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Anaerobic digestion modeling of the main components of organic fraction of municipal solid waste

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ABSTRACT

The organic fraction of municipal solid waste (OFMSW) is composed of several heterogeneous organic and inorganic wastes. The diversity of composition, the high volatile solid content and the biodegradable material that this waste offers make it quite an interesting option for anaerobic digestion (AD). Depending on the substrate composition, the biological degradation and kinetics of the AD could vary. Biochemical methane potential (BMP) tests are used as a tool to evaluate the methane production of several fractions of OFMSW, in order to study the influence of each fraction in the final mixture. The kinetic parameters of methane curves and the prediction of final productions are studied by different approaches to model equations using linear, exponential, logistic and Gaussian models. The analyses of the fractions indicate that organic substrates such as meat/fish which are in a small proportion in the final mixture, obtain major productivities (291 ± 3 mlCH$_4$/gVS), however others such as paper (217 ± 5 mlCH$_4$/gVS) could have their productivity enhanced due to their high VS present in the final mixture. Both the Gomperzt and the first order model fit reasonably with all the fractions, although substrates with lag phase adjust only to the Gompertz model explaining 99% of the experimental results.

1. Introduction

The organic fraction of municipal solid waste (OFMSW) is the single largest component of the waste stream by weight in Europe. About 22.4 million tons of municipal solid waste were collected in Spain during the year 2012 with just 4.1 million corresponding to separated wastes (INE, 2012). OFMSW is a common name for heterogeneous waste mixtures from

Abbreviations: μ, microorganisms growing speed (d^{-1}) for first-order model; γ, maximum volume accumulated (mlCH$_4$/gVS) for first-order model; α, fraction of non-biodegradable substrate for biogas generation model; λ, lag-phase parameter (d) from Gompertz model; AD, anaerobic digestion; BMP, biological methane potential; BSA, bovine serum albumin; CODs, soluble chemical oxygen demand; CODt, total chemical oxygen demand; FO, first-order model; GE, Gaussian equation; GM, Gompertz model; K, kinetic parameter (mlCH$_4$/gVS/d) from; MWS, municipal waste sludge Gompertz model; LF, logistic function; OF, organic fraction (fruit/vegetable, meat/fish, cereal); OFMSW, organic fraction of municipal solid waste (fruit/vegetable, meat/fish, cereal, garden, plastic, paper); P, maximum biogas production parameter (mlCH$_4$/gVS added) from Gompertz model; t, time (d) from Gompertz model; TKN, total Kjeldahl nitrogen; TS, total solids; VS, volatile solids.

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residential, commercial, partly industrial and urban areas. It is made up of different organic and inorganic fractions such as food, vegetables, paper, wood, plastic, glass, metals and other inert materials. Despite the variability in its composition, the organic content constitutes the highest percentage of the solid waste which can be broken down into simpler compounds by anaerobic microorganisms (Bilgili et al., 2009). This waste is of particular interest for anaerobic digestion (AD) due to the high volatile solids (VS) that the organic fraction offers (Fantozzi and Buratti, 2011).

The AD of OFMSW has attracted much interest in recent years (Fdez-Güelfo and Álvarez-Gallego, 2011). AD presents interesting advantages compared to traditional aerobic treatment such as the high capacity to break down slowly degradable substrates at high concentrations, short hydraulic retention times, very slow sludge production, limited energy requirements and energy recovery through methane combustion (Aguilar-Garnica et al., 2009).

OFMSW is typically very diverse in nature. Its anaerobic degradability depends on its composition, in terms of carbohydrates, proteins, lipids and slowly degradable fractions such as lingo-cellulose. The composition of the particulate substrates is considered to be the limiting factor in a high-solid system, as a result of the effect of these particles on the hydrolysis process, as hydrolysis rates differ significantly for different particulate components (grease, proteins, and carbohydrates). Subsequent biological degradation kinetics also differ with the substrate composition, because each of the successive hydrolysis products is degraded by different a bacterial population (Zaher et al., 2009).

There are few studies addressing the anaerobic biodegradability of mixtures of proteins, carbohydrates, and lipids: Breure et al. (1986) investigated the influence of high concentrations of carbohydrates; Kuang (2002) investigated the influence of canola oil, starch, and yeast extract using different mixing ratios on methanogenesis in an up-flow anaerobic sludge blanket reactor; Tommaso et al. (2003) studied the influence of the carbohydrate and lipids on anaerobic degradation of bovine serum albumin (BSA) in an immobilized horizontal-flow anaerobic biomass reactor fed with BSA based substrates.

Theoretical and experimental studies have attempted to estimate the biogas yield from solid waste. The biochemical methane potential (BMP) test is a valuable, quick and inexpensive method for the determination of the potential rate and extent of the conversion of wastes to methane and in the assessment of which material can be digested (Owen et al., 1979; Gunaseelan, 1997; De la Rubia et al., 2011).

The development of adequate models and their parameterization by fitting the model equation to experimental results obtained in specific assays is a very important task (Fdez-Güelfo and Álvarez-Gallego, 2011). Mathematical models have been used since the 1960s to describe anaerobic digestion (Lawrence and McCarty, 1969). Due to the role of microbes in the anaerobic digestion process, kinetic models, in particularly the first order, are commonly applied to simulate AD (De Gioannis et al., 2009; Kumar et al., 2004). In addition, biogas accumulation could be simulated by an exponential rise to the maximum as well as the modified Gompertz equation commonly used in the simulation of methane and hydrogen production. So far, the investigations using OFMSW have rarely been undertaken (Banks and Lo, 2003; Lo, 2005; Boni et al., 2007; Lo and Liao, 2007; Lo et al., 2009).

The objective of this paper is double; firstly it aims to evaluate the influence of each fraction in the final mixture of OFMSW in order to optimize the properties and characterization, and thus enhance the biodegradability of this waste. Secondly, the purpose of this research is to compare the experimental results obtained when operating BMP tests treating OFMSW and their components in terms of the kinetic constants and methane potentials of several mathematical models. The comparison also aims to show the relative advantages of using diverse modeling tools (Gaussian equation, first order model, Gompertz model or logistic function).

2. Material and methods

2.1. *Substrate and inoculum*

All the fractions that compounded the final mixture of OFMSW were evaluated by BMP tests separately. At the same time, both the final mixture (OFMSW) and the mixture of organic fractions (OF), which is composed only of food (fruit/vegetable; meat/fish; cereal), were also submitted to BMP tests. For all the assays, both a synthetic mixture and fractions were obtained and tested, in order to establish a distinctive substrate for all the experiments, always using the same waste as an equivalent fraction for each measure of fruit, vegetable, meat, fish, cereal, plastic, paper or garden. Given the small amount of substrate that should be used for these tests and the heterogeneity that real OFMSW could provide, this mixture offers the perfect conditions for evaluating and comparing other parameters that could have an influence on the biodegradability process. The different proportions for achieving a mixture comparable to the real one were taken from related studies (Boulanger et al., 2012), where previous research works confirm the similarity of this mixture to existent OFMSW. The characterization of the substrates and their proportion in the mixture is presented in Table 1.

2.2. *Biochemical methane potential tests*

The BMP assays were performed following an internal method from the University of Valladolid (UVa) based on standardized assays for research purposes (Angelidaki et al., 2009). Glass bottles of 2 L capacity were used to carry out the tests. The substrate and a mesophilic inoculum coming from a reactor fed with mixed sludge were introduced following a substrate/inoculum ratio in terms of VS (1 gVS substrate/1 gVS inoculum) for all the assays. This ratio was selected as the optimum in previous works, meaning that due to the high VS contained by the substrates, it would contain a larger quantity of inoculum than substrate. Also, some macronutrients and micronutrients were added to ensure the activity of the inoculum (Field et al., 1988). Once the bottles were closed they were placed in a rotational stirrer (5 rpm).

Tests were carried out in triplicate, including a blank to evaluate the final production of the inoculum and obtain the net production in each test; and a control with cellulose simply to determine if the inoculum works normally in case there is any inhibition problem. Periodical monitoring analyses of biogas production, using a pressure meter, and of biogas composition, using gas chromatography, were performed during the tests and therefore a result of less than 1% of the whole production would indicate the end of the experiments.

Methane potential is expressed here as the net volume of methane per g of initial substrate VS content (mlCH_4/gVS added). These results were obtained from the triplicate