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Different aspects of dry anaerobic digestion for bio-energy: An overview

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ABSTRACT

Dry anaerobic digestion (DAD) is an attractive method for the stabilization of solid organic waste with high solid concentration (22–40%). This article provides different aspects for bio-energy production through dry anaerobic digestion suggested by different researchers. Basic fundamental aspects like reactions occurring in the process, microbial species involved in the process, effect of feedstocks and operational parameters like pH, temperature, C/N ratio, VFA concentration, etc. with types of reactors are summarized. A number of scenarios and the effect of changing individual parameters of the environmental impacts of dry anaerobic digestion process for biogas production are considered. Mobility of mass nutrient and energy flow in the above said process are also parts of this review article. We conclude that long term research and development for improvement and optimization of operational parameters in dry anaerobic digestion is necessary.

Contents

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1. Introduction

Anaerobic digestion (AD) is a biological process that converts organic matter into a methane rich gas. It is a well established technology for the treatment of organic fraction of various waste materials [1–3]. Water has an important role in the controlling of the whole AD process. It is responsible for the growth of microbial population and also worked as a buffering agent for all the substrate and reactants. The AD process are classified in different ways such as on the basis of the reactor design, operating parameters such as pH, total solids (TS), volatile solids (VS) contents and biodegradability of substrate. In order to facilitate the above said process, recommended percentage of total solid in digester, can be categorized i.e. with low (< 15%), medium (15–20%) and high (20–40%) total solids [4–6]. Therefore, the wet anaerobic digestion system are characterized by total solids less than that 15% and dry system are characterized by total solids higher than 15%.

However, AD was found to be an attractive method especially in present time because it offers a spectrum of striking advantages [5]. This technology is very salient in Asian countries because of its suitable waste characteristics. Thus, anaerobic treatment provides a method of reducing pollution from various operations (agricultural, municipal and industrial operations). Among the biological treatments, AD is the most cost-effective, owing to the high energy recovery linked to the process and its limited environmental impact [6]. This process is considered as innovative and attractive technology for waste stabilization with significant mass and volume reduction with the generation of valuable by products such as biogas and fertilizer. The anaerobic digestion of biomass waste is now an established and commercially proven approach for treatment and recycling [7].

Wet Digestion requires the huge amount of water, which may be either equal or greater than the quantity of biomass. This result in a huge wasting of water, which should be avoided taking into consideration the condition of water scarcity in India. Also the high percentage of water present in the digested slurry severely decreases per unit volume nutrient value of manure, which hampers the transportation economics of manure. Drying of manure involves huge requirement of land and energy and also loss of its nutrient value. In this view, dry anaerobic digestion (DAD) is a process that is rapidly gaining momentum to new advances especially in the area of anaerobic fermentation and has become a major focus of interest in waste management throughout the world. The DAD performance is very robust as it allows very high production rates [8]. This process is more feasible to wide range of organic wastes including wastewater sludge from industries with the recovery of renewable energy and reduction in pollution load [9]. Application of this process is limitedly practiced especially in developing countries due to the lack of appropriate treatment system configurations and mainly due to the longer time required for the bio-stabilization of waste. In this regard, DAD is remarkable method that could offer potential by-products such as fertilizer and energy generation. The process also results in a lower production of leachate and easy handlings of digested residues that can be further treated by aerobic composting processes are used as organic fertilizer [10].

Dry Anaerobic Digestion (DAD) process is more popular nowadays among researchers and in corporate sector for laboratory scale and pilot studies because of its reduced cost and potential by-products. But, sometimes the process shows inhibition problem [11], which may be due to requirement of large amount of inoculums, long retention time [12], accumulation of VFA [13] and type of complex solid waste materials [14]. Therefore, to develop a suitable and feasible DAD process, it is important to review and suggest the improvement required for the sustainable approach. In this regard, various aspects of the process, operational parameters, environmental impacts of the process, economic analysis, mass balance and energy flow have been included in this article.

2. Basic kinetics involved in process

Anaerobic digestion of organic matters occurs in four steps, called as hydrolysis; acidogenesis; acetogenesis; and methanogenesis. There is a consortium of microorganisms such as acidogenic bacteria, acetogenic bacteria, and methanogens, etc., which are responsible in biogas production from organic materials. The organic matters are found in any waste in the form of polymers such as carbohydrates (cellulose, hemicelluloses, starch, etc.), oils, fats and proteins. In general, microorganisms are not capable to utilize these polymers because of large size of molecule, which cannot penetrate the cell wall of the microorganisms. Therefore, acidogenic bacteria produce extracellular enzymes such as cellulose, xylanase, amylase, lipage, proteolytic enzymes, etc., to hydrolyze these polymers. The carbohydrates, proteins and oils and fats are hydrolyzed into monomeric sugars, amino acids and fatty acids, respectively. An approximate chemical formula for the mixture of organic waste is $C_6H_{10}O_4$ [15]. The hydrolysis reaction can be written as [15]:

$$C_6H_{10}O_4 + 2H_2O \rightarrow C_6H_{12}O_6 + H_2 \quad (1)$$

The hydrolyzed organic compounds (monomeric sugars, amino acids and fatty acids) are utilized by the acidogenic or acid forming bacteria for their growth and accumulate volatile fatty acids such as acetic acid, propionic acid, butyric acid and valeric acid along with carbon dioxide, water and hydrogen, called acidogenesis. These bacteria are fast-growing with a doubling time of about 30 min. The accumulation of volatile fatty acids can be written as [15]:

$$C_6H_{12}O_6 \leftrightarrow 2CH_3CH_2OH + 2CO_2 \quad (2)$$

$$C_6H_{12}O_6 + 2H_2 \leftrightarrow 2CH_3CH_2COOH + 2H_2O \quad (3)$$

The volatile fatty acids except acetic acid such as propionic acid, butyric acid and valeric acid are again utilized by acetogenic bacteria for their growth and form acetic acid and hydrogen, called acetogenesis. These bacteria grow slowly with a doubling time of 1.5 to 4 days. The acetogenesis reaction can be written as [15]:

$$CH_3CH_2COOH + 2H_2O \leftrightarrow CH_3COOH + CO_2 + 3H_2 \quad (4)$$

Finally, methanogens utilize acetic acid, hydrogen and carbon dioxide and form methane gas, called methanogenesis. The