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Mathematical Modeling and Simulation of Anaerobic Digestion of Solid Waste

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Abstract

Waste management and energy crisis are the greatest issues that the world is facing today. This problem can be overcome by anaerobic digestion of solid waste, where the waste is converted to biogas: a mixture of mainly carbon dioxide and methane gas. Because of the growing need of anaerobic digestion of solid waste, increased efforts in reducing biogas plant design cost and optimizing process operation is crucial. One way of doing this can be through mathematical modeling of the anaerobic process. The purpose of this paper is to use the Anaerobic Digestion Model no.1 (ADM1), which gives complete information about the physico-chemical reactions in the anaerobic process, to investigate how different parameters in the model affect biogas production. A model was implemented in MATLAB and can be used to find out how the factors such as pH and Volatile Fatty Acid (VFA) affect the daily biogas production.

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1. Introduction

Energy crisis and waste management are the major issues that the world is facing today. In order to overcome this problem, an efficient way of technology is needed. Organic fraction of solid waste is required to manage in such a way as to minimize the negative environmental impact, fewer hazards to human health and maintain ecological balance. Anaerobic digestion of solid waste is an effective technology that treats different types of organic waste.

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The main advantages of anaerobic digestion of solid waste are in terms of energy, cost, and ecological balance, which make this technology much better than other conversion process [1]. Different types of systems are available for the treatment of solid waste through anaerobic digestion, such as batch process, continuous process, single stage and multi stage process. The anaerobic digestion is one of the innovative technologies in the field of waste treatment. There are several varieties of researches undergoing in the field of waste treatment. The main aim of these researches is to analyze the parameters that will affect the production of biogas. There are a number of factors that affect the production of biogas, such as pH, Volatile Fatty Acid, temperature, quantity of substrate being used, and alkalinity. The level of these factors must be in correct proportion in order to keep the production of biogas in a particular level. Anaerobic digestion of solid waste is limited in developing countries due to the lack of proper treatment systems. Designing of reactor and selection of operational criteria depend on substrate characteristics and cost.

The anaerobic digestion of solid waste has a lot of applications over other conversion techniques. However, each mode of operation always has its own advantages and disadvantages. The purpose of this study is to develop a mathematical modeling of anaerobic digestion of solid waste and optimize the environmental condition such as pH, Volatile Fatty Acid, temperature for increasing the biogas production in a shorter retention time. Dynamic modeling and simulation is increasingly being employed as an aid in the design and operation of waste treatment especially in Europe. But most developing countries like India are still following conventional design technique based on the static models or empirical formulae derived either from past pilot scale studies or from performance of already existing waste treatment plant elsewhere. A dynamic model can be a useful tool for the prediction of process performance in transient conditions and for a better understanding of the process and its optimal working conditions. The main objective is to develop a mathematical model for the batch study of anaerobic digestion of Organic Fraction of Municipal Solid Waste (OFMSW). To achieve this objective we are adapting the default ADM1 for modeling and simulation of anaerobic digestion of organic fraction of municipal solid waste and calibrating the model using lab scale data from the batch study.

2. Mathematical modelling and simulation of batch reactor

2.1. Anaerobic Digestion Model No1 (ADM1)

Because of the growing need in anaerobic digestion of solid waste, increased efforts in reducing biogas plant design cost and optimizing process operation is crucial. One way of doing this can be through mathematical modeling of the anaerobic process. This is a fact that has been recognized by researchers for a long time. Between the years 1972 and 2006 there have been about 750 publications concerning mathematical modeling of anaerobic digestion. But evaluating the merits of every scientific model on anaerobic digestion available would be a daunting task. Therefore, in recognizing both the great potential benefits of a functional model and the need of a more widely accepted mathematical description of the anaerobic process, the international water association (IWA) formed a task group aiming at the creation of a mathematical model of anaerobic digestion. Quoting Batstone et al (2002), the full aims of the so called “Anaerobic Digestion Model no.1” (ADM1) [2] are: increased model application for full scale plant design, operation and optimization, further development work on process optimization and control, aimed at direct implementation in full scale plants, common basis for further development and validation studies to make outcomes more comparable and competitive, and assisting technology transfer from research to the industry.

The ADM1 model describes the five main biochemical steps (involving biological enzymes) in an anaerobic digester. It starts with disintegration, followed by hydrolysis, acidogenesis, acetogenesis and methanogenesis. Seen in fig.1.The process can be described by the following steps:

In the disintegration step, complex biomass molecules are broken down to lipids (i.e. fats), carbohydrates and proteins. In hydrolysis, molecules of carbohydrates, lipids and proteins are broken down to long chain fatty acids (LCFAs) amino acids and sugars. In acidogenesis, these LCFAs, amino acids and sugars are broken down to volatile fatty acids (VFAs), namely propionate, valerate, butyrate and some acetate. These VFAs are then transformed into acetate in the acetogenesis. This acetate is finally transformed into methane gas and carbon dioxide, in the methanogenesis.

All in all, there are 26 different compounds taken into account by the ADM1 model. An important group of components in the ADM1 model is biomass (i.e. anaerobic bacteria groups). In the ADM1 model, there are seven types of biomass [5] that degrade eight different components (long chain fatty acids, amino acids, sugars, valerate and butyrate, propionate, acetate and hydrogen). These biomass groups have different sensibilities to process disturbances. These disturbances are referred to as inhibition. Inhibition occurs when the uptake of a compound and growth of biomass is decreased. This can lead to a less efficient process, with lower methane yields or even a

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