

Potential Use of Primary Sludge from Potato Processing Industry WWTP as a Co-substrate in Anaerobic Digestion of Organic Fraction of Municipal Solid Waste

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Abstract

This paper presents the results of a preliminary study on the characteristics of excess sludge resulting from aerobic treatment of potato industry wastewater (later be called potato sludge), its methane production potential and the solids elimination potential. The results of this study are considered important to examine the suitability of potato sludge as a co-substrate in anaerobic digestion of Organic Fraction of Municipal Solid Waste (OFMSW).

From this study, it was revealed that potato sludge has relatively high organic matter content. The volatile solids content of the sludge reached about 22 % of the total weight. It had a maximum methane production of around $0.40 \text{ m}^3 \text{ CH}_4 \cdot \text{kg}^{-1} \text{ VS}$. More than 80 % of its maximum methane production in batch assays was achieved within the first 4 days of incubation indicating that it was easily degradable. The concentrations of heavy metals in the potato sludge were lower than the inhibitory or toxic concentration limit. More than 70 % of its volatile solids were eliminated during solid elimination tests. Therefore, potato sludge is considered as suitable for anaerobic digestion either as a sole substrate or co-substrate..

Keywords: anaerobic digestion, co-digestion, co-substrate, methane production, volatile solids elimination

1. Introduction

Substrate characteristics

The characteristics of a substrate determine the successful anaerobic digestion process (*e.g.* high biogas production potential and organic matter degradability). In case of food processing industry waste, substrate characteristics may vary due to the method of collection, weather season, cultural habits of the community *etc.* Substrate characteristics such as its composition, C/N ratio and particle size will be briefly discussed in this sub-chapter.

The degradability and biogas production potential from solid waste in an anaerobic digester are dependent on the amount of the main components: lipids, proteins,

carbohydrates such as cellulose and hemicelluloses as well as lignin (Hartmann and Ahring, 2006). Among them lipids are the most significant substances in the anaerobic digestion, since the methane yield from lipids is higher than from most other organic materials. The theoretical gas yield of glyceride trioleate is, for example, 1.4 m^3 per kilogram of oil with a methane content of 70% (Hanaki *et al.*, 1981; Angelidaki *et al.*, 1990). Although organic waste with a high content of lipids is an attractive substrate for biogas production, Neves *et al.* (2008) reported that the lowest hydrolysis rate constants were obtained in the assays fed with kitchen waste that contained an excess of lipids. This was presumably due to a synergetic effect on the degradation of the other

components since lipids adsorb onto solid surfaces and may delay the hydrolysis process by reducing the accessibility of enzyme attack. Lignocellulosic (cellulose and hemicelluloses which are tightly bound to the lignin) waste can be found in abundant amount in the form of garden waste, paper residue or agricultural waste. Due to the presence of lignin, lignocellulosic waste is considered to be quite resistant to anaerobic digestion and hydrolysis is the rate limiting step in the overall process. In order to improve the rate of enzyme hydrolysis and increase yields of fermentable sugars from cellulose or hemicellulose in lignocellulosic waste, several pretreatment methods such as thermal (steam or hot water), chemical (acid, lime or ammonia addition) or combination of both methods were proposed by several authors (e.g. Mosier *et al.*, 2005; Fernandes *et al.* 2009).

The composition of waste also determines the relative amounts of organic carbon and nitrogen present in the waste substrate (C/N ratio). A solid waste substrate with high C/N ratio is not suitable for bacterial growth due to deficiency of nitrogen. As a result the gas production rate and solids degradability will be low. On the other hand, if the C/N ratio is very low, the degradation process leads to ammonia accumulation which is toxic to the bacteria (Hartmann and Ahring, 2006). Kayhanian and Hardy (1995) found that a C/N ratio (based on biodegradable organic carbon and nitrogen) within the range of 25–30 is considered to be optimum for an anaerobic digester. To maintain the C/N level of the digester material at optimum levels, substrates with high C/N ratio can be co-digested with nutrient-rich organic wastes (low C/N ratio) like animal manure or foodwaste (Zaher *et al.*, 2007).

The particle size has a significant role in anaerobic digestion of solid waste, especially during hydrolysis since a smaller particle size provides a greater area for enzymatic attack (Palmowski and Müller, 2000; Hartmann and Ahring, 2006). The increase of the average particle size in anaerobic digestion of foodwaste was reported to decrease the maximum substrate utilization rate coefficient (Kim *et al.*, 2000). Mshandete *et al.* (2006) reported that by reducing the size to 2 mm, the potential methane production of sisal fiber waste will improve to more than 20 % and the total fiber degradation increased from 31% to 70% compared to the untreated fibers.

Inhibitory substances

Inhibition in anaerobic digestion process by the presence of toxic substances can occur to varying degrees, causing upset of biogas production and organic removal or even digester failure (Stronach *et al.*, 1986). These kinds of substances can be found as components of the feeding substrate (organic solid waste) or as byproducts of the metabolic activities of bacteria consortium in the digester. Previous publications on anaerobic digestion show a wide variation in the inhibition/toxicity levels for

most substances. The main reason for these variations is the significant influence by microbiological mechanisms such as acclimation, antagonism, and synergism (Chen *et al.*, 2008). Acclimation is the ability of microorganism to rearrange their metabolic resources to overcome the metabolic block produced by the inhibitory or toxic substances when the concentrations of these substances are slowly increased within the environment. Antagonism is defined as a reduction of the toxic effect of one substance by the presence of another, whereas synergism is an increase in the toxic effect of one substance by the presence of another. Several substances with inhibitory/toxic potential to anaerobic digestion, such as ammonia, sulfide, light metal ions, heavy metals and organic substances, will be briefly presented in this sub-chapter.

Ammonia. Ammonia is a hydrolysis product formed during anaerobic digestion of solid waste by degradation of nitrogenous matter in the form of proteins, phospholipids, nitrogenous lipids and nucleic acid (Kayhanian, 1999; Sung and Liu, 2003). The inhibition mechanisms of ammonia are presumably due to the change of intracellular pH, the increase of maintenance energy requirement to overcome the toxic conditions, and inhibition of specific enzyme reactions (Whittmann *et al.*, 1995). In a solution, ammonium exists in the form of ammonium ion and free ammonia. Free ammonia is reported to have a more pronounced inhibition effect since it is freely membrane-permeable and may diffuse passively into the cell, causing proton imbalance and/or potassium deficiency (Eldem *et al.*, 2004; Gallert *et al.*, 1998).

Sulfide. The formation of hydrogen sulfide in anaerobic digestion is the result of the reduction of oxidized sulfur compounds and of the dissimilation of sulfur-containing amino acids such as cysteine by sulfate reducing bacteria. The reduction is performed by two major groups of SRB including incomplete oxidizers, which oxidize compounds such as lactate to acetate and CO₂ and complete oxidizers (acetoclastic SRB), which completely convert acetate to CO₂ and HCO₃⁻. Both groups utilize hydrogen for sulfate reduction (Hilton and Oleszkiewicz, 1988). Inhibition caused by sulfate reduction can be differentiated into two stages. Primary inhibition is indicated by lower methane production due to competition of SRB and methanogenic bacteria to obtain common organic and inorganic substrates. Secondary inhibition results from the toxicity of sulfide to various anaerobic bacteria groups (Chen *et al.*, 2008).

Light metal ions. The light metal ions including sodium, potassium, calcium, and magnesium are commonly present in the digestate of anaerobic reactors. They may be produced by the degradation of organic matter in the feeding substrate or by chemicals addition for pH adjustment. Moderate concentrations of these ions are needed to stimulate microbial growth, however excessive amounts will slow down growth, and even higher concentrations can cause severe inhibition or toxicity. Salt

toxicity is primarily associated with bacterial cells dehydration due to osmotic pressure (Chen *et al.*, 1999). Although the cations of salts in solution must always be associated with the anions, the toxic action of salts was found to be predominantly determined by the cation. The role of the anions was relatively minor and largely associated with their effect on properties such as the pH of the media. If compared on a molar concentration basis, monovalent cations, such as sodium and potassium, were less toxic than the divalent cations, such as calcium and magnesium (McCarthy and McKinney, 1961).

Heavy metals. Similar with light metal ions, the presence of heavy metals in trace concentration will stimulate the growth of anaerobic digester's flora. However, unlike other toxic substances, heavy metals are not biodegradable and can accumulate to potentially toxic concentrations. An extensive study on the performance of anaerobic reactors found that heavy metal toxicity is one of the major causes of anaerobic digester upset or failure (Swanwick *et al.*, 1969 in Chen *et al.*, 2008). The toxic effect of heavy metals is attributed to their ability to inactivate a wide range of enzyme function and structures by binding of the metals with thiol (sulfhydryl) and other groups on protein molecules or by replacing naturally occurring metals in prosthetic groups of enzymes (Sanchez *et al.*, 1996; Chen *et al.*, 2008). The toxicity of heavy metals in anaerobic digestion depends upon the various chemical forms which the metals may assume under anaerobic conditions at the temperature and pH value in the digester. For instance, heavy metals in the precipitated form have little toxic effect on the biological system (Angelidaki and Westermann, 1983).

Organic substances. Many organic compounds were reported to have an inhibitory potential to anaerobic digestion processes. The accumulation of hydrophobic organic pollutants in bacterial membranes causes the membrane to swell and leak, disrupting ion gradients and eventually causing the breaking of cellular membranes (Heipieper *et al.*, 1994; Sikkema *et al.*, 1994 in Chen *et al.*, 2008). The toxicity concentration of organic compounds ranges vary widely and is affected by many parameters, including toxicant concentration, biomass concentration, toxicant exposure time, cell age, feeding pattern, acclimation and temperature (Yang and Speece, 1986). Several important organic substances which are inhibitory to anaerobic digestion are: chlorophenols, halogenated aliphatic, nitrogen-substituted aromatic, long-chain fatty acids and lignins/lignin related compounds.

Co-digestion of OFMSW with other types of waste

Co-digestion of OFMSW with other types of waste is an interesting alternative to improve biogas production, to obtain a more stable process and to achieve a better handling of waste. However, some possible disadvantages (e.g transport costs of co-substrate, additional pre-treatment facilities and the problems arising from the harmonization of the waste generators) have to be taken into account (Mata-Alvarez *et al.*, 2003). The key factor

of successful co-digestion is that the balance of macro and micro nutrients can be assured by co-substrate.

A good co-substrate should fulfil several requirements, such as: i) its concentration of organic substances should be comparable with biowaste, so that addition will not significantly affect the hydraulic retention time, ii) it should consist of easily degradable organics with a high biogas production potential, iii) it may not contain any dangerous or poisonous substances, which hinder anaerobic digestion or composting, iv) it should have a content of macro and micro nutrients which have possibility to improve the characteristics of main substrate, v) it must be available in sufficient quantities at a reasonable price and should be storable and vi) it should be pumpable without danger of clogging, thus allowing safe automatic feeding.

Various types of solid waste streams such as sewage sludge, animal manure and organic industrial waste have been proposed as co-substrate for anaerobic digestion of OFMSW. Reports on co-digestion of the organic fraction of municipal solid waste with any other waste streams, such as energy crops (Nordberg and Edström, 2005), market residues (Gallert *et al.*, 2003), sewage sludge (Hartmann *et al.*, 2003) and manure (Hartmann and Ahring, 2005) are existing. Sewage sludge is available in abundant quantity in line with the presence of wastewater treatment plants. Co-digestion with sewage sludge will improve the characteristics of OFMSW including its content of micro and macro nutrients, lead to a better C/N ratio and facilitate the adjustment of moisture content. The optimal mixture of OFMSW and sewage sludge depends on the specific waste characteristics and the system used in the digestion process. For wet anaerobic digestion, the best performance (in term of biogas production and VS reduction) can be achieved when the mixture of OFMSW and sewage sludge is within the range of 80:20 on TS basis or 25:75 on volume basis (Hartmann *et al.*, 2003).

It has been discussed previously that animal manure has been used as a substrate for anaerobic digestion since more than 2000 years ago. The advantages of using animal manure as co-substrate in anaerobic digestion of OFMSW are: its abundant availability and its high buffer capacity mainly due to its ammonia content. Furthermore, animal manure has low TS content which can be used to adjust the moisture of OFMSW and wide variety of nutrients which are necessary for optimal bacterial growth. Macias-Corral *et al.* (2008) reported that co-digestion of OFMSW and cow manure resulted in higher methane gas yields and promoted synergistic effects resulting in higher mass conversion and lower weight and volume of digested waste.

Full-scale applications of solid waste co-digestion have been reported by several authors. Angelidaki and Ellegaard (2003) reported that in 2001, Denmark had already 22 large-scale centralized biogas plants operated

under co-digestion mode and treating mainly manure together with other organic waste such as industrial organic wastes, source sorted household waste, and sewage sludge. Positive results including the increase of energy production and degradation efficiency from a full-scale co-digestion of sewage sludge and OFMSW in Velenje, Slovenia were also reported (Zupančič *et al.*, 2008). Despite the positive results from laboratory experiments and/or full-scale experience, in Europe co-digestion is less applied than it was expected. It is quite common that an organic solid co-substrate is added to manure digesters in small amounts, but often these co-substrates are high-energy yielding industrial sludge and only quite exceptionally, solid waste from households or market waste is added. Among the biogas plants identified, only about 9.7 % of the organic solid waste treated was done by means of co-digestion, mostly with liquid manure. The percentage of installed co-digestion plants has dropped from 23% in the period 1990–1995 to 5% in the period 2006–2010. However, due to the high prices for agricultural crops, many energy crop digestion plants are looking for organic waste feedstock (de Baere, 2008).

REFERENCES

- [1] G. Eason, B. Noble, and I.N. Sneddon, "On certain integrals of Lipschitz-Hankel type involving products of Bessel functions," *Phil. Trans. Roy. Soc. London*, vol. A247, pp. 529-551, April 1955.
- [2] J. Clerk Maxwell, *A Treatise on Electricity and Magnetism*, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68-73.
- [3] I.S. Jacobs and C.P. Bean, "Fine particles, thin films and exchange anisotropy," in *Magnetism*, vol. III, G.T. Rado and H. Suhl, Eds. New York: Academic, 1963, pp. 271-350.
- [4] K. Elissa, "Title of paper if known," unpublished.
- [5] R. Nicole, "Title of paper with only first word capitalized," *J. Name Stand. Abbrev.*, in press.
- [6] Y. Yorozu, M. Hirano, K. Oka, and Y. Tagawa, "Electron spectroscopy studies on magneto-optical media and plastic substrate interface," *IEEE Transl. J. Magn. Japan*, vol. 2, pp. 740-741, August 1987 [*Digests 9th Annual Conf. Magnetics Japan*, p. 301, 1982].
- [7] M. Young, *The Technical Writer's Handbook*. Mill Valley, CA: University Science, 1989.