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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

Table 1 – OFMSW main and specific characterization of the substrates evaluated by BMP tests. Values in bold indicate major content of lipid, carbohydrate, protein and fiber for each substrate.

		Proportion in OFMSW % (weight)	Proportion in OFMSW % (VS)	TS (g/kg)	VS (g/kg)	CODt (g/kg)	NH_4^+ (gN/kg)	Lipid (g/kg)	Carbohydrate (g/kg)	Protein (g/kg)	Fiber (g/kg)	C/N
	OFMSW		–	461	386	468	–	6	172	125	**253**	103
	OF	56.4	19.5	138	134	150	0.44	19	**448**	174	58	21
	OF											
	Fruit/veg	41.7	11.1	108	103	127	0.17	4	190	187	125	25
	Meat/fish	3.9	2.5	253	241	371	2.47	**28**	<1	**876**	<1	4
	Cereal	10.7	6.1	221	220	370	0.53	1	**833**	58	<1	47
OFMSW	Paper	27.7	52.5	940	731	843	0.31	6	8	9	**663**	296
	Garden	7.5	8.7	508	449	626	4.35	14	18	55	225	66
	Plastic	8.4	19.2	998	886	155	–					

average for each assay. A standard deviation was also calculated in order to identify the error among the triplicates.

2.3. *Synergistic effects*

To evaluate the influence of each substrate in the final mixtures and calculate the possible synergistic effects that could be produced during the biodegradation process, the subsequent Eq. (1) was followed (Arribas et al., 2012):

$$\alpha = \frac{\text{Experimental production}}{\text{Theoretical production}} \tag{1}$$

The “Experimental production” is the result of the BMP tests for the different mixtures while the “Theoretical production” refers to the final values of the mixture obtained from the BMP tests of each raw substrate considering the VS of each substrate contained in the final mixture. The result of α indicates the following:

- $\alpha > 1$; the mixture has a synergistic effect in the final production.
- $\alpha = 1$; the substrates work independently from the mixture.
- $\alpha < 1$; the mixture has a competitive effect in the final production.

2.4. *Model comparison*

Models based on kinetic parameters enable the effect of the most important process variables on systems performance to be predicted (Fdez-Güelfo and Álvarez-Gallego, 2011). The fitting of model equations to experimental results obtained in specific assays is a very important tool in determining the optimum substrate and operational conditions. Biogas production rates of OFMSW AD were simulated using linear, exponential, logistic and Gaussian equations (Table 2). The solver method from excel was chosen as the linear programming tool in this work.

For the aforementioned Table 2 the following parameters are presented where P ($mlCH_4/gVS$) is the biogas production rate at time t (d) over the digestion period; γ ($mlCH_4/gVS$) is the maximum volume accumulated at an infinite digestion time; μ (d or d^{-1}) is the specific microorganisms growing speed; K ($mlCH_4/gVS/d$) is the specific rate constant; t_0 is the initial time (d) and λ (d) is the lag phase in the logistic and Gompertz equations.

2.5. *Analytical methods*

For the analytical and characterization methodologies an internal protocol based on standard methods (APHA, 2005) was used to determine the most significant characteristics of the inoculum and the substrate (total and volatile solids TS, VS; total and soluble Chemical Oxygen Demand CODt, CODs; Total Kjeldahl Nitrogen, NKT).

In order to study the influence of the composition in terms of proteins, carbohydrates, lipids and fiber, an extended characterization was carried out using gravimetric techniques (EPA, 1664; CE regulation 152/2009) for grease and fiber, volumetric procedures (CE regulation 152/2009) for carbohydrates and elemental analyses (IT-MA-014 AOAC) for protein determination.

Table 2 – Models applied in order to evaluate its accuracy comparing to the BMP tests.

Reference	Equation	Characteristics
Lo et al. (2010)	$P = \gamma * \exp\left(-0.5 * \left(\frac{(t-t_0)}{\mu}\right)^2\right)$ (2)	Gaussian equation (GE) in which the biogas production rates and microbial kinetics growth and decay follow the normal distribution over the digestion period.
Bilgili et al. (2009), De Gioannis et al. (2009)	$P = \gamma * (1 - \exp(-\mu t))$ (3)	First-order model (FO) in which biogas accumulation was simulated using exponential rise to a maximum.
Lay et al. (1997)	$P = \gamma - \exp\left(-\exp\left(\frac{k}{\gamma}(\lambda - t)e^1 + 1\right)\right)$ (4)	Modify Gompertz model (GM) assuming that the rate of gas production is proportional to the microbial activity.
Altas (2009)	$P = \frac{\gamma}{(1 + \exp(4 * (k/\gamma) * (\lambda - t) + 2))}$ (5)	Logistic function (LF) fitting the global biogas production kinetics with an initial exponential increase and a final stabilization at a maximal production level.

2.6. *Experimental procedure*

The biodegradability of OFMSW, the corresponding organic fraction (OF) and the different substrates that form the final mixture of OFMSW were evaluated individually using BMP tests. Once the assays were finished, the main parameters were analyzed to evaluate the effectiveness of the process, taking into account the removal results.

All the results were submitted to a modeling process in order to confirm the accuracy of the data obtained, and to compare the necessary parameters of a model equation made to fit with this kind of substrate.

2.7. *Statistical analysis*

The BMP tests were carried out in triplicate. The deviation of each assay from the average was considered and represented with the methane curves to indicate the consistency of the BMP experiments. In addition, to determine and compare the accuracy of the experimental results with different models, a regression coefficient and the relative error were calculated (Eq. (6)) by comparing the experimental and prediction productivities for each model, in order to select the optimum model equation. Statistical methods were performed using excel software.

$$\text{error} = \frac{BMP_{exp} - BMP_{th}}{BMP_{th}} \quad (6)$$

3. Results and discussion

3.1. *Test modeling*

The experimental results of the BMP tests were submitted to the previously explained models (Table 2) to determine the optimum fitting of the BMP tests to a specific model equation and to examine the methane curves through the kinetic parameters presented in Table 3.

The Gaussian model could give a slight approach of the productivity, but generally does not fit with the experimental data, with values of r^2 below 0.90 in all cases. Nevertheless, substrates such as garden, paper or meat/fish, with a slow increase in biogas, fit better than other substrates with higher kinetics at the start of the assay. The first order model, modified Gompertz equation and logistic function offer some information through kinetic parameters and methane potentials to the results obtained, such as the growing speed of microorganisms (μ) or a period of lag phase (λ) which is only in evidence in some substrates. Meat/fish and paper, whose methane curves show slower kinetics during the first days, fit better with the Gompertz or logistic model (regression coefficients of 0.99). This indicates the need for an additional parameter in the equation (λ) to achieve the perfect adjustment for some of the substrates that could have a lag phase or an adaptation period. Observing the specific rate constant (K) in both the Gompertz and logistic models, it is clear that the kinetics are equivalent in both equations, and that there is correspondence between the higher biodegradability kinetics with OF and fruit/veg which obtain half of their methane production in the first days. Similar behaviors patterns are obtained for simplified models for these two substrates with higher values for μ. This data validates the accuracy of the application of the model equation to the experimental results. Even though the final production is higher for wastes such as meat/fish or paper, they have a lag phase period that slows down the process.

Looking at the consistency of the two models GM and FO for BMP results these two models are represented in the following Fig. 1, indicating the experimental (dots) and modeling (solid line) data in order to compare the main kinetic parameters and methane potentials. The standard deviation calculated from the results of the triplicates is also represented showing the consistency of the experiments.

Generally there is an overall agreement between the models and the experimental data. Even in comparison with the r^2 results, the first order model obtains slightly better results, reaching the highest regression coefficients in most of the cases (results over 0.96). This means that this model might explain the 96% of the total variation in the experimental data as it is represented in Fig. 1. Due to the mixed culture of several microbial species, there will be different specific growth rates (μ) between substrates and, as a consequence, the relative proportion of the different species can vary with time. This is the case of fruit/vegetable or OF that obtain higher values of μ ($0.39\,d^{-1}$ and $0.47\,d^{-1}$ respectively) when analyzed alone than in the final mixture of OFMSW with values of $0.24\,d^{-1}$ for μ.

Looking at the shape of the modeled curves for the Gompertz equation, it is observed initial values for P distinct to 0 have been observed in substrates with imperceptible or null

Table 3 – Parameter estimation for the applied models. Values in bold and italic indicate optimal and pessimal data respectively.

	MODEL	γ (mlCH$_4$/gVS)	μ (d)	μ (d^{-1})	K (mlCH$_4$/gVS/d)	λ (d)	r^2
OFMSW	GE	90	20.52	–	–	–	0.80
	FO	140	–	0.24	–	–	**0.99**
	GM	135	–	–	26.23	0.37	0.98
	LF	133	–	–	28.23	0.65	0.97
OF	GE	118	23.10	–	–	–	0.75
	FO	183	–	0.47	–	–	**0.98**
	GM	179	–	–	47.94	0.00	0.97
	LF	178	–	–	48.32	0.12	0.96
Fruit/veg	GE	94	22.96	–	–	–	0.73
	FO	148	–	0.39	–	–	**0.98**
	GM	150	–	–	43.79	0.00	0.97
	LF	149	–	–	44.93	0.17	0.96
Meat/fish	GE	310	16.83	–	–	–	0.89
	FO	367	–	0.06	–	–	0.95
	GM	299	–	–	21.42	2.54	**1.00**
	LF	292	–	–	21.74	3.14	0.99
Cereal	GE	108	18.90	–	–	–	0.88
	FO	166	–	0.2	–	–	**0.98**
	GM	158	–	–	24.59	0.13	0.96
	LF	155	–	–	25.62	0.38	0.94
Garden	GE	57	17.24	–	–	–	0.95
	FO	75	–	0.12	–	–	**0.98**
	GM	57	–	–	2.68	0.00	0.91
	LF	68	–	–	5.85	0.00	0.92
Paper	GE	185	17.29	–	–	–	0.86
	FO	235	–	0.1	–	–	0.98
	GM	216	–	–	17.98	0.68	**0.99**
	LF	211	–	–	18.36	1.16	0.98

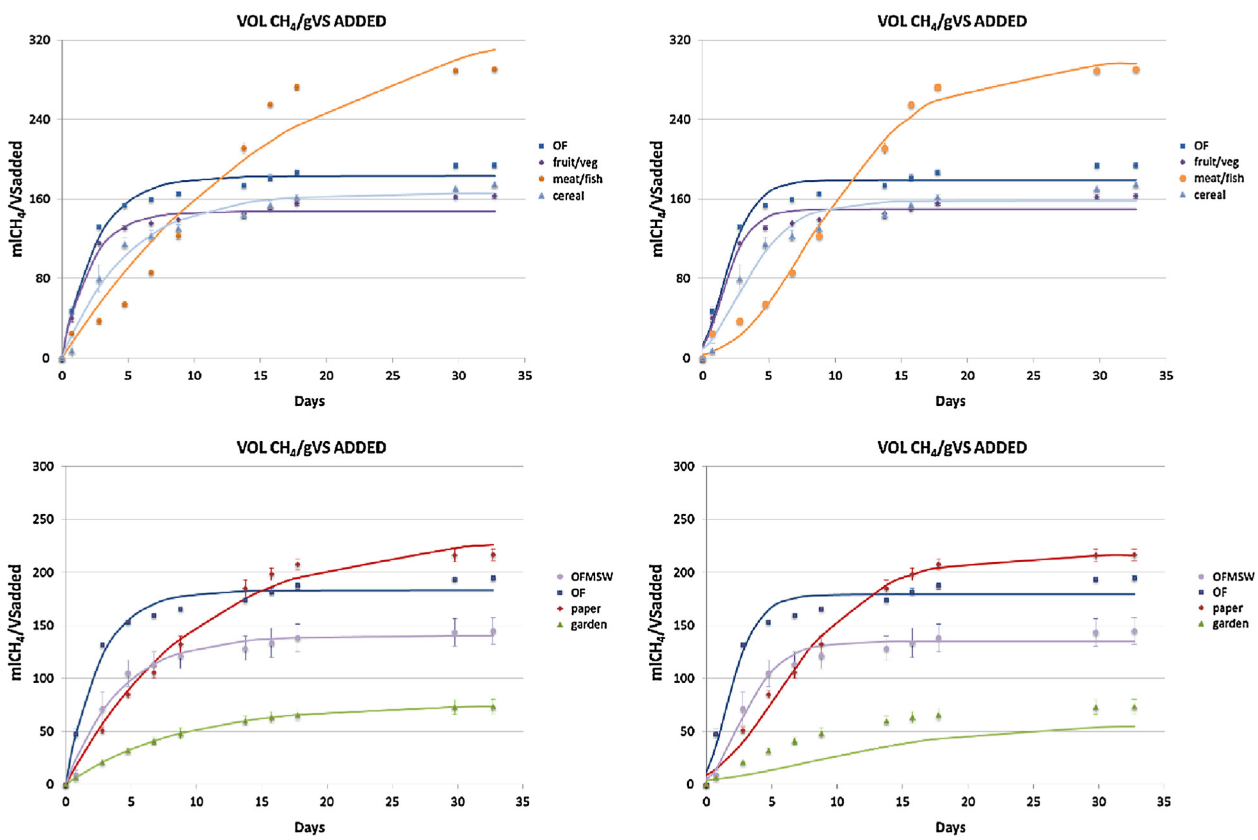

Fig. 1 – Model comparison. First-order model left and Gompertz model right. Experimental results are represented by dots while modeling results are indicated by lines.

Table 4 – Synergistic and competitive effects of the final mixtures.

	Experimental production	Theoretical production	α
OFMSW	145 ± 12	156	0.93
OF	194 ± 3	185	1.05

values of λ, such as OF with initial values of 11.82 $mlCH_4$/gVS. There is also a notable difference among models for substrates with low biodegradability such as garden, whose progressive curves are difficult to model with Gompertz and logistic equations, although first-order model obtains regression values of 0.98. A comparison between four models was also done by Donoso-Bravo et al. (2010), who used Gompertz, transfer, logistical and first order equations applied to the biogas production from anaerobic batch tests for primary and secondary pre-treated sludge.

In spite of the results obtained, Gaussian equation, Gompertz model and logistic function showed worse agreements with the experimental data than the first order model which, as the r^2 indicates, is more consistent and describes better the evolution with time in the AD process. Besides, by using this model, the maximum biogas production rate can be calculated accurately for batch AD being also useful as prediction tool.

3.2. *Study of the fractions of OFMSW*

The following study is established taking into account the modeling results of Gompertz and first order models depending on the fitting of each substrate. Then, substrates such as meat/fish are represented better by GM while the rest of substrates can be explained by FO.

The BMP results indicate that wastes as meat/fish or paper obtain the highest productivities (291 and 216 $mlCH_4$/gVS respectively) although the mixture with other wastes reduces the methane potential, obtaining lower values for OFMSW (194 $mlCH_4$/gVS) and OF (145 $mlCH_4$/gVS).

The mixture of different substrates could produce changes in the final production due to synergistic effects, which would explain its behavior (Table 4). The theoretical production is calculated considering that the volatile solids of the substrates involved in each mixture worked independently, and their individual production rates are maintained constant in the final mixtures. Then, considering the previous equation, the results of α indicate that the mixtures have a competitive effect in the final production of the total mixture (OFMSW) while in the OF a slight positive synergistic effect is produced with the mixture of the organic material, obtaining also better experimental productivity.

The synergy of the OF is due only to the mixture of *food fractions*. The high productivity of meat/fish is supported by its composition of lipids (28.04 g/kg) and proteins (876.12 g/kg), however this substrate also has slower kinetics due to its lipid content. The kinetics for meat/fish indicate a slow biodegradability during the first ten days while other food fractions such as fruit/vegetable or cereal had obtained half of their productivity on the third day of experiment. The lipid material that this substrate contains makes it biodegradable slowly, with an adaptability period for the inoculum of three days, as is indicated in the Gompertz model, after which the increase of the productivity begins. Nevertheless, its slight contribution to the final OF (12.6%VS) does not play a part in enhancing the final production, while other substrates with lower productivities such as fruit/vegetable or cereal have more influence (57%VS and 31%VS respectively). The cereal fraction reaches greater productions than that of fruit/vegetable since it has higher CODt, although the specific growing rate is 40% better in fruit/vegetable. Meat/fish achieves also good methane percentages of 70% while the rest of the organic substrates and the final mixture OF get only reach 60%. *Other fractions* such as paper also obtain higher productivities, the high VS (731 g/kg) and CODt (843 g/kg) that contains enhance its methane potential, although the kinetic is also slow due to the high fiber content (662.66 g/kg) which is scarcely a biodegradable compound. This substrate presents also a lag phase (0.68 d) less marked than meat/fish. Its contribution to the final mixture is relatively high with 52%VS in OFMSW, nevertheless the final productivity is lower due to the other fractions and the competitive effects produced by the mixture of substrates with different properties. The garden fraction is basically composed of fiber, it has a higher CODt and VS, however the final productivity and kinetics of this substrate are lower than the others. The high ammonium content of the garden fraction (4 g/kg) could be the cause of inhibition problems in the biodegradability process and low methane production. Methane percentages of around 60% are obtained for paper, whereas the garden fraction barely achieves 55%. As result the final mixture of OFMSW achieve percentages of under 56%.

The lower productivity of the *OFMSW compared with OF* indicates that the more highly organic material is supported manly part by food fractions (fruit/veg, meat/fish and cereal) and also some materials such as paper whose higher productivity could enhance the final production, while garden or plastic wastes could decrease the final methane production. Kinetic parameters based on the first order model show faster biodegradability for fruit/vegetable and OF (0.39 and 0.47 d^{-1} respectively). All the components of OF are easily biodegradable with the exception of meat/fish, even though it makes a slight contribution within the mixture.

Table 5 – Statistical results for the applying models. Reliability and reproducibility for each mathematical model. Best modeling results for each substrate are indicated in bold.

	γ exp ($mlCH_4$/gVS)	γ model ($mlCH_4$/gVS)				Error %				r^2			
		GE	FO	GM	LF	GE	FO	GM	LF	GE	FO	GM	LF
OFMSW	145 ± 12	90	140	135	133	61	**3**	7	9	0.80	**0.99**	0.98	0.97
OF	194 ± 3	118	183	179	178	64	**6**	8	9	0.75	**0.98**	0.97	0.96
Fruit/veg	163 ± 2	94	148	150	149	74	11	**9**	10	0.73	**0.98**	0.97	0.96
Meat/fish	291 ± 3	310	367	299	292	−6	−21	−3	**−1**	0.89	0.95	1.00	**0.99**
Cereal	175 ± 3	108	166	158	155	61	**5**	10	12	0.88	**0.98**	0.96	0.94
Garden	77 ± 7	57	75	57	68	34	**2**	35	12	0.95	**0.98**	0.91	0.92
Paper	217 ± 5	185	235	216	211	17	−8	**0**	3	0.86	0.98	**0.99**	0.98

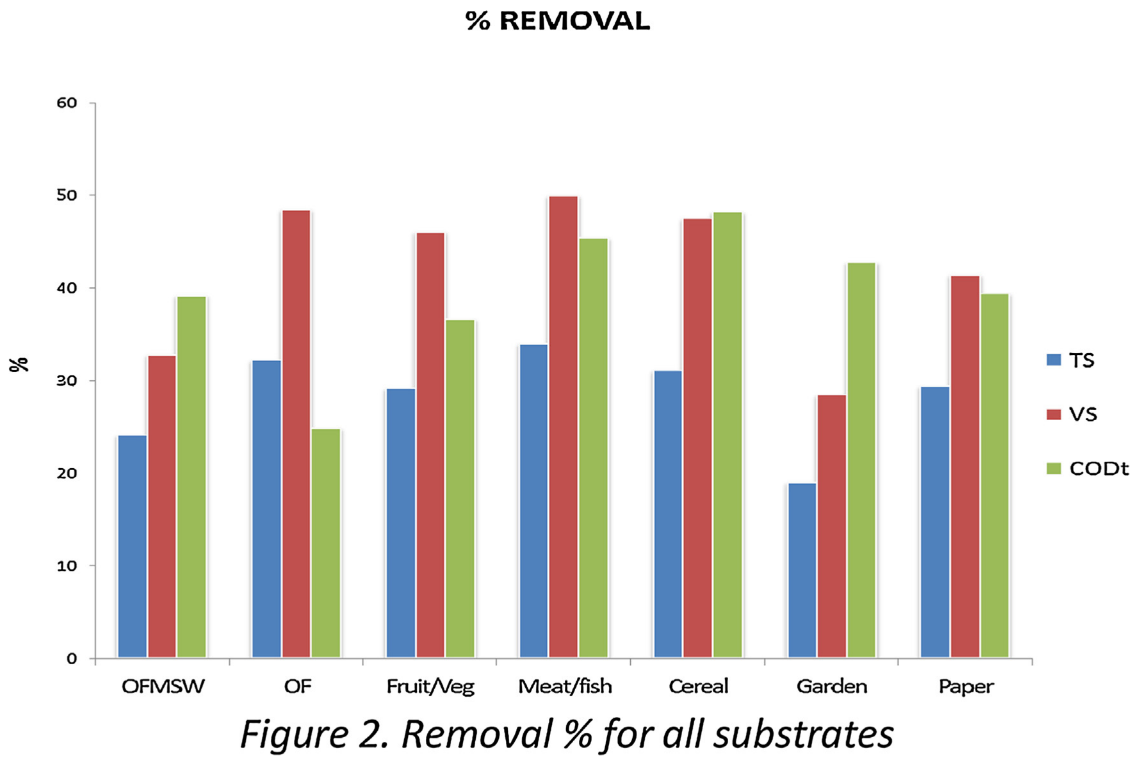

Fig. 2 – Removal % for all substrates.

The fact that substrates produce more biogas by themselves than in the final mixture led to the idea of a more specific segregation of the OFMSW, at least inert and low biodegradable wastes such as plastic or garden matter should be rejected to the maximum in the process while the addition of highly biodegradable material such as paper could also enhance de productivity and make the process more advantageous.

3.3. *Statistical analysis*

The four models were compared in order to analyze the most significant parameters in each case and to determine the optimum model for the prediction of the methane potential of this kind of wastes. The prediction capacity (error) and the ability to reproduce the methane curves (r^2) were studied from the experimental BMP results (Table 5). For the prediction capacity the relative error was calculated (Eq. (6)) using the experimental and model values for the final productions, while the regression coefficient of each method was considered in order to evaluate their reliability.

In terms of reproducibility FO is the model that best adjusts to the methanogenic curves except for meat/fish or paper which fit with complex models such as GM or LF. However in some cases there are some models that are not reproducible, although they can predict with an error of below 10% the final production of some substrates. This is the case of GE or LF for meat/fish, with GM being the model that best represents the methane curve of this substrate. Similar behavior occurs for FO and LF in the degradation of paper.

3.4. *Removal efficiency*

The removal percentages of each substrate were obtained at the end of the experiment. All the parameters (TS, VS, and CODt) were analyzed and compared to the initial data in order to evaluate the removal percentages. For the estimation of the equivalent removal of each substrate the efficiency produced by the inoculum in the blanks assays were considered in order to obtain the final results (Fig. 2).

Removal percentages of over 30% for TS and 40% for VS were obtained for most of the substrates. The highest removal results were obtained for the food fractions due to their composition and high biodegradability, achieving 34% TS and 50% VS for meat/fish which also represents the highest productivity.

4. Conclusions

The methane productivity results of separate fractions indicate that organic substrates such as meat/fish have the higher productivities, although their contribution to the OFMSW (2.5%VS) is minimal, while other poorly biodegradable substrates such as garden or fruit/vegetable with percentages of 9% and 11% (VS) respectively in the final mixture, could decrease the methane potential of OFMSW. The use of four simple models in the anaerobic digestion of OFMSW and its components showed to be an appropriate tool used to obtain performance parameters, allowing for a more reliable comparison between the digestion of different substrates. Food organic substrates are characterized by their quick biodegradability due to their composition and high VS content. The kinetic curves of some substrates such as meat/fish or paper are explained by a period of adaptation or lag phase due to their high lipid content for meat/fish and fiber in the case of paper, although their productivities are the highest ones. The adjustment of models shows the need for more than two parameters to explain the kinetics of these two substrates. Otherwise the first-order model fits almost perfectly with the rest of the substrates with regression coefficients above 0.96.

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