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Anaerobic Digestion of Kitchen Wastes: "Biogas Production and Pretreatment of Wastes, A Review"

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***Abstract*-** Currently, much of our biodegradable wastes such as kitchen wastes, agricultural wastes & animal wastes are used to produce Biogas, a powerful greenhouse gas. Anaerobic digestion (AD) is a treatment that composts these wastes in the absence of oxygen, producing a biogas that can be used to generate Heat & Power. Producing renewable energy from our biodegradable wastes helps to tackle the energy crisis. It is effectively a controlled and enclosed version of the anaerobic breakdown of organic wastes which releases methane. AD produces a biogas made up of around 60 per cent methane and 40 per cent carbon dioxide (CO_2). As well as biogas, AD produces a solid and liquid residue called digestate which can be used as a soil conditioner to fertilise land. The amount of biogas and the quality of digestates obtained will vary according to the feedstock used. More gas will be produced if the feedstock is more liable to decompose.

***Index Terms*-** Anaerobic digestion, kitchen wastes, Hydrolysis, VFA,

I. Introduction

Anaerobic digestion (AD) is historically one of the oldest processing technologies used by mankind. Until the 1970s, it was commonly used only in the wastewater treatment plants waste management (Palmisano at al. 1996). The amount of generated waste continuously increases and due to the large environmental impacts of its improper treatment, its management has become an environmental and social concern. Rapid biodegradation of the organic waste is of key importance to identify environmental more responsible way to process it rather than land filling or composting it. Anaerobic digestion has the advantage of biogas production and can lead to efficient resource recovery and contribution to the conservation of non-renewable energy sources. Even though proven to be effective for treating organics, anaerobic digestion plants are facing difficulties in obtaining fairly clean feedstock that results in technical difficulties with the equipment and poor compost quality. In this study we have reviewed the anaerobic digestion reactions, biogas production, challenges & management of kitchen wastes,

II. Anaerobic Digestion

Anaerobic Digestion (AD) is a biological process that happens naturally when bacteria breaks down organic matter in environments in the absence of oxygen. Anaerobic digestion (AD) is a microbial decomposition of organic matter into methane, carbon dioxide, inorganic nutrients and compost in oxygen depleted environment and presence of the hydrogen gas. This process is also known as bio-methanogenesis for rapid and controlled decomposition of organic wastes i.e. kitchen wastes and biomass feedstock to methane, carbon dioxide and stabilized residue. In the generalized scheme of the anaerobic digestion, the feedstock is collected, coarsely shredded and placed into a reactor with active inoculums of methanogenic microorganisms. Since the methane is a significant greenhouse gas, anaerobic digestion has higher control over the methane production and contributes to lower the carbon foot print of the kitchen waste management in the way that the fugitive emissions are lower than then the emissions in the cases of the land filling and aerobic composting.

Generally three main reactions occur during the entire process of the anaerobic digestion to methane: hydrolysis, acid forming and methanogenesis. Although AD can be considered to take place in three stages all reactions occur simultaneously and are interdependent.

2.1- Hydrolysis.

Hydrolysis is a reaction that breaks down the complex organic molecules into soluble monomers (constituents) (Fig.1, Stage-1). This reaction is catalyzed by enzymes excreted from the hydrolytic and fermentative bacteria (cellulase, protease and lipase). End products of this reaction are soluble sugars, amino acids; glycerol and long- chain carboxylic acids (Ralph & Dong 2010).

The approximate chemical formula for organic waste is $C_6H_{10}O_4$ (Shefali & Themelis 2002)

Hydrolysis reaction of organic fraction is represented by following reaction:

$C_6H_{10}O_4 + 2H_2O \rightarrow C_6H_{12}O_6 + 2H_2$ (Ostrem & Themelis 2004)

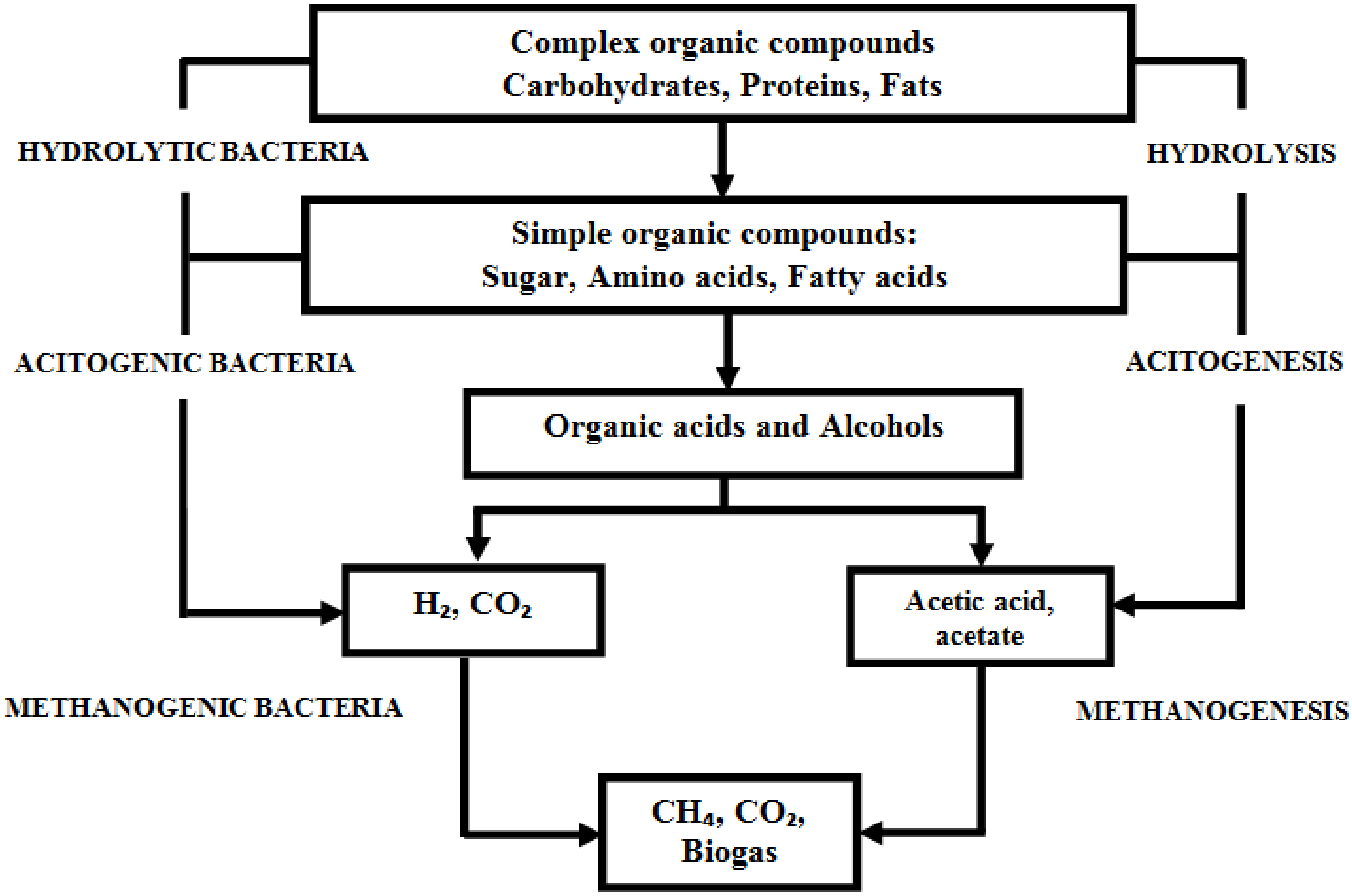

Figure 1: Overall process of anaerobic decomposition of kitchen wastes.

2.2- Acitogenesis.

This stage is facilitated by microorganisms known as acid formers that transform the products of the hydrolysis into simple organic acids such as acetic, propionic and butyricacid as well as ethanol, carbon dioxide and hydrogen. (Fig. 1, Stage- 2). Acid forming stage comprises two reactions, fermentation and the acetogenesis reactions. During the fermentation the soluble organic products of the hydrolysis are transformed into simple organic compounds, mostly volatile (short chain) fatty acids such as propionic, formic, butyric, valeric etc, ketones and alcohols.
Typical reactions occurring at this stage are the following
- Conversion of the glucose to ethanol:
- Conversion of the glucose to propionate: (Ostrem & Themelis 2004)

The acetogenesis is completed through carbohydrate fermentation and results in acetate, CO_2 and H_2, compounds that can be utilized by the methanogens. The presence of hydrogen is critical importance in acetogenesis of compounds such as propionic & butyric acid. These reactions can only proceed if the concentration of H_2 is very low (Ralph & Dong 2010). Thus the presence of hydrogen scavenging bacteria is essential to ensure the thermodynamic feasibility of this reaction (Ostrem & Themelis 2004).

Important reactions during the acetogenesis stage are as follow (Ostrem & Themelis 2004)
- Conversion of glucose to acetate:
- Conversion of ethanol to acetate:
- Conversion of propionate to acetate:
- Conversion of bicarbonate to acetate:

2.3 –Methanogenesis.

Methanogenesis is a reaction facilitated by the methanogenic microorganisms that convert soluble mater into methane (Fig.1, stage-3). Two thirds of the total methane produced is derived converting the acetic acid or by fermentation of alcohol formed in the second stage such as methanol. The other one third of the produced methane is a result of the reduction of the carbon dioxide by hydrogen. Considering that the methane has high climate change potential the goal is to find an alternative in order to lower the environmental foot print of the organic waste treatment. Therefore this stage is avoided and instead of methane the production of volatile fatty acids is targeted.

The reactions that occur during this stage are as follows (Ostrem & Themelis 2004).
- Acetate conversion:
$2CH_3CH_2OH + CO_2 \leftrightarrow 2CH_3COOH + CH_4$

Followed by: $CH_3COOH \leftrightarrow CH_4 + CO_2$

- Methanol conversion:

$$CH_3OH + H_2 \leftrightarrow CH_4 + H_2O$$

- Carbon dioxide reduction by hydrogen

$$CO_2 + 4H_2 \leftrightarrow CH_4 + H_2O$$

III. Comparative properties & composition of Biogas

The composition of biogas depends on a number of factors such as the process design and the nature of the substrate that is digested. The main components are methane and carbon dioxide, but several other components also exist in the biogas. The table-1 below lists the typical properties of biogas, landfill gas & natural gas. The table-2 shows the composition of Biogas in Anaerobic digestion.

Table 1: Properties of biogas, landfill gas & natural gas

Properties	Units	Landfill gas	Biogas	Natural gas
Lower calorific value	MJ/Nm3 kWh/Nm3 MJ/kg	16 4.4 12.3	23 6.5 20	39 11 48
Density	kg/Nm3	1.3	1.1	0.82
Relative density	-	1.1	0.9	0.63
Wobbe index, upper	MJ/Nm3	18	27	55
Methane number	-	>130	>135	73
Methane	Vol-%	45	65	90
Methane, range	Vol-%	35-65	60-70	85-92
Heavy hydrocarbons	Vol-%	0	0	9
Hydrogen	Vol-%	0-3	0	-
Carbon dioxide	Vol-%	40	35	0.7
Carbon dioxide, range	Vol-%	15-40	30-40	0.2-1.5
Nitrogen	Vol-%	15	0.2	0.3
Nitrogen, range	Vol-%	5-40	-	0.3-1.0
Oxygen	Vol-%	1	0	-
Oxygen, range	Vol-%	0-5	-	-
Hydrogen sulphide	Ppm	<100	<500	3.1
Hydrogen sulphide, range	Ppm	5	100	-
Total chlorine as Cl-	mg/Nm3	20-200	0-5	-

Sources: Energigaser och miljö, Svenskt Gastekniskt Center, 2006.
Energinet.dk, www.energinet.dk, 2011-02-15

Table 2: Approximate Biogas Composition in Anaerobic Digestion

Gas	**Concentration %**
CH_4	50-70
CO_2	25-30
N_2	0-10
H_2O	0-5
H_2S	0-3
O_2	0-3
C_xH_y	0-1
NH_3	0-0.5
R_2SiO	0-50 mg/m3

IV. PARAMETERS AFFECTING THE ANAEROBIC DIGESTION OF KITCHEN WASTES

4.1- pH value.

The pH value of the reacting material is a pivotal factor in the AD of kitchen waste. The importance of the pH is due to the fact that methanogenic bacteria are very sensitive to acidic conditions and their growth and methane production are inhibited in acidic environment. In batch reactors pH value is closer dependent of the retention time and loading rate.

Different stages of the AD process have different optimal pH values. Also the pH value changes in response to the biological transformations during different stages of AD process. Production of organic acids during the acetogenesis can lower the pH below 5 what is lethal for methanogens and cause decrease in the methanogens population. Consequently this would lead to acid accumulation, since the methanogens are responsible for the consumption of the formed acids, and digester failure. Constant pH is crucial in the start-up phase because fresh waste has to go first thru the stage of hydrolysis and acidogenesis before any methane can be formed, which will lower the pH. In order to keep the value of pH on the equilibrium buffer has to be added into the system, such as calcium carbonate or lime.

4.2 -Composition of the kitchen waste.

It is important to know the composition of the kitchen waste in order to be able to predict both the bio-methanization potential and most efficient AD facility design. The bio-methanization potential of the waste depends on the concentration of four main components: proteins, lipids, carbohydrates, and cellulose. This is due to different bio-chemical characteristics of these components (Nerves et al. 2007)

The highest methane yields have systems with excess of lipids but with longest retention time. The methanization of the reactors with excess of cellulose and carbohydrates respectively. The lowest rates of the hydrolysis are with an excess of lipids and cellulose, indicating that when these components are in excess, a slower hydrolysis is induced (Nerves et al. 2007).

4.3- Loading rate.

Organic loading rate is a measure of the biological conversion capacity of the AD system. It determines the amount of feedstock feasible as an input in the AD system. Overloading of the system can results in low biogas yield. This happens due to accumulation of inhibiting substances such as fatty acids in the digester slurry (Vandevivere et al. 1999). The events that would occur in the case of overloading the system, it would cause proliferation of the acidogenic bacteria further decreasing the pH in the system and disturbing the population of the methanogenic bacteria. Also there is a definite relationship between the biogas yield and loading rate. This is the concept that we have to use in the design of this study. The loading rate is at the point in favour of the acidogenesis avoiding the methane production and maximizing the VFA production in it.

4.4- Retention time.

Retention time in the AD reactors, refers to the time that feedstock stays in the digester. It is determined by the average time needed for decomposition of the organic material, as measured by the chemical oxygen demand (COD) and the biological oxygen demand (BOD) of the influent and the effluent material. The longer the substrate is kept under proper reaction conditions, the more complete its degradation will be. However, the rate of the reaction decreases with longer residence time, indicating that there is an optimal retention time that will achieve the benefits of digestion in a cost effective way (Viswanath et al. 1991). The appropriate time depends on the type of feedstock; environmental conditions and intended use of the digested material (Ostrem & Themelis 2004)

4.5- Operating temperature.

Operating temperature is the most important factor determining the performance of the AD reactors because it is an essential condition for survival and optimum thriving of the microbial consortia. Despite the fact that they can survive a wide range of temperatures, bacteria have two optimum ranges of temperature, defined as mesophilic and thermophilic temperature optimum. Mesophilic digesters have an operating temperature 25- 40 °C and thermophilic digesters have operating temperature range of 50-65C.

Thermophilic digesters allow higher loading rate and yield higher methane production, substrate degradation and pathogen destruction. Also, the higher temperature shortens the required retention time because it speeds up the reactions of degradation of the organic material. However, the thermophilic anaerobic bacteria are very sensitive to toxins and small environmental changes. Furthermore, bacteria needs more time (over a month) to develop redox population. These systems are harder to maintain and are less attractive for commercial application because they require additional energy input for self heating.

Mesophilic AD reactors operate with robust microbial consortia that tolerate greater changes in the environment and are more stable and easier to maintain. Another advantage is that usually these systems do not need any additional energy input for heating the system. On the other hand, the disadvantages of the mesophilic AD systems are longer retention time and lower biogas production. However due to the fact that they are easier to operate and maintain, as well as the lower investment cost, they are more attractive for commercial scale points.

V. PRE-TREATMENT METHODS TO ENHANCE ANAEROBIC DIGESTION

Anaerobic digestion (AD) is more favorable than composting, due to its high energy recovery and limited environmental impacts. AD is a well studied biological process, and it is matured in many technical aspects whereas most sustainable alternative of the process in terms of environmental and economical aspects is still being studied. One of the major concerns of AD is the long retention time, which is due to the rate limiting factor, hydrolysis of complex polymeric substances. In this regard, to enhance the biogas yield and reduce the retention time and volume of digesters, extensive research has been conducted on various pre-treatment methods.

Nevertheless, among the numerous studies, fewer studies are available on the effects of pre-treatment methods on AD of kitchen wastes. Various microbial consortia, which have substantially different physiological properties and nutrient requirements, govern the different biological stages of AD process; thus, multi-stage AD systems are more preferable than one-stage systems. However, due to economical reasons one-stage systems are absolutely predominant in industrial scale.

Based on the reasons mentioned above, this study aims to investigate the most sustainable alternative to treat kitchen wastes with AD. To achieve the aim several objectives are pointed out:

→ To conduct batch experiment on mesophilic AD of kitchen waste.

→ To study the effect of thermal and chemical pre-treatment methods, through batch experiments.

→ To estimate the most economical method through cost benefit analysis.

→ To conduct one-stage and multi-stage semi-continuous experiment using the batch experiment results.

→ To investigate the environmental impacts of the semicontinuous systems through Life cycle assessment (LCA).

Thermal and chemical (ozonation) pre-treatment methods are selected to be studied for this work. The reasons for selecting these pre-treatment methods or the advantages include the following:

→ Previous studies have shown that both thermal and chemical pre-treatment methods enhance the AD process performance.

→ Both pre-treatment methods can reduce the amount of pathogen micro-organisms.

→ No additional chemicals needed to neutralize the substrate after pre-treatment and prior to AD.

→ Extra-cost can be recovered by the increased biogas production due to pretreatments.

Different concentration of ozone and different temperatures with various contact times will also be investigated. The net profit of each pre-treatment method will be calculated based on the extra biogas production due to pre-treatment method, and the total extra cost.

Semi-continuous experiments will be conducted with both one-stage and multi-stage reactors at mesophilic conditions. Moreover, temperature phased anaerobic digestion (TPAD) will also be conducted as another type of the multi-stage system. TPAD will consist of two stages, namely:

1) The fermentation stage at thermophilic temperature.
2) Methanation stage at mesophilic temperature.

When treating wastes, AD can be used to process specific source separated waste streams such as separately collected kitchen waste. The digestate will be uncontaminated so can be used as a soil improver. To minimize the impact our waste has on the climate, Friends of the Earth believes that compostable and recyclable material should be separated at source for treatment or reprocessing, using AD where suitable.

5.1- Trace Element Supplementation.

A further part of the study is to establish whether 'kitchen waste only' digestion could be stably operated through the addition of trace elements to the feedstock. A range of different trace element dosing mixes is applied and successful and stable digestion at a particular loading rate per day, generating high biogas yields.

Selenium and cobalt are the key trace elements needed for the long term stability of kitchen waste digesters, and these are likely to be lacking in kitchen waste. Their absence causes problems during digestion at ammonia levels. The research (Project WR1208) has shown that the minimum concentrations recommended in kitchen waste digesters for selenium and cobalt is around 0.16 & 0.22 mg / l respectively, when using a moderate organic loading rate. However, it should be noted that adding too much selenium (greater than 1.5 mg / l) is likely to be toxic to the microbes in the digester Molybdenum, tungsten, nickel and other trace elements also appear to contribute in some regard towards providing sustained stability of kitchen waste digestion at high loading rates (e.g. 5 kg VS/m3/day). The addition of trace elements to a long term severely VFA laden digester only has a relatively slow and slight effect. Feeding at very low loading rates is required in addition to trace element supplementation for the digester to recover.

5.2- Pre-processing of kitchen waste.

Shredded kitchen waste is added to the feed tank, diluted with recycled feedstock and macerated. The aim of pre-shredding is to produce a consistent feed and reduced plant "down-time" due to pipe blockages by large organic objects. The maceration of the shredded kitchen waste improved mechanical action and digestibility. Although kitchen waste is a pliable material, it needs to be transformed into a more liquid form to allow the waste to be pumped. This is done by recirculation and maceration with liquid digestate or water added to reduce the solids content of the waste.The shredding procedure enables easy removal of any cling-film from waste and produces a consistent feed within hours of adding the waste to the reception tanks. Shredding of the kitchen waste reduces its particle size and increases its surface area.

Reduction in particle size provides a greater surface area for the attachment of bacteria which promotes the hydrolysis step within the reception tank. Hydrolysis is performed by the excretion of extracellular enzymes (e.g. cellulase, protease, amylase, etc.) or other metabolic catalysts by the hydrolytic bacteria. The hydrolysis products (amino acids, sugars) are utilised by the microbes for the production of cell mass, intermediate products such as proprionic and butyric acids, other long chain fatty acids, and alcohols. These compounds are substrates for methanogenic bacteria which produce methane. The recycled digestate also acts as an inoculum. It introduces fermentative bacteria accelerating the breakdown of the kitchen waste during the hydrolysis stage as described above. It is noted that the temperature in the reception tank increased (compared to ambient temperature), and the solubility of the feedstock increased because of microbial activity. However, the practice of recycling digestate eventually leads to an accumulation of inhibitory substrates, such as volatile fatty acids or ammonia, within the digester medium, and then water must be added to reduce the concentration of these chemicals.

5.3- Mechanical biological treatment.

AD can also be combined with mechanical sorting systems to process residual mixed wastes (mechanical biological treatment or MBT). After recyclable and compostable materials have been separated from the waste stream, MBT is the best way to treat the remaining waste in terms of the environment, and in particular climate change. MBT should occur in small, localized treatment plants to minimize waste transport.

In an MBT facility, the waste goes through two processes, though the order can vary:

1. Machinery is used to mechanically remove any remaining recyclable waste still left in the waste stream (e.g. metals, plastics, glass)

2. The waste is composted or anaerobically digested. This reduces the volume of waste and makes it biologically inactive so it can be landfilled without releasing methane.

Semi-continuous experiments will be conducted with both one-stage and multi-stage reactors at mesophilic conditions. Moreover, temperature phased anaerobic digestion (TPAD) will also be conducted as another type of the multi-stage system. TPAD will consist of two stages, namely:

1) The fermentation stage at thermophilic temperature.
2) Methanation stage at mesophilic temperature.

Mechanical biological treatment (MBT) of waste is now being widely implemented. Mixed waste is subjected to a series of mechanical and biological operations to reduce volume and achieve partial stabilization of the organic carbon. Typically, mechanical operations (sorting, shredding, and crushing) first produce a series of waste fractions for recycling or for subsequent treatment (including combustion or secondary biological processes). The biological steps consist of either aerobic composting or anaerobic digestion. Composting can occur either in open windows or in closed buildings with gas collection and treatment. Compost products and digestion residuals can have potential horticultural or agricultural applications; some MBT residualsare landfilled, or soil-like residuals can be used as landfill cover. Under landfill conditions, residual materials retain some potential for CH_4 generation (Bockreis and Steinberg, 2005). Reductions of as much as 40–60% of the original organic carbon are possible with MBT (Kaartinen, 2004). Compared with landfilling, MBT can theoretically reduce CH_4 generation by as much as 90% (Kuehle-Weidemeier and Doedens, 2003).

VI. CONCLUSION

Anaerobic digestion is a proven technology for processing source-separated organic wastes and has experienced significant growth. This technology is superior to the land filing and also the aerobic composting. The most successful AD processes at this time are thermophilic processes.

Even though AD is effective, there are problems associated with the application of this technology in diverting organics from the landfills and composting facilities. Additional difficulties in the operation of AD plants are due to the problem of getting fairly clean feedstock what on the other side is crucial factor for the compost quality and the overall efficiency of the AD process. It is therefore, very important to exercise the discipline required to minimize contamination of source-separated organic wastes and for the AD process to include extensive pre-treatment for contaminant separation.

The study carried out in this review has shown that the anaerobic digestion of kitchen waste is a feasible alternative to biogas generation. This finding is of special importance because this lowers the operating costs, decreases the capital and operating costs of the anaerobic digestion of source-separated kitchen waste, and reduces the greenhouse gas emissions of both processes.

Further research is necessary to collect additional data on the use of the Anaerobic Digester using kitchen wastes. Also, further experiments should be performed for identifying the optimum operating parameters for producing higher concentrations of VFAs in the liquid product of an acetogenesis reactor. In addition, technical and economic feasibility studies of the environmental and economic aspects of the industrial application of this process alternative should be carried out.

REFERENCES

[1] APHA, 21. Gray D. et al., (2008), Anaerobic digestion for Food Waste, USEPA No. EPA- R9- WST-06-004005. Standard Methods for the examination of water and wastewater, 21st Edition, American Public Health Association, Washington, D.C.

[2] Arsova, L., 2010. Denitrification in the WWTP, Volatile Fatty Acids vs. Methanol. Arsova, L., 2009a. Private Communication with Mr. Kevin Matthews,

[3] Barlaz, Morton A et al., 2008. "An Assessment of the State-of-the-Practice of Food Waste Composting in North America", Available at: http://www.ncbi.nlm.nih.gov/pubmed/19097144.

[4] de Hullu, J., Maassen, J.I.W., van Meel, P.A., Shazad, S., Vaessen, J.M.P. (2008). Comparing different biogas upgrading techniques. Eindhoven University of Technology, The Netherlands.

[5] DiStefano, Thomas D. & Belenky, L.G., 2009. "Life-Cycle Analysis of Energy and Greenhouse Gas Emissions from Anaerobic Biodegradation of Municipal Solid Waste". Journal of Environmental Engineering, 135(11), p.1097.
Available at: http://link.aip.org/link/JOEEDU/v135/i11/p1097/s1&Agg=doi.

[6] Elefsiniotis, P. & Wareham, G.D., 2006. "Utilization Patterns of Volatile Fatty Acids in The Denitrification Reaction". Enzyme and Microbial Technology, 41(2007), pp.92-97.EPA, U.E.P.A., 2007. "Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2006

[7] Gebrezgabher, S. a et al., 2010. "Economic analysis of anaerobic digestion—A case of Green power biogas plant in The Netherlands". NJAS - Wageningen Journal of Life Sciences, 57(2), pp.109-115.
Available at: http://linkinghub.elsevier.com/retrieve/pii/S1573521409000049

[8] Gray D. et al., (2008), Anaerobic digestion for Food Waste, USEPA No. EPA-R9-WST-06-004

[9] Lim, S.-J. et al., 2008. "Anaerobic organic acid production of food waste in once-a-day feeding and drawing-off bioreactor". Bioresource Technology, 99, pp.7866- 7874.

[10] Liu, C.-fang et al., 2007. "Prediction of methane yield at optimum pH for anaerobic digestion of organic fraction of municipal solid waste". Bioresource Technology, 99, pp.882-888.

[11] Levis, J.W. et al., 2010. "Assessment of the state of food waste treatment in the United States and Canada". Waste management (New York, N.Y.), 30(8-9), pp.1486-94.
Available at: http://www.ncbi.nlm.nih.gov/pubmed/20171867.

[12] Ma J., Doung T., (2011), Enhanced biomethanation of kitchen waste by different pre-treatment methods, Bioresource Technology 102 (2011) 592-599.

[13] Mata-Alvarez J., Mace S., Llabres P., (2000), Anaerobic digestion of organic solid wastes. An overview of research achievements and perspectives, Bioresource Technology, 74 (2000) 3-16 President of Canada Composting.

[14] Nand, K , Sumithra Devi, S. & Viswanath, P., 1991. "Anaerobic Digestion of Fruit and Vegetable Processing Wastes for Biogas Production.
Bioresource Technology, 40, pp.43- 48.

[15] Ostrem, K. & Themelis, Nickolas J., 2004. "GREENING WASTE: ANAEROBIC DIGESTION FOR TREATING THE ORGANIC FRACTION OF MUNICIPAL SOLID WASTES"
Available at:http://www.seas.columbia.edu/earth/wtert/sofos/Ostrem_Thesis_final.pdf

[16] Parkin, G.F. & Owen, W.F., 1986. "Fundamentals of Anaerobic Digestion of Waste water Sludge. Journal of Environmental Engineering", 112(5), pp.867-920.
Available at: http://cedb.asce.org/cgi/WWWdisplay.cgi?49921

[17] Palmisano, A.C. & Barlaz, Morton A., 1996. "Microbiology of solid waste,"
Rozej, A., Montusiewicz, A. & Lebiocka, M., 2008. No Title. Archives of Env. Protection, 34(3), pp.299-304. Sans, C. et al., 1995. "Volatile Fatty Acids Production by Mesophilic Fermentation of Mechanically- Sorted Urban Organic waste in a Plug- Flow Reactor."
Bioresource Technology, 51, pp.89-96.

[18] Ralph, M. & Dong, G.J.-, 2010. "Environmental Microbiology Second." A JOHN WILEY & SONS, INC., PUBLICATION.

[19] Shefali, V. & Themelis, Nickolas J., 2002. "ANAEROBIC DIGESTION OF BIODEGRADABLEORGANICS IN MUNICIPAL SOLID WASTE".
Available at: http://www.seas.columbia.edu/earth/vermathesis.pdf.

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