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Short communication

Anaerobic co-digestion of sewage sludge and grease trap: Assessment of enzyme addition

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ABSTRACT

Anaerobic co-digestion of grease trap and sewage sludge from a wastewater treatment plant is evaluated. Enzyme-lipase application, both addition and dosage, are evaluated by fitting the methane production of biochemical potential tests with the first order model. The enzyme addition effect, at 2, 5 and 10% of grease trap (%GT VS_{FED}^{-1}) and the enzymes doses, between 0.25 and 1.67% (v/v), without and with grease trap presence were studied. Grease trap addition showed a negative effect on the waste biodegradability, which was completely overcome by the addition of lipase. Enzyme addition improved notably the methane production for all grease trap fractions studied. In regards to the dosage, the best result was achieved between 0.33 and 0.83% (v/v) of enzyme. The co-digestion of sewage sludge and grease trap may be a feasible process by using lipases due to the saving in operational costs and the increase in the biogas production

1. Introduction

Anaerobic digestion is a consolidated technology in the treatment of organic solid waste. Among them, one of the most important applications has been the anaerobic treatment and stabilization of sewage sludge (SS) generated from the surplus of biomass produced in the aeration tank of activated sludge systems in wastewater treatment plants (WWTPs) [1]. From the anaerobic degradation of SS, biogas, a renewable energy source, is obtained which may be converted in thermal and/or electric energy.

Grease trap (GT) is a solid waste (scum layer) obtained from the flotation process in a WWTP, which is composed by several types of oil and fat. Normally, GT is collected and disposed in landfills; however, this waste must be stabilized prior to disposing due to strict regulations and the associated problems with this type of waste (such as foul odors). Anaerobic digestion might be used in order to degrade and stabilize GT along with SS. An important advantage of this is that the same existing facilities for sewage sludge degradation can be used, thereby not comprising further investment costs. Moreover, the GT, due to its high lipid-content, represents an attractive source for biomethanization, due to the higher methane yield obtained when compared to proteins or carbohydrates. Anaerobic co-digestion is a process where several wastes are used as substrate, for instance, SS and lipid-rich waste [2]. Luostarinen et al. [3] found that the co-digestion of SS and GT (from meat industry) improved the biogas production and methane yield at low and high GT concentrations. Davidsson et al. [4] evaluated the anaerobic digestion of these wastes in batch and continuous pilot-scale digestion tests, obtaining that the addition of GT increased methane yield and methane potential in batch tests. In any case, the research in this field is preliminary and several operational conditions must be studied in order to improve the process.

The enzymes application can improve the anaerobic degradation of lipids, since catalyzes the hydrolysis of long chain fatty acids. Enzymes are biodegradable and harmless for the anaerobic treatment processes and aquatic ecosystems; in addition, their contribution to the BOD in the waste stream is negligible. Lipases have been used in anaerobic treatment of fat-wastewater [5–7]. However, there is a lack of literature regarding the enzyme lipase application in anaerobic co-degradation of solid-lipid waste such as GT and SS. The aim of this study is to assess the effect of lipase addition and its dosage (Biolipase L®) in the anaerobic co-digestion of GT and SS. A simplified mathematical model was used to estimate some kinetic parameters in order to compare the methane production profiles as well as to count with some criteria for a preliminary economical evaluation of the lipase application.

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2. Materials and methods

2.1. Anaerobic batch tests

Batch anaerobic digestion tests were carried out to assess the SS-GT biodegradability. All the experiments were done in duplicate. Anaerobic sludge (inoculum) from a pilot-scale anaerobic digester treating mixed waste-activated sludge was used as inoculum for the anaerobic test. Serum bottles, with a volume of 60 ml were used. Reactors were incubated at 35 °C and magnetically stirred. Anaerobic biodegradability was calculated following biogas production and composition. The results of biogas test were expressed in specific units ($mlCH_4\,g\,VS^{-1}$).

2.2. Substrate and enzyme characteristics

For this experiment mixed SS (60% primary sludge and 40% secondary sludge) and GT from a conventional WWTP in Valladolid (Spain) were used. 1 ml^{-1} of macro-micronutrients and 1 $g\,L^{-1}$ of sodium bicarbonate were added in all assays in order to supply the necessary elements and enough alkalinity to maintain the pH above 7. The characterization of the substrates (SS and GT) and the inoculum for experiment 1 and 2 are presented in Table 1.

Two series of anaerobic batch experiments were carried out in order to evaluate: (1) the effect of the enzyme addition and (2) the enzyme dosage. For experiment 1, three concentrations of GT were evaluated: 2, 5 and 10 (%w as $\%GT\,VS_{FED}^{-1}$). In the assays with enzyme addition a constant dose of 0.25 (% v/v) was added. In experiment 2, four enzyme doses were tested 0.25, 0.33, 0.83 and 1.67 (% v/v) and two types of batch tests were carried out: only SS and SS + GT (5%w). For all the experiments, a certain volume of inoculum and substrate (SS and GT) was added in order to maintain the substrate-inoculum ratio of 0.5 $g\,VS_S\,g\,VS_I^{-1}$. A commercial lipase, BIOLIPASA L (Catalog no. 9001-62-1), obtained from Biocon S.A., Spain, was used. This formula comes in a liquid transparent solution and has an activity of 50,000 $U\,g^{-1}$. This lipase has an increase activity from pH 7 to 10 and an optimum temperature of 30 °C, although it remains very active between 15 and 40 °C.

2.3. Kinetic model

In the case that the hydrolysis of the particulate organic matter is the rate limiting step, a first order equation (Eq. (1)) may be used to estimate the hydrolysis rate (k_h, d^{-1}) and the biodegradability extent or anaerobic biodegradability (B_0, $mlCH_4\,g\,VS^{-1}$) from a batch test [8]. Afterwards, these parameters can be used, as a first approximation at least, of the parameters of more complex models of the co-digestion in a continuous system [9,10].

$$B = B_0 \cdot (1 - \exp(-k_h \cdot t)) \quad (1)$$

where B is the methane production ($mlCH_4\,g\,VS^{-1}$) and t is the time of the assay (d). Nonlinear optimization by the least squares procedure is applied to calculate the unknown parameters (B_0 and k_h) and by minimizing a cost function (Eq. (2)), which measures the difference between the experimental measurements and the corresponding simulated value. Matlab® was used to solve the least squared procedure.

$$J\left(\theta\right) = \min \sum_{t=1}^{N} \left(y_{\exp}(t) - y(t,\theta)\right)^2 \quad (2)$$

where J is the objective function, y_{exp} is the experimental methane production (as $mlCH_4\,g\,VS^{-1}$), y is the corresponding simulated value, θ is the vector of parameters and N is the number of measurements. The accuracy of the estimated parameters was obtained through the Fisher information matrix (FIM), which summarizes the quantity and quality of information obtained in the experiment and assuming proper model selection with no data autocorrelation and uncorrelated error, the inverse of the FIM (Eq. (3)) gives us an estimation of the parameter estimation covariance matrix (C_j)

$$C_J = (F(\theta))^{-1} \text{ where } F(\theta) = \sum_{i=1}^{N} \left[\frac{\partial y_i(t,\theta)}{\partial \theta}\right]^T Q_i^{-1} \left[\frac{\partial y_i(t,\theta)}{\partial \theta}\right] \quad (3)$$

Finally, once the covariance matrix is available, an approximation of the standard deviation (σ) of the parameters can be estimated through Eq. (4).

$$\sigma(\theta_i) = \sqrt{C_J} \quad (4)$$

2.4. Analytical methods

Total solids (TS) and volatile solids (VS) concentrations in all samples were determined by heating at 105 °C during 24 h for total solids and 550 °C during 2 h for volatile solids concentration and grease content by Soxhlet extraction according to the procedures described in Standard Methods for Examination of Water and Wastewater [11]. Biogas volume was measured manually by a pressure transmitter (Druck, PTX 1400, range 1 bar) in the head space of each reactor. After the daily pressure measurement, the biogas in the head space was released, what reduced the pressure in the head space to atmospheric pressure. This pressure difference was converted into biogas volume, using the ideal gas Law and standard conditions (P = 1 bar and T = 0 °C) as reference. The methane content was measured by gas chromatography through the injection of 1 ml of sample directly in the column.

3. Results and discussion

3.1. Enzyme addition influence

The kinetic parameters B_0 and k_h, obtained from fitting Eq. (1) with the cumulative methane production data for each experiment, are shown in Table 2.

Fig. 1 shows that the addition of the lipase increases the total methane production of the anaerobic co-digestion of SS and GT in batch conditions for all the GT concentrations. Nonetheless, the methane content of the biogas was not affected by the use of the lipase, keeping a value within 63–68%. In Table 2 (experiment 1) the estimated values of the kinetic parameters along with their respective standard deviation of the model are presented. The enzyme addition caused a notable enhancement of the waste biodegradability for all the studied conditions in regards to those assays without enzyme. For 2%, 5% and 10% of GT, the enzyme addition increased B_0, in about 130%, 127% and 78%, respectively. This sharp increase may be explained by the fact that without the enzyme, the presence of GT may have impaired the substrate accessibility for the anaerobic biomass [12], which was not the case when enzyme was present. These mass transfer problems had to take place, as it is confirmed by the results discussed in the next sub-section, since the hydrolysis of GT as such does not justify the values of the increase in the biodegradability. In regards to the hydrolytic coefficients, the obtained values are in the range of the common reported values for anaerobic degradation of solid waste [13]. However, the lipase addition does not produce any significant change in the solid properties since the coefficient values do not vary substantially.

For all GT concentrations enzyme doses, the first order model adequately described methane production as it can be observed from the values of the determination coefficient (r^2) which indicates the goodness-of-fit of the model

3.2. Enzyme dosage effect

Once the effect of the lipase addition was evaluated, several enzyme doses (0.25, 0.33, 0.83 and 1.67%, v/v) were tested, with and without the presence of GT. Nevertheless, it is worth to point out that this experiment was carried out with substrate and inoculum from the same origin but taken at different time, which can certainly exert an effect on the results, as discussed below. The enzyme addition without GT (only SS as substrate) was tested in order to evaluate the potential effect of the enzyme on the SS degradability and its contribution to the total methane produced. Figs. 2 and 3

Table 1
Substrate and inoculum characterization.

	Grease trap		Sewage sludge		Inoculum	
	Exp 1	Exp 2	Exp 1	Exp 2	Exp 1	Exp 2
TS ($g\,L^{-1}$)	35.1	28.5	27.9	32.1	29.3	28.3
VS ($g\,L^{-1}$)	26.1	26.8	15.5	23.3	16.7	15.7
Grease ($g\,L^{-1}$)	22.1	22.7	–	–	–	–