	0.66
4	0.19	0.37
Average	0.15	0.51
SD*	0.07	0.13

*Standard Deviation

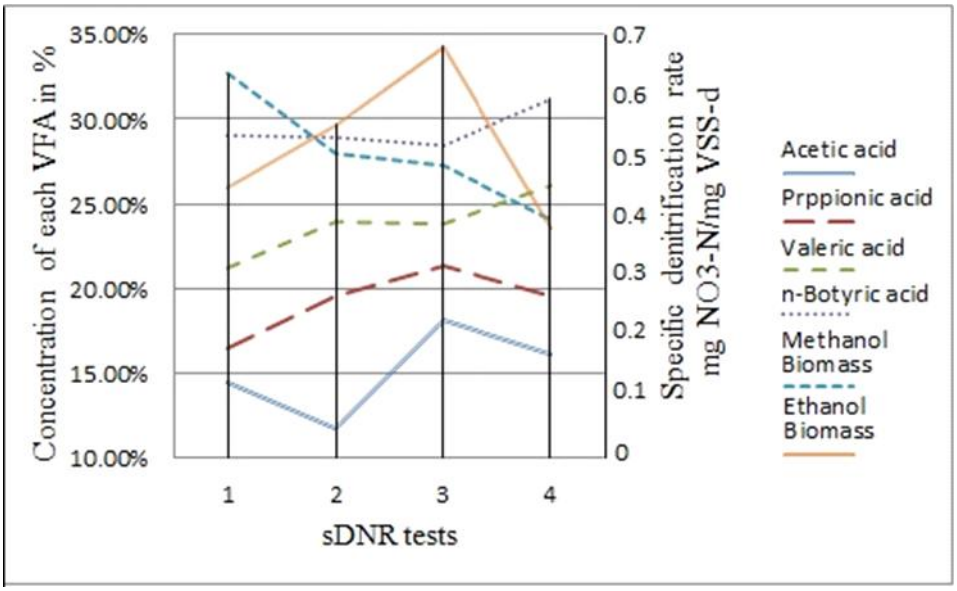

Fig. 2: sDNR results and VFA speciation in the supplemental carbon source

Table 6: SDNR results reported in previous studies

Carbon source	Specific denitrification rate (mg N/mg VSS-d)	Reference
Effluent VFA	0.12-0.28	(Katehis *et al.*, 2003)
	0.0111	(P Elefsiniotis *et al.*, 2004)
	0.28	(Pavan *et al.*, 1998)
	0.054	(Llabres *et al.*, 1999)
	0.048	(Min *et al.*, 2002)
	0.08	(Ezenekwe *et al.*, 2002)

Table 7: Comparison of the methanol and VFA mixture based on stoichiometry

	g SCS*	g biomass produced
Methanol	2.44	0.49
Acetic acid	3.73	0.68
Propionic acid	2.62	0.68
n-Butyric acid	2.08	0.68
Valeric acid	2.11	0.68
Experimental Mixture	2.55	0.69

*supplemental carbon source, values are given per grN-NO3 removed.

developers are facing. AD has technically been proven to be successful in treating the organic wastes and resulting in biogas and compost as final products, both marketable and produced this way are contribute to increasing the sustainability of the waste management. In order to see what might be the benefits of the shifting from methanol to VFAs for the purpose of this study, additional calculations were made, based on the experimental results and the stoichiometry of the denitrification process with methanol and VFA. The purpose was to see how much of methanol would be replaced by VFAs and what are the potential benefits of that. The findings are shown in table 7.

These results show that the amount of VFA mixture needed to remove 1 gr N-NO3 is about the same as for methanol. However the amount of biomass produced during denitrification with VFA mixture is larger than in the case of denitrification with methanol. This is important from the point that more biomass leads to higher denitrification rate and more efficient denitrification. This corresponds with the experimental results reported by previous studies that observed that denitrifiers prefer acetate over methanol and these results in higher denitrification rates (Elefsiniotis *et al.*, 2004; Bayshtok *et al.*, 2009).

Although the same amount is needed, the VFA mixture is less costly because it can be produced on the WWTP site using the existing AD reactors. In this case, the VFA mixture can be produced from the WWTP sludge or even in co-digestion with the food waste from the MSW.

It is important to emphasize that these results were obtained on the basis of stoichiometric calculations and may not be the perfect representation of what may occur in actual tests and on the field.

CONFLICT OF INTEREST

The authors declare that there are no conflicts regarding the publication of this manuscript.

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