INTERNATIONAL JOURNAL OF PLANT, ANIMAL AND ENVIRONMENTAL SCIENCES

IJPAES

Volume-3, Issue-4, Oct-Dec-2013 ISSN 2231-4490

www.ijpaes.com

Received: 15th July-2013 Revised: 21st July-2013 Accepted: 29th July-2013

Review article

A REVIEW ON DECOMPOSITION AS A TECHNOLOGY FOR SUSTAINABLE ENERGY MANAGEMENT

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ABSTRACT: Millions of tons of solid waste are generated each year from municipal, industrial and agricultural sources. Unmanaged organic waste fractions from farming, industry and municipalities decompose in the environment, resulting in large-scale contamination of land, water, air and great threat to environmental quality. India alone generates 42 million tons of municipal solid waste per year. On the other hand 88% of world economy for electrical and thermal energy is met through non-renewable resources mainly petroleum and natural gas. These raw materials besides being exhausted their extraction processing and combustion adversely affects the natural environment. To tackle these issues countries have been incorporating alternative forms of waste management strategies to produce energy where organic waste is greatly reduced by the action of microorganisms through decomposition. Decomposition of organic matter is essential to the functioning of terrestrial ecosystems.
Key words: Solid waste, contamination, environment, waste management, decomposition.

INTRODUCTION

Decomposition is the natural process of dead animal or plant tissue being rotted or broken down. In decomposition there are different products are released like carbon dioxide (CO_2), energy, water, plant nutrients and resynthesized organic carbon compounds [25]. Soil microorganisms use soil organic matter as food. As they breakdown the organic matter, any excess nutrients (N, P and S) are released into soil in forms that plants can use as mineralization product. Decomposition is carried out by vertebrates, invertebrates, fungi and bacteria through food chain and food web and is characterized by many biological and physical processes, including biological respiration, leaching and fragmentation [19, 17]. All these process have closed relationship with each other and work synergistically. Biological respiration is a process of releasing energy from the breakdown of glucose which takes place in plants. Oxygen enters plant cells through the stomata and produces their food via photosynthesis and release energy. Decomposition by vertebrates and invertebrates are faster, commonly through digestion which occurs in a series of processes and where complex organic matter broken down both in the presence of oxygen and absence of oxygen at times mediated by microorganisms and energy is absorbed in the form of ATP molecules. However, complete breakdown do not occur since waste will still contain reasonable amount of non decomposed material. The result of decomposition is that the building blocks required for life can be recycled. An important service provided by invertebrate is waste- recycling. Earthworms break the leaves into smaller pieces and the process called fragmentation. This is an important step, because smaller fragments have more surface area to support the growth of bacteria and fungi. Bacterial growth is especially affected by fragment size, since fungi can penetrate substances more easily than bacteria. Rainwater percolates through the leaves, dissolving and carrying away some of the chemicals in the leaves either in aerobic and anaerobic conditions. Decomposition is controlled by many factors mainly including site conditions like temperature, humidity and O_2/CO_2 concentration, substrate quality including species, size, component and position [19]. Decomposition can be broadly classified into two types i) aerobic and ii) anaerobic decomposition. Aerobic decomposition involves the use of oxygen as an electron acceptor by microorganisms during the degradation of organic matter into CO_2, water, nitrates and sulphates.

$C_6H_{12}O_6$ + Oxygen → CO_2 + H_2O

Anaerobic digestion is a process in which microorganisms break down biodegradable material in the absence of oxygen, used for industrial or domestic purposes to manage waste or to release energy.

$C_6H_{12}O_6$ → $2C_3H_6O_3$ + 2 ATP

In aerobic decomposition heterotrophic microorganisms completely metabolize macromolecular carbon from organic particles to CO_2 and cell biomass, whereas anaerobic decomposition occurs in multi stage breakdown by mutualistic consortia of organisms. Variety of conclusions have been made between aerobic and anaerobic decomposition where in slurry and sediment the aerobic decomposition is faster for a variety of organic substrates [6, 31], or slower [58] while other indicates that oxygen has no significant impact on the rate or organic matter degradation [28, 31]. However, aerobic decomposition of organic compound oxidizes and reduces economically important gases and it is high energy consuming process [15] where as anaerobic decomposition can be effectively maintained to recycle and produce economically viable products without creating environmental hazards. Anaerobic digestion with energy recovery is an attractive method for the treatment of solid waste and waste water. Anaerobic decomposition have many advantages over the aerobic processes, such as low consumption of energy, low sludge production, smaller space requirements and lower overall costs [11, 2, 34, 32, 33]. The production of biogas via anaerobic digestion of agricultural residues and industrial wastewater would benefit society by providing a clean fuel from renewable feedstocks. Biogas production from large quantities of agricultural restudies, animal wastes, municipal and industrial wastes appears to have potential alternative renewable energy for many countries and mooted appropriate research to adopt biogas technology to local conditions [45].

Aerobic decomposition

Living organisms using oxygen feed upon organic matter consume nitrogen, phosphorous, carbon and other nutrients in which carbon serves as main energy during respiration and form CO_2 where two third of this is released into atmosphere and one portion along with nitrogen stored in the living cell. Excess nitrogen is released into atmosphere as ammonia and some fixed into soil as nitrates along with other nutrients like phosphorus, potash, and various micro nutrients. In the process great amount of heat is released and also increase the organic matter temperature where mesophilic organics replace by thermophilic organisms. Innumerable enzymes were involved in aerobic decomposition process where many are specific to individual classes of compounds and each compound is usually metabolized completely by a microorganism [10]. Most polymeric organic compounds were digested by this process which is lacking in anaerobic respiration process which depends on slow hydrolytic and fermentative bacteria for the supply of metabolizable low molecular substrates [24, 1]. As result aerobic mineralization was found to be two to three times faster than anaerobic [62]. The difference between aerobic an anaerobic degradation is due to function of molecular oxygen under aerobic conditions. Dipolar function of oxygen in degradation of organic matter as terminal electron acceptor for electrons released during oxidation of organic carbon and reactant in oxygenase - catalyzed attack on the substrate molecules. The first function may be transferred in the absence of oxygen to other oxidized compounds such as sulfate there is no equivalent to oxygen that can fulfill its functions as reactant in the primary transformation of important substrates. Out of too many primary reactions observed in natural environments only few can be catalyzed in the absence of oxygen [42]. Since there are limitations of anaerobic bacteria to hydrolyze certain classes of structurally complex and aromatic organic compounds they are slower than aerobic decomposers. However, due to scientific understanding in anaerobic technology and increasing reliability of this process anaerobic technology is considered to be an attractive technology for alternative fuel and organic waste management.

Anaerobic decomposition

Anaerobic decomposition technology is a biochemical reaction carried out by several types of microorganisms that require little or no oxygen to live. During this process a gas that is mainly composed of methane and carbon dioxide referred as biogas is produced. The amount of gas produced varies with biochemical characteristics of organic wastes, consortia of microorganisms, pH, temperature, etc.

Evidences show that biogas was first reported to be used in 10th century BC Assyria for heating bath water [35] and in Persia during 16th century. Jan Baptit Van Helmont first determined that flammable gases could evolve from decaying organic matter in 17th century [61]. The relationship between amount of decaying organic matter and amount of flammable gas produced was established by Alessandro Volta in 1776. Production of methane through anaerobic decomposition of cattle manure was established by Humphry Davy 1808 [59]. The first ever reported biogas unit was constructed in leper colony in Mumbai in 1859 [43]. Involvement of microorganisms in formation of methane during decomposition was identified by Beuchamp, in 1868. Omelianski, in 1890 isolated microbes responsible for the release of hydrogen, acetic acid and butyric acid formed due to microorganism mediated reaction between hydrogen and carbon dioxide during methane formation in cellulose decomposition [40]. Biogas recovered during sewage treatment plant in 1895 in England used to fuel street lamps in Exeter [39]. However, development of microbiology in 1930 led to research by Buswell [9] and others to identify anaerobic bacteria and conditions that promote methane production. Buswell developed formula for substrate selection and biogas production factors however, the equation was not satisfactory with regards to important factors in anaerobic decomposition later [51]. Later it was identified that anaerobic digestion is the degradation of organic materials by microorganisms able to utilize molecules other than oxygen as hydrogen accepters [49]. The process of biogas production was identified in three stages by Marchaim [38] which includes hydrolysis, acetogenesis and methonogenesis. Shih [56] identified mesophilic and thermophilic conditions of biogas production where mesophilic conditions were consistent in production where as thermophilic conditions increase the biogas production. However, anaerobic digestion progresses with several complex sequential and parallel biological reactions with many intermittent products through a sequential action of microorganisms producing substrates for other organisms [46,47,18]. These reactions were consolidated into four phases as Hydrolysis/liquefaction, acidogenesis, acetogenesis and methanogenesis.

Hydrolysis

Hydrolysis is the first stage in anaerobic digestion which depolymerise the carbohydrates, proteins and lipids into monomers by the extracellular enzymes like cellulase, amylase protease and lipase. Polysaccharides are converted into simple sugars, monomeric or dimeric. Lipids are hydrolysed into long and short chain fatty acids and glycerol moieties with help of lipase produced by Clostridia and Micrococci. Proteins are broken down into amino acids, small peptides, ammonia and CO_2 with the help of Bacteriodes, Butyrivibrio, Clostridium, Fusobacterium Slenomonas and Streptococcus species [41]. Starch into glucose units, hemicelluloses is broken into variety of monosaccharides such as glucose, xylose, arabinose and mannose [43]. Both obligate and facultative bacteria are involved in hydrolysis and fermentation and removes small amounts of oxygen introduced during feeding the digester. Hydrolysis of biomass has been approached primarily as an enzymatic phenomenon, not as microbial. As a result of this lignocellulosic material degrading microorganisms are less studied [20, 36]. Microorganisms with the ability to degrade the components of lignocellulosic materials are found among a wide range of taxonomic groups. There are as many aerobic and anaerobic cellulolytic microorganisms in Actinomycetales (aerobic, phylum Actinobacteria) and in the Clostridiales (anaerobic, Phylum Firmicutes). Anaerobic cellulolytic microorganisms can be found in genera Activibrio, Anaerocellum, Butyrivibrio, Caldicellulosiruptor, Clostridium, Eubactrium, Fervidobacterium, Halocella, Spirochaeta, Thermotoga, Fibrobacter and Ruminococcus. Diverse microbial populations have been reported by Boone et al. [7] for biodegradation of organic matter to form methane and carbon dioxide was only preliminary. Specific studies exploring specific microorganisms like cellulolytic bacteria [60, 8], land fill sites and sewage sludge digester [50] were also not complete.

Acidogenesis

In Acidogenesis acid forming microbes use fatty acids and amino acids from hydrolysis as substrates and produce organic acids, such as acetic, propionic, butyric and other short chain fatty acids, alcohols, H_2 and CO_2 [26, 18]. Acidogenesis is usually the fastest reaction in the anaerobic conversion of complex organic matter in liquid phase digestion [44]. During steady state in anaerobic degradation, the main pathway is via acetate, carbon dioxide and hydrogen, and these reduced fermentation products can be used directly by the methanogens [54]. The accumulation of electron sinks such as lactate, ethanol, propionate, butyrate and higher volatile fatty acids (VFAs) is responsible for the bacteria to increase hydrogen concentration in the medium. Many kinds of bacteria are involved in hydrolysis and acidogenesis and as a result several kinds of organic acids and alcohols are produced [22]. The concentration and proportion of individual VFAs produced in the acidogenic stage is important for the overall performance of anaerobic digestion since acetic and butyric acids are the preferred precursors for methane formation [24].

Acetogenesis

The acetogens further degrade propionic, butyric and valeric acids formed in acidogenesis to acetate, formate, carbon dioxide, and hydrogen. These acetogens are slow growing and sensitive to fluctuations in organic loads, environmental changes [64] and low hydrogen partial pressure. Therefore syntrophic association with hydrogen consuming methanogens are required [40,14,53,55]. This intermediate conversion is important for the successful production of biogas since electron sinks are not directly utilized by the methanogens [37]. The acetogens include Syntrophomonas wolfeii which degrade valerate and butyrate. Syntrophomonas wolinii degrade propionate and homoacetogenic bacteria, which convert the products of acidogenesis into acetic acid, hydrogen and carbon dioxide [66]. The efficiency of anaerobic degradation of organic matter is dependent upon synchronized metabolism of acid forming and methane forming bacteria, imbalances in this synchrony leads to instability in anaerobic digestion and lead to accumulation of intermediate acid products which inhibit methanogenic bacteria [48,12]. Therefore enough acidogenic and methanogenic consortia is required for effective anaerobic decomposition and methane production

Methanogenesis

Methanogens utilized hydrogen, methanol, methylamines, alcohols, formate and carbon dioxide to form methane [23]. Methane is produced through aceticlastic pathway [4, 27, 30, 57, 63]. Hydrogen pathway is energy yielding than acetate pathway increases the rate of methane formation by keeping the low hydrogen pressure. Hydrogen is recognized as controlling parameter in anaerobic digestion, but is rarely detected in well functioning methanogenic digesters [5]. The hydrogen-utilizing methanogens have been found to be more resistant to environmental changes than aceticlastic methanogens. Therefore, methanogenesis from acetate has been shown to be rate limiting in several cases of anaerobic treatment of easily hydrolysable waste [44]. All known methanogenic species can produce methane from H_2/CO_2 [21] which belong to Archaea, group. Although they possess a prokaryotic cell structure and organization, they share some common features with eukaryotes homologous sequences in rRNA and tRNA, the presence of introns in their genomes, similar RNA polymerase subunit organization, immunological homologues and translation systems [16, 66]. Methanogenic microorganisms are obligate anaerobes sensitive to environmental changes [52]. This group contains acetotrophic methanogens, hydrogenotrophic methanogens, and methylotrophs which convert methyl compounds methanol and methyl amines. Out of many methanogenic genera, only two Methanosarcina and Methanosaeta, are known to grow by the aceticlastic reaction (Zinder, 1984). Some of the acetate-utilising methanogens are Methanosaeta soenhngenii and Methanosarcina barkeri [63,3]. Species of Methanosaeta grow very slowly, with doubling times of 4 to 9 days [29, 65]. Therefore it is essential that the effective consortia of methanogens are required for effective degradation of organic matter and methane production.

CONCLUSION

Natural ecology had given numerous sustainable technologies for human life. Understanding the processes in the way it operates is essential for strengthening the technology at industrial scale. Decomposition is an important technology of the above which is complex and being used consciously and unconsciously from the time immemorial by mankind. This technology undergoes series of action/reaction by many biotic and abiotic factors which can be broadly classified into aerobic and anaerobic based on presence or absence oxygen. The present review was able to understand that enzyme digestion is common in all the macro and microorganisms action during which ATP molecules were absorbed for energy. In the process product of one process forms the substrate for other and gradually acted upon by variety of microorganisms forming a food chain with complex web. However, first step in decomposition is to increase the area exposed to such activity. This is followed by reactions in the presence of oxygen which is rapid convertor of Carbohydrate, protein, lipid and fats into simpler compounds. These compounds can proceed in anaerobic or aerobic conditions where the review was able to understand that anaerobic decomposition would be more energy efficient as a large scale technology. Knowledge on anaerobic processes is being studied in detail only recently, though their uses have been realized more than a century before. This is basically due to required advances in other fields of science like microbiology, biotechnology, biophysics, biochemistry, etc. However, the present knowledge on decomposition is not sufficient to use it at industrial scale with complete control of all its parameters and factors. However attempts are being made in many countries and progressing with research inputs on time to time basis. Aerobic decomposition is found to be faster but their economics is not comparable with anaerobic. In anaerobic decomposition all the four stages are dealt in detail but further research is need to strengthen to use it at the maximum.

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