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Resource-Efficient Technologies 2 (2016) 143–147

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Research paper

Theoretical analysis of biogas potential prediction from agricultural waste

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Received 19 April 2016; received in revised form 9 August 2016; accepted 12 August 2016

Available online 23 August 2016

Abstract

A simplistic theoretical study of anaerobic digestion in order to predict the biogas amount of agricultural waste is proposed. A wide variety of models exist, but most of them rely on algebraic equations instead of biochemical equations and require many input parameters as well as computation time. This work provides a simplified model that predicts the biogas amount produced and could be applied for agricultural energy feasibility studies for instance dimensioning bioreactors digesting animal waste slurries. The method can be used for other feedstock materials and repeated for other similar applications, in an effort to expand anaerobic digestion systems as a clean energy source.

Keywords: Biogas; Anaerobic digestion; Animal slurries; Modeling

1. Introduction

Nowadays, the depletion of fossil fuels and the environmental compliance concerning the reduction of the greenhouse gases have attracted the interest in non-conventional fuel from bio-resources and -waste. Anaerobic digestion transforms waste material into valuable sources reducing in parallel the waste volumes [1,2]. Biogas is produced from anaerobic digestion and is considered a clean energy source for those who want an alternative energy pathway. Anaerobic digesters convert organic waste (waste water sludge, agricultural and food waste, animal and human manure) into energy (biogas). In addition, the digestate produced is a good soil additive and can be used by agricultural farmers in order to enhance crop production. The advantages from anaerobic digestion include energy production (biogas), material recovery (fertilizers) and waste elimination (waste treatment) [3,4]. Moreover, biogas production can enhance agricultural sector to overcome energy problems, increase the efficiency and of course to serve as a service taking account the environmental compliance [5–7] (Fig. 1).

The mathematical models can indicate digester performance capabilities and hence research efforts are currently focused on the development of advanced models with high accuracy level. Tomei et al. refer there is a wide variety of mathematical models for the description of anaerobic digestion ranging from steady-state to very complex dynamic models [9]. The most currently state-of-the-art model is the IWA ADM1 developed by the corresponding IWA Task Group. Batstone et al. described the capability of this model to predict the major processes occurring in an anaerobic digestion system, and acts as a unified base for modeling of anaerobic digestion [10]. Although efforts have been made in the modeling of anaerobic digestion by ADM1, various issues still remain unsolved. For instance, the kinetics involving hydrolysis is simplified in ADM1 by assuming first order kinetics. The majority of other parameters are assumed constant, given by the literature or by separate research. One specific case is the development of accurate models for the anaerobic digestion of solid waste. Moreover, issues like co-digestion or microbial community data have to be taken into account in order to develop more precise and accurate models [11,12].

However, our study focuses on biogas potential using a simplistic model in order to define the theoretical total amount of biogas that can be generated from agricultural material. The theoretical amount of biogas that can be produced from a feed can be calculated from the relative amounts of carbon, hydrogen, oxygen, nitrogen and sulfur in the material (Boyle's formula). Not all of the biomass materials can be processed. This model could help to achieve widespread utilization of the

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http://dx.doi.org/10.1016/j.reffit.2016.08.001

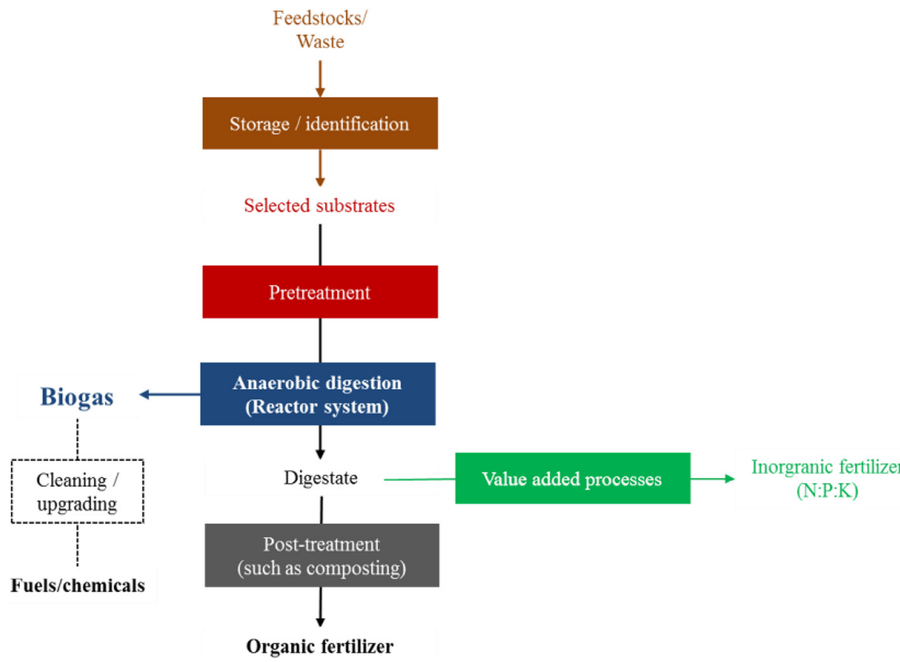

Fig. 1. Overview of AD technology [8].

large body of knowledge of anaerobic process available from research studies and operational experience in small agricultural farms.

2. Materials and methods

To apply this model to a specific feedstock, we need to know the chemical components of the feedstock. The model considers only carbon, hydrogen, oxygen, nitrogen and sulfur as input elements, and the relative ratios of these elements can be taken from published values for ultimate analyses of those waste.

Table 1
Composition of the feedstocks based on ultimate analysis from literature data [13–16].

Feedstock	Chicken litter (dried)	Swine solids (dried)	Feedlot manure (dried)
Ultimate analysis, %			
C	45.32	47.3	45.39
H	5.85	5.9	5.35
O	27.38	20.1	30.98
N	5.16	4.58	0.96
S	0.45	0.93	0.29
P	–	–	–
Cl	0.35	–	1.16

Table 1 below includes the values of ultimate analyses for the agricultural waste used in this study based on literature data.

The composition of animal slurries depends on the type of animal, the feed they are given, and the external conditions that they are in. Because of the variation in waste composition for different types of each animal in different conditions, only one set of published values for ultimate analysis is used instead of averaging over published values. Agricultural wastes are very complex mixtures and different approaches are used to describe their composition. The elemental composition used here is the most basic method to describe the non-aqueous components of the waste. This model aims to provide a balance between simplicity and effective biogas prediction. The purpose is not to create a model that takes all factors into account and predicts biogas output to a very high level of precision (Fig. 2).

It can predict biogas output assuming that a reaction goes to completion. Knowledge on the biodegradation of organics and methane production is necessary in the prediction of reactor performance under varying operational conditions. In this study, a simple model is used in order to estimate the theoretical biogas potential. This model has to be applicable for agricultural small-scale activities in order to determine the digester size [17,18].

There is a wide variety of models developed so far and for this reason is required a convergent action to consolidate the

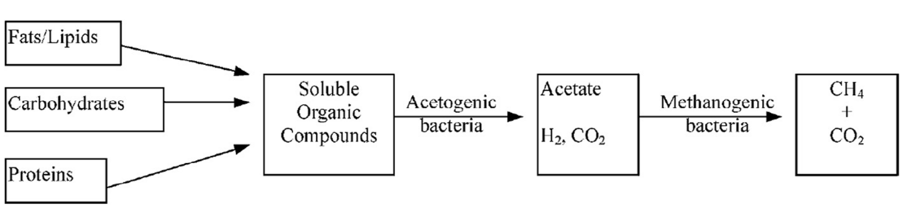

Fig. 2. Schematic biochemical process stages of anaerobic digestion. Adopted form the source [17].