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Theoretical methane production generated by the co-digestion of organic fraction municipal solid waste and biological sludge

A. Nielfa, R. Cano, M. Fdz-Polanco *

Universidad de Valladolid, Chemical Engineering and Environmental Technology Department, Prado de la Magdalena 47011, Valladolid, Spain

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ABSTRACT

The co-digestion of two problematic and available wastes, namely Organic Fraction Municipal Solid Waste (OFMSW) and biological sludge, was carried out in this work. Biochemical Methane Potential (BMP) tests are a useful tool for determining the best substrate and co-digestion configurations, however there are some methodologies destined to save costs and time from this process by using the theoretical final methane potential of a substrate from its organic composition. Besides there are some models capable not only of reproducing the methane curve behavior, but also of predicting final methane productions from the first days of experimentation. Methodologies based in the elemental composition for the determination of theoretical production fit better with the experimental results and behavior, nevertheless the Gompertz model was capable of predicting the final productivity within the 7th day of experiment, selecting at the same time the co-digestion of 80% OFMSW and 20% Biological sludge as the optimum.

1. Introduction

In Spain about 18 million tons per year of organic fraction municipal solid waste (OFMSW) were produced during the year 2011 [20]. At the same time, the amount of biological sludge from waste water treatment plants (WWTP) is growing with the increase in the volume of treated wastewater, and the management of biological sludge has thus become an environmental and economic issue [29].

The anaerobic digestion (AD) of biological sludge and OFMSW contributes not only towards achieving the aim of the European directive [29], but also provides a route by which some of the energy inherent in this material can be recovered [28]. Moreover, the AD process offers the possibility to recycle nutrients, reduce greenhouse emissions, reduce odors and controlled waste disposal [2].

The anaerobic co-digestion of organic wastes has several advantages: the economical scale can increase as the quantity of waste increases; inhibitory compounds are diluted; the diversity of bacterial species increases due to the nutrition from a wide variety of organic wastes and helps stabilize a digester ecosystem [10,18]. The numbers of co-digestion plants are continuously increasing in many European countries and have become a standard practice [7].

Besides, researchers have been studying the co-digestion of OFMSW and biological sludge with different waste and mixture proportions; Hartmann et al. [19], consider the co-digestion of OFMSW and manure, establishing a mixture ratio of 50% VS as optimum, while Fernandez et al. [16], compare the co-digestion of OFMSW with fats from vegetable and animal origin. For biological sludge, its co-digestion with tanning residues were studied by Di Berardino and Martinho [14], revealing this to be technically feasible and economically advantageous and Komatsu et al. [23] obtained increases from 66% to 82% with the co-digestion of sewage sludge and rice straw using a mixture ratio of 1:0.5 based in TS.

Biological sludge and OFMSW are two available wastes with a high methane potential due to their high VS solid content, especially OFMSW, whose inherent problems derived from landfilling or incineration could be solved by the co-digestion process. Several studies had determined the optimum mixture ratio for these two substrates: Kim et al. [22] determine an optimum ratio of 50% VS for both substrates, Sosnowski et al. [33] define a 75% dw biological sludge and 25% dw for OFMSW as optimum, La Cour jansen et al. [25] explain how the mixture of 80% VS for sewage sludge and 20% for OFMSW is the best option and Cabbai et al. [9] studied ratios in volatile solids (VS) of 0.23 and 2.09 gVS/gVS for biological sludge with good results. Then, a depth study is needed, in order to optimize the substrates mixture ratio, the parameters involve in the biodegradation process and the kinetic parameters.

The biochemical methane potential (BMP) tests are applicable when used to expose which types of substrates, from a variety of

* Corresponding author. Tel.: +34 660901929.
E-mail addresses: anielfa@iq.uva.es (A. Nielfa), maria@iq.uva.es (M. Fdz-Polanco).

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Nomenclature

λ	Lag-phase parameter (days) from Gompertz model
γ	Maximum volume accumulated ($mlCH_4/gVS$) from Gompertz model
μ	Specific microorganisms growing speed (d^{-1})
α	Synergistic effect
AD	Anaerobic digestion
BD	Biodegradability
BMP	Biological methane potential
BMP_{th}	Theoretical BMP
bmp_{exp}	Experimental BMP
COD	Chemical oxygen cemand
COD_t	Total chemical oxygen demand
K	Kinetic parameter ($mLCH_4/gVS/d$) from Gompertz model
n_{CH_4}	Amount of molecular methane (mol)
OFMSW	Organic fraction municipal solid waste
P	Maximum biogas production parameter ($mLCH_4/gVS$) from Gompertz model
p	Atmospheric pressure (atm)
R	Gas constant (atm L/mol K)
T	Temperature (K)
t	Time (days) from Gompertz model
TS	Total solids
UVa	University of Valladolid
VS	Volatile solids
WWTP	Waste water treatment plant

possibilities, have the highest biochemical potential. In addition BMP assays can be used to estimate the optimum ratios between co-substrates when co-digestion is intended [24].

Waste has a complex composition which is difficult to describe in detail but can be readily analyzed by bulk chemical processes [2]. Some works have concluded that the organic matter composition in the substrates has a strong impact on AD performances, showing the existence of a relationship between the quantity of methane produces and the organic matter used, not only the biodegradable fraction but also the non-biodegradable fraction [27]. Examples of approaches for obtaining quick BMP results include the use of empirical relationships based on the chemical and biochemical composition of the material [34]. The theoretical methane potential is widely recognized in order to give an indication of the maximum methane production expected from a specific waste [2], although the experimental methane yields are often much lower than theoretical yield due to the difficulty in degrading tightly lignocellulosic material [30]. Several methods could help to determine theoretical methane potentials based on chemical oxygen demand (COD) characterization [35]; elemental composition [32] or organic fraction composition [27]; however, these methods do not provide any information about the kinetic parameters involved in the process.

It is commonly known that well-controlled batch degradation follows certain patterns that can be modeled using a mathematical expression. Therefore, another way to obtain quick BMP results, which includes the kinetic information, is the use of mathematical prediction models [34].

The objective of this research paper is to present and evaluate strategies for predicting the BMP of the co-digestion of OFMSW and biological sludge using several approaches and two mathematical models, to save time and costs derived from the BMP tests, and to optimize the co-digestion ratios for these two substrates for subsequent experiments in full scale digesters.

2. Materials and methods

Several experiments were carried out using BMP tests at mesophilic conditions in order to evaluate the optimum ratio for the co-digestion of OFMSW and biological sludge, and thus estimate the increase or diminution of productivity from the sole substrates. A variety of co-digestion mixtures were selected for this work in order to cover all the possibilities that allow co-digestion in both real WWTP or waste treatment plants, in order to achieve the optimum conditions for obtaining the best productivity and kinetics.

2.1. Substrates and co-digestion mixtures

A synthetic substrate simulating the OFMSW and a biological sludge from the WWTP were used for the assays. In order to avoid the heterogeneity that real OFMSW can offer and thus evaluate the optimum mixture ratio for these two substrates, a synthetic OFMSW was considered. This synthetic fraction was composed of several organic and inorganic materials. The proportions of mixture were determined from previous studies in which the use of synthetic mixture obtained good results [6]. A typical characterization of a real OFMSW can be observe in Table 1.

The co-digestion of biological sludge and OFMSW has been considered by some authors without existing an agreement according to the optimum mixture, then a large range of ratios have been considered in this study using weight percentages to get the desired mixtures. The concentration of each co-digestion has not being modified in order to study the problems derived of the TS concentration.Table 2 shows the four different co-digestion mixtures that were considered in this work.

A full characterization of the substrates, co-digested mixtures and the inoculum used for the experiments are presented in Tables 3 and 4. The characterization of the co-digestion mixtures was obtained from the theoretic mixture of the sole substrates OFMSW and biological sludge.

2.2. Analytical methods

The main characterization of the inoculum and the co-substrates was accomplished following an internal method of the University of Valladolid (UVa) based on standard methods [3]. Total and volatile solids (TS, VS) and total chemical oxygen demand (CODt) were determined.

To calculate the theoretical potential using several methodologies, an extended characterization is necessary performed by external laboratories. Gravimetric techniques were used to determine grease content [15,12] and gross fiber (Weende Method), volumetric procedures [12] for carbohydrate content, and elemental analyses [31] for protein content and elemental composition.

2.3. Experimental biochemical methane potential (BMP) tests

The BMP assays were performed following an internal method from the UVa based on standardized assays for research purposes

Table 1
MSW typical characterization.

CODt	g/kg	542
CODs	g/kg	92
TS	g/kg	468
VS	g/kg	394
pH[a]		7.8
Phosphorus[a]	dw%	0.002
Sodium[a]	dw%	4.8
Potassium[a]	dw%	0.35

[a] Source: [38].