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Anaerobic degradation kinetics of particulate organic matter in untreated and sonicated sewage sludge: Role of the inoculum

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Abstract

Degradation kinetics of particulate matter in anaerobic digestion of secondary sludge, untreated and sonicated, was investigated by carrying out batch tests at different feed/inoculum ratio (*F*/*I*) (in the range of 0.1–4.0). Particulate COD degradation data were analysed using the four equations most widely utilized to model the hydrolysis process and the related kinetic parameters were evaluated. The increase of *F*/*I* results in a correspondent increase of the process rate up to one order of magnitude in the investigated interval for both untreated and sonicated sludge. The maximum step increase is observed in the range of 0.1–2.0 while for *F*/*I* varying from 2.0 to 4.0 only a modest enhancement of the process kinetics is detected. The effect of sonication on kinetics is not appreciable at low *F*/*I*, due to the low fraction of fed sludge and to the consequent strong substrate limitation, whereas at high *F*/*I* a slight increase is evidenced.

Keywords: Anaerobic digestion; Sewage sludge; Particulate matter degradation; Hydrolysis kinetics; Ultrasound treatment

1. Introduction

Anaerobic treatments are extensively employed to stabilise sewage sludge in wastewater treatment plants of medium and large capacities (>50,000 p.e.). The main objective of sludge anaerobic digestion is the degradation and destruction of organic substances, with consequent reduction of the odorous emissions and pathogens. This conversion is catalyzed by a large number of bacteria, that operate in synergy, catalyzing different chemical reactions so the metabolic pathways involved in the anaerobic degradation are quite complex. Detailed and accurate anaerobic process models have been proposed in the last decades (Batstone et al., 2002; Siegrist et al., 2002) but still it remains a bottleneck for the evaluation of the kinetic parameters for complex substrate matrices as it is the sewage sludge. Data available are essentially referred to the degradation of simpler substrates or substrates having a more specific interest for industrial application and to the treatment of concentrated wastewater. In the last years a renewed interest for the anaerobic digestion of sludge raised from the chance of a possible increase in energy recovery and solids degradation by applying an appropriate secondary sludge pre-treatment like sonication (Wang et al., 1999; Tiehm et al., 2001; Lafitte-Trouqué and Forster, 2002; Braguglia et al., 2006). In fact, ultrasound treatment leads to the breakage of the cell walls and bacteria membranes, so improving the bacterial eso-enzymes release into solution and enhancing the biocatalysis of the hydrolytic reactions.

In order to evaluate the anaerobic digestion performance, both in terms of removal efficiency and energy recovery, an accurate model and reliable kinetic and stoichiometric parameters are required. In the literature models there is a general agreement on considering the hydrolysis of particulate matter as kinetically limiting step of the whole process (Li and Noike, 1992; Shimizu et al., 1993).

With the aim to give a contribution to anaerobic sludge digestion modelling, in the present study degradation

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kinetics of particulate matter was investigated on secondary sludge, untreated and sonicated, with batch tests carried out at different feed/inoculum ratio (F/I) (in the range of 0.1–4.0). Particulate COD degradation data were analysed with four widely used equations for simulating the hydrolysis process and the related kinetic parameters have been evaluated from the data fitting.

2. Methods

2.1. Sludge

The secondary sludge was obtained from the municipal "Roma-Nord" wastewater treatment plant, one of the four wastewater treatment plants serving the city of Rome managed by ACEA, the public company having in charge the management of water and wastewater treatment plants of Rome municipality. It is a conventional activated sludge plant including screening, primary clarification and secondary treatment and serves about 700,000 p.e. It is operated with a quite high sludge age (≅20 d).

Secondary sludge and anaerobic inoculum were sampled respectively from the recycle stream before thickener and from the full scale digester of the plant fed with primary and secondary sludge. The digester sludge had VS of 14–18 gL^{-1} and a VS/TS ratio of 0.6–0.7. The sampled secondary sludge was gravity thickened for 24 h at 4 °C before feeding the bench scale anaerobic reactors.

2.2. Sludge disintegration by ultrasound

The disintegration by ultrasound was performed with an ultrasonic processor UP400S (Dr. Hielscher, Germany) operating at nominal power of 300 W and 24 kHz. The power control had an amplitude of 20–100%. The sonotrode has a diameter of 22 mm making the device suitable for sample volume of 500 mL. Disintegration degree can be calculated according to Braguglia et al. (2006). The specific energy input was in the range 4500–6500 kJ kg^{-1} dry solids depending on the TS of the treated sample, and the degree of disintegration was about 10%. The ultrasound treatment was carried out immediately before starting the digestion test.

2.3. Anaerobic digestion tests

Experiments were carried out at 37 °C on bench scale anaerobic reactors of 0.4 L (working volume) that were operated in batch mode, immersed in a temperature controlled, agitated water bath (ISCO, Italy). The stirring system has a power input of 10 W m^{-3} that is in the interval of values 9–14 W m^{-3} of digester volume reported in US EPA (1979) to ensure a proper reactor mixing. So the experimental apparatus is able to reasonably reproduce the mixing conditions of a real system.

The reactors were fed with a mixture of inoculum and secondary sludge, either untreated or sonicated: the added inoculum was varied in each test to attain the prefixed F/I ratio measured on volatile solid (VS) base. At regular time intervals, one digestion reactor containing untreated and one containing sonicated sludge were stopped and the sludge characterization was performed. The same procedure was performed for the blank test with sole inoculum.

The produced biogas was collected in calibrated 1-L eudiometer tube placed on the digestion bottle via a ground-glass connection. The tube has a glass hose-coupling from which a sufficiently long hose connection leads to a levelling flask. The upper end of the eudiometer tube is fitted with a conical stopcock adjusting the zero point (DIN 38414). The liquid contained in the tube and in the levelling flask was NaCl at pH 3 to avoid CO_2 losses by carbonate formation. The biogas was read daily. Some intrinsic problems related with this equipment caused uncertainty in the measure during the tests.

2.4. Analytical procedures

Volatile solids, measured in triplicates, were determined drying the samples at 105 °C for 24 h to obtain the concentration of dry solids. In the next step, the dry solids were incinerated at 550 °C for 2 h. The residues after incineration represent the inorganic part of the dry solids. The difference between the total dry solids and the inorganic ones gives the loss on ignition generally referred as volatile solids. Total and soluble COD, measured in duplicates, were determined by photometric detection of chromate consumption by the organic compounds, subsequent to digestion in concentrated sulphuric acid solution for 2 h at 148 °C by means of COD Cell Test by Spectroquant Merck (EPA method 410.4). To determine total COD, sludge sample was preliminarily magnetically stirred for approximately 10 min, then, under stirring, aliquots were manually pipetted (adjustable Gilson pipette, max. 5 mL) and transferred into COD cuvettes. The soluble phase was analysed by removing the particulate matter by centrifugation (10 min at 6000 rpm) and by subsequent centrate filtration through 0.45 μm pore size membrane filters.

Particulate COD has been calculated by difference between total and soluble COD concentration.

3. Kinetic equations

3.1. First order

The first order kinetics can be formulated in two different forms taking into account the dependence of the reaction rates on the biomass concentration or not. The simplified form is a first order kinetics with respect to the substrate:

$$\frac{dX_S}{dt} = -k \cdot X_S \quad (1)$$

where X_S is the particulate substrate concentration and k is the kinetic constant.