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Review on Modeling and Simulation of Anaerobic Biological Wastewater and Sludge Treatment Processes

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ABSTRACT

The microbial growth studies have also been carried out under steady state or transient conditions by Monod model, Contois model, Haldane model, Andrews model and model due to Hill and Barth. The inhibitory effects on performance of digester by the presence of unionized volatile fatty acids, volatile fatty acids, pH, ammonia and high loading rates in terms of high influent substrate concentration are also considered. Simulation of the developed model under transient conditions can quantify the extent of process stability which is considered to be of paramount importance in selecting a suitability of a process for specific application.

Key words: Modelling and simulation of biological processes, anaerobic digestion, distillery sent wash, sludge, model validation

ANAEROBIC TREATMENT TECHNOLOGY

Out of the numerous equipments the most popular and economically feasible, technology is anaerobic digestion, mostly preferred by industry. It is also preferred because it can handle wastes of high organic contents, provide with less solids generation (compared to aerobic), generate energy, requires lower reactor volume, needs lesser amount of nutrients, sustain shock loading with mesophilic, thermophilic microorganisms and varying pH. The anaerobic digester can also handle different kind of wastes from sludge to wastewater having high organic loads. The later might contain organics consisting of lipids, proteins, polysaccharides including cellulose and nucleic acids. The simplified treatment technology by anaerobic digestion process can be shown in Figure 1. Further anaerobic process generally is a slow process as compared to aerobic with approximate residence time of 30 day to 60 day.

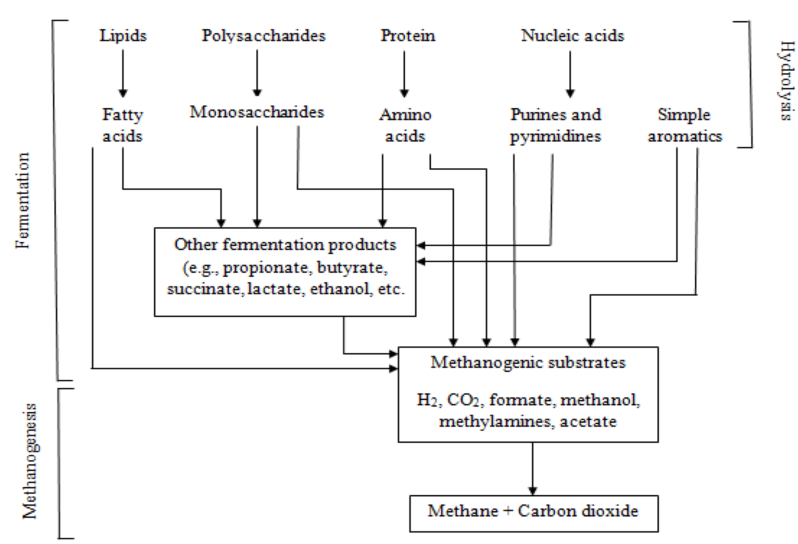

Figure 1: Detailed description of anaerobic digestion process [Bailey *et al.* (1987); Tchobanoglous *et al.* (2003)]

The mechanism of anaerobic treatment involves mainly three stages - conversion of solid waste containing insoluble organics to soluble organics in presence of *Proteolytic, Lipolytic and Cellulolytic* enzymes; microbial digestion of soluble organics to volatile fatty acids such as acetic, butyric, formic, propionic and short chain fatty acids in presence of acid producing bacteria (facultative anaerobes), finally conversion from volatile fatty acids and alcohol to methane and carbon dioxide. The second stage is referred acidogenesis, acting at pH values 4-6 at temperature 35ºC and third stage is methanogenesis at a pH value of 7-7.8 at temperature 35 - 40ºC. In the acidogenic step the microorganisms are enteric bacteria or clostridia species (*Peptococcus* anaerobes, *Lactobacillus, Actinomyces, Staphylococcus* and *Escherichia coli*) whereas in methanogenic step *Methanobacterium, Metanobacillus, Methanococuus, Methanothrix, Methanosarcina,* etc. are used (Rao *et al*., 1988; Singh-Nee *et al*., 1995; Singh *et al*., 1998; Panwar *et al*., 2002; Pratibha *et al*., 2004; Mishra *et al*., 2008). The details of all these mechanisms and process technology are available elsewhere Bailey *et al*. (1987); Tchobanoglous *et al.* (2003). Though large bodies of literature available on operational and design aspects of anaerobic digester there are some unprobed and unexplored aspects exist till today respect of treatment to different kind of wastes.

Effect of Cations

Various kind of wastes for anaerobic treatment differ in composition containing metal ions such as Na^+, K^+,Ca^+ influence the performance of anaerobic digestion process. It is very interesting to note that these are acting as a stimulant at low level of concentration (less than 100 mg/L) but act as a toxic at higher concentration (above 100 mg/L). Cation helps to sustain digester conditions in terms of alkalinity. Therefore, there is urgent need to examine the effect of metal ions on digester performance using sewage and distillery waste differing widely in their characteristics.
The main aim is to consider two kinds of wastes cited above is that they differ in terms of production of methane and carbon dioxide from volatile fatty acids, which is considered, is to be a rate determining step. Other minor products are H_2, CO, H_2S and NO. In fact, these compounds induce inhibitory effects and also increase toxicity. Another important consideration is inhibition by volatile fatty acids (Total volatile fatty acids and unionized form of volatile fatty acids) and ammonia. It is also well known that the rate limiting step of methane formation is affected by that formation of carbon dioxide, VFA and ammonia. However in what extent the digester is affected is largely unknown for both sewage sludge as well as distillery wastes. Therefore, enough scope exists to examine the effects of above mentioned parameters on the performance viz. stability of anaerobic digester.

Modelling

Modelling is very important in understanding the interrelation of different parameters pertaining to the system under consideration (sewage sludge and distillery waste) and therefore optimization followed by control. It further directs the designer through simulation, how better the design of the anaerobic digester is and to what extent further improvement is made possible. Therefore, development of model has become an essential step in process simulation. For anaerobic treatment various kinds of models are available. These are kinetic models, transport phenomena models based on equation of continuity and population balance models to quantify the population of microbial species. Kinetic model is generally employed to estimate the microbial growth kinetic parameters for all kind of waste as it varies from waste to waste. These data will take care of the kinetic part of the total transport phenomena model. Unfortunately, these data are sparingly available for sewage sludge because of its variability of composition. Whereas, not enough data is available related to microbial growth kinetics for distillery wastes.

From the survey of the kinetic models available for anaerobic treatment of sludge as well as distillery waste it is found that models due to Monod, Contois, Haldane, Andrews and Hill and Barth are most suitable for the present investigation. Whereas other models as mentioned in Table 2.1 are not amenable for analysis in the present case. The present work undertakes to estimate of the kinetic parameters of distillery wastes through scaling up the experimental results of many earlier investigators (Borja *et al*., 1993; Jimenez *et al*., 2003).

Modelling based on unsteady and steady state mass balance

There are many transport phenomena based models available in literature for different types of waste in anaerobic digester. These are due to Hill *et al*. (1977); Havlik *et al*. (1984); Moletta *et al*. (1986); Smith *et al*. (1988); Kiley *et al*. (1996) and many others. The studies on model stability enhancement by various researchers (Topiwala *et al*., 1971; Durate *et al.*, 1981; Bello-Mendoza *et al*., 1998; Azeiteiro *et al*., 2001; Beneventi *et al*., 2009) by considering wall growth factor (WGF) for sewage sludges. The above models though use the equation of continuity there is absence of models incorporating all the parameters at a place. Models from each investigator differ from each other and omit one step or the other. Hence, it is very important to develop a model incorporating all the aspects as mentioned in the previous models including their shortcomings.

Validation of the models

Every developed model requires validation from the experimental data or data available from literature. Therefore, without exception the present model also needs validation. Hence, attempt is to be explored to find out the way how best the present model predicts the accuracy and reproducibility of the data.

Simulation of the model

The dynamic model should be simulated through experimental results or obtained from published literature. Simulation predicts the time response of state variables of wastes, step changes of influent substrate concentrations, response to step changes in hydraulic retention time, pH and initial process conditions (Simunovic *et al*., 1995; Boresi *et al*., 2002; Dyka *et al*., 2005; Huang *et al*., 2005; Beneventi *et al*., 2010; Clement *et al*., 2011). The effect of various parameters on the response (percentage COD removal, methane formation and its corresponding flow rates) and the inhibition effect of ammonia, fatty acids on the performance and stability of digester.

All these aspects have not been explicitly dealt with in details by previous investigators in their respective models. Therefore, there is an urgent need to examine these factors on the overall performance of digester. Studies must be made to reexamine the interaction, gas phase, liquid phase and biological phase.

CONCLUSIONS

Research on the development of mathematical models for anaerobic digestion process is going on by considering various aspects. Efforts are being made by various researchers again and again for the development of model which fits better and well with the process operations. The present investigation has been planned to develop transient transport phenomena models across anaerobic digester taking into account most of the pertinent variables that instabilize process conditions with an aim to enhance the stability of digester.

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