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Pre-treatment and anaerobic digestion of food waste for high rate methane production – A review

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ABSTRACT

Food waste with high decomposition potential can be successfully digested anaerobically for the production of biogas. As the fossil-fuel reserves decline anaerobic digestion can be a better alternative as a renewable energy source. The byproducts such as biogas with 50–60% methane content can be efficiently used for electricity production and the final digested sludge as a fertilizer. Even though anaerobic digestion is a proven technology, still there exist some technical difficulties (organic loading rate, solid retention time, biogas composition, specific gas production) and scientific understandings (carbon to nitrogen ratio, volatile fatty acids production, pH variation, nutrient concentration) in operating reactors for solid organic wastes. First the paper gives an overview of certain fundamental aspects of anaerobic digestion considered important for the digestion of food waste and its biochemical reactions. Then it describes food waste as the substrate for anaerobic digestion and its optimal conditions for the increased activity of biogas production. Finally it has been reviewed about the performance of the different pre-treatment methods and anaerobic reactor configurations in the digestion of food waste for increasing methane content in the biogas.

Contents

Abbreviations: AD, anaerobic digestion; FW, food waste; CH_4, methane; CO_2, carbon dioxide; MSW, municipal solid waste; TS, total solids; VS, volatile solids; COD, chemical oxygen demand; *F*/*I*, food to inoculum; C/N, carbon to nitrogen; HRT, hydraulic retention time; SRT, solids retention time; OLR, organic loading rate; UASB, upflow anaerobic sludge blanket; UASS, upflow anaerobic solid state reactor; SS-AD, solid state-AD; VFA, volatile fatty acids; H_2, hydrogen; NH_3, ammonia; H_2S, hydrogen sulfide; BMP, biochemical methane potential; $NaHCO_3$, sodium bicarbonate; NaOH, sodium hydroxide; KOH, potassium hydroxide; $Mg(OH)_2$, magnesium hydroxide; $Ca(OH)_2$, calcium hydroxide.

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Introduction

AD consists by a number of complex biochemical reactions carried out by several types of microorganisms that require little or no oxygen to survive. During this process, a gas that is mainly composed of CH_4 and CO_2, also referred to as biogas, is produced. The amount of gas produced varies with the amount of organic waste fed to the digester and temperature influences the rate of decomposition and gas production. The overall conversion process of complex organic matter into CH_4 and CO_2 can be divided into four steps: hydrolysis, acidification, acetogenesis and methanogenesis. Biological processes like composting and AD have advantages because they are natural treatment processes over other technologies using microorganisms, which need less energy input; and less harm to atmosphere over other technologies such as incineration, pyrolysis, etc. AD has distinctive potential to act simultaneously as waste treatment and resource recovery process. AD revealed an admirable life cycle analysis enactment paralleled to some other treatment technologies like composting or incineration as it can recover the energy. In addition, the residues are stable and hence a compost potential for agriculture [1].

There is a major concern in reducing and recycling waste as much as possible during the treatment process with respect to both energy and materials. AD is an old and currently developing technology that is considered promising for the future of gas production and waste reduction [2]. AD is one of the processes adopted for the treatment and recycling of MSW. Although, AD has both benefits of waste treatment and energy generation, it includes higher residence time and the inability of anaerobes to completely utilize every organics such as high lignin percentage waste and highly insoluble organic polymers in MSW within the residence time because of its lower hydrolysis rate [3]. Due to its capability of reducing waste, high calorific value biogas production and pathogens free final product, AD of solid organic waste has earned much attention [4]. AD earns many points than other treatment process, with respect to global warming which plays a major role in ecological balance [5,6]. AD is preferentially suited for high moisture content or semi-solid organic materials. AD tests performed with semi-solid and pasty proteins and lipids products from slaughterhouses, pharmaceutical, food, beverage industries, distilleries and municipal bio-wastes. Batch AD test was conducted with the variety of substrates such as animal fat, flotation sludge, stomach and gut contents, blood, food leftovers showed a biogas yield ranging from 0.3 to 1.36 L/g of VS added and for the same substrates continuous AD test performed, HRT ranging between 12 and 60 d according to the organic materials added, process temperature of 35 °C, was maintained to attain maximum gas yield [7].

Roughly one third of all food produced for human consumption is wasted yearly totaling 1.3 billion tones, as reported by global food waste published in 2011 by the Food and Agriculture Organization of the United Nation [8]. However this waste is evenly distributed between developing and industrialized nations with 40% of the FW in the developing nations occurring in the production and processing phases of consumption while in the industrialized nations, 40% occurs at the retail and consumer levels of consumption. When such amount of FW is digested anaerobically it has the potential to generate 367 m^3 of biogas per dry tonne at about 65% CH_4 with an energy content of 6.025×10^{-9} T W h/m^3, much amount of energy can be recovered. In addition, transportation of FW to landfills and greenhouse gas emissions from the landfill sites will be reduced by implementing AD. Thus AD of food waste needs few pre-treatments and optimum conditions for better digestion and to recover maximum biogas due to its readily available organics and highly complex oil contents. The present paper is a review of various pre-treatments techniques, optimum conditions and types of anaerobic reactors to enhance the bio-methane production from FW.

Anaerobic digestion process and biochemical reactions

When the anaerobic digester works properly, the conversion of the intermediate products (i.e., the products of the first three steps) is virtually complete, so that the concentrations of these are low at any time. In the hydrolysis process, macro molecules like proteins, polysaccharides and fats that compose the cellular mass of the microorganisms are converted into smaller molecules that are soluble in water: peptides, saccharides and fatty acids. The hydrolysis or solubilization process is done by exo-enzymes excreted by fermentative bacteria. Hydrolysis is a relatively slow process and generally it limits the rate of the overall AD process. Polymers are transformed into soluble monomers through enzymatic hydrolysis.

$$n\,C_6H_{10}O_5 + n\,H_2O \xrightarrow{\text{Hydrolysis}} n\,C_6H_{12}O_6 \quad (1)$$

The Reaction (1) is catalyzed by extracellular microbial enzymes known as hydrolyses or lyses. Depending on the type of the reaction they catalyze, these hydrolyses can be esterase, glycosidase or peptidase. For example, lipases hydrolyze the ester bonds of lipids to produce fatty acids and glycerol. Lyses, on the other side, catalyze the non-hydrolytic removal of groups from substrates [9]. The major class of anaerobic bacteria degrading cellulose include *Bacterioides succinogenes*,*Clostridium lochhadii*, *Clostridium cellobioporus*, *Ruminococcus flavefaciens*, *Ruminococcus albus*, *Butyrivibrio fibrosolvens*, *Clostridium thermocellum*, *Clostridium stercorarium* and *Micromonospora bispora*. The dungs of various animals such as cow, pig, etc. has been used as an inoculum in anaerobic digestion of food waste. The anaerobes present in the dungs belong to the digestive system of the species. The predominant bacteria found to degrade the hemicelluloses in the rumen are *Bacterioides ruminicola*. *B. fibrisolvens*, *R. flavenfaciens*, and *R. albus*[9]. The second step of the AD process is acidogenesis or acidification as given in Reaction (2), a process that results in the conversion of the hydrolyzed