A REVIEW OF THE ANAEROBIC DIGESTION PROCESS

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ABSTRACT
As one of the oldest biological waste treatment processes, anaerobic digestion offers the advantages of low energy requirement, high treatment efficiency, low excess sludge production, low nutrient requirement, no oxygen requirement and energy recovery. This paper reviews the process covering its fundamental requirements, factors affecting it, effect of mixing as well as mixing regimes. The fundamental stage-wise processes of hydrolysis, acidogenesis, acetogenesis and methanogenesis were described. The factors affecting the performance of anaerobic digesters include feeding rate, feeding mode (retention time), temperature, pH and alkalinity, nutrient content, toxicity, mixing frequency and intensity as well as the method of mixing. The factors affecting mixing in digesters are in turn reviewed in considerable detail. The relevance of anaerobic digestion in the light of the enforcement of the Kyoto Protocol was also discussed, together with the rationale for waste treatment options for minimisation of greenhouse gases. It is concluded that treatment options for waste management should include anaerobic digestion in which methane is captured for power generation, a planned process flow to minimise pumping of wastewater, planned biosolid flow to minimise internal transport and systems that avoid incineration using fossil fuel. Finally, more recent developments in the areas of microbial fuel cell as well as biological production of hydrogen were discussed. With the emergence of "white biotechnology" leading to the pursuit of bio-refinery projects, it is suggested that anaerobic digestion should now be integrated with bio-refinery activities to find its exclusive niches.

INTRODUCTION

Anaerobic digestion is one of the oldest biological waste treatment processes. It was a century ago that anaerobic digestion was first applied in wastewater treatment. With the use of digester heating and mixing, it has become the most common method of sewage sludge stabilisation. It has also been applied to processing wastes originating from industries such as dairy, abattoir, piggery, palm oil, brewery and other food processing forms. These agricultural wastes are relatively concentrated, having a high content of biodegradable organic matter. Anaerobic digestion offers the advantages of low energy requirement, high treatment efficiency, low excess sludge production, low nutrient requirement, no oxygen requirement and energy recovery. It has been shown that both the capital and operational costs of anaerobic treatment increase relatively slowly with increasing waste strength, compared with aerobic treatment (Eckenfelder *et al.*, 1988).

Recognition of the potential of anaerobic processes has led to the development of highly advanced reactor configurations for improved biomethanation. Anaerobic microorganisms being used in waste management are present ubiquitously in many natural ecosystems. Whether studied under natural conditions or within controlled systems, anaerobic processes have become a focus of multidisciplinary research resulting in a broadening of their application throughout the world. Anaerobic processes are being studied in fields as diverse as soil and sediment systems, gastrointestinal tracts of animals, geothermal vents, municipal landfills, and of course, liquid waste management.

There have been significant efforts to promote small-scale biomethanation plants for methane production and fertiliser conservation in both China and India. In 1930, the Chinese government granted a patent for a biogas production system to an entrepreneur who then built up a gas production company with branches in 13 provinces (Xu, 1983). In 1939, biomethanation research was initiated in India at the then Imperial Agricultural Research Institute, largely due to concern over increased use of manure as cooking fuel, with its consequent loss as fertiliser. The aim then was to make use of manure as a fuel source without destroying its usefulness as a fertiliser (Idnani and Acharaya, 1963). The research resulted in the development of the well-known floating-dome biogas plant, which was promoted by the Khadi and Village Industries Commission as well as the Gobar Gas Research Station for rural areas of India. Similarly, interest shown by the Chinese government in the 1970's resulted in the building of over 6.5 million units of family-size fixed-dome type biogas plants in 30 million villages (Xu, 1983).

Meanwhile in the west, advanced anaerobic configurations such as the anaerobic filter were developed in the 1970's, while the Upflow Anaerobic Sludge Blanket (UASB) process was developed in 1979. As a result of its effectiveness and low cost, anaerobic treatment has received considerable attention throughout the world.

FUNDAMENTALS OF ANAEROBIC DIGESTION

Conceptually, anaerobic digestion of complex organics can be described as a stage-wise process involving:

1. Hydrolysis
2. Acidogenesis
3. Acetogenesis and homoacetogenesis
4. Methanogenesis

At least five groups of bacteria are known to be involved, namely, fermentative bacteria, hydrogen-producing acetogenic bacteria, hydrogen-consuming acetogenic bacteria, carbon dioxide reducing methanogens and acetoclastic methanogens. However, the division is only arbitrary and schematic since in actual fact the bacteria cannot be separated due to the fact that each group is metabolically dependent on one another, i.e. they are ecologically syntrophical (McInerney *et al.*, 1979).

Hydrolysis

Hydrolysis and liquefaction are achieved due to the presence of hydrolytic enzymes produced and excreted by bacteria. Once complex organics are hydrolysed, they are converted to short chain organic acids, sugars, amino acids and eventually to acetic, propionic, butyric and valeric acids. This stage is commonly called the "acid-forming" or acidogenic phase and is described in the following section. During hydrolysis, no stabilisation of the organic waste occurs. The overall rate of stabilisation and methanogenesis of complex polymeric compounds is often limited by the rate of hydrolysis, particularly for agricultural wastes containing insoluble solids. There must be sufficient hydrolytic enzymes having intimate contact with the organic fraction. This fact emphasizes the importance of having a large, active microbial population, sufficient organic substrate and uniform mixing. Acid-forming bacteria may be facultative, obligate anaerobes or a combination of both. They are inhibited by hydrogen which, however, is an energy source for some methanogenic bacteria which reduce carbon dioxide to methane.

The rate of hydrolysis is dependent on the type of biopolymer as well as on environmental factors. The anaerobic rate of hydrolysis for each type of complex substrate varies, with that of carbohydrates being generally more rapid than that of proteins. Gujer and Zehnder (1983) found that the hydrolysis rate constants for lipids, protein, cellulose and hemicellulose were 0.08 to 1.7, 0.02 to 0.03, 0.04 to 0.13, and 0.54 day^{-1}, respectively. The hydrolysis and fermentation of cellulose by a continuous culture of *Ruminococcus albus* follows first-order kinetics while its rate constant was found to be 1.18 day^{-1} (Pavlostathis *et al.*, 1988). The rate of hydrolysis appears to be affected by pH, with the highest rate for cellulosic materials being at pH 6.7 (Eastman and Ferguson, 1981). It is also influenced by temperature, with optimum hydrolysis being found to be at 40° C (Tong and McCarty, 1991). A detailed review of