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A respirometric method for characterising the organic composition and biodegradation kinetics and the temperature influence on the biodegradation kinetics, for a mixture of sludge and bulking agent to be co-composted

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Abstract

A respirometric method was set up to study kinetics of biological reactions involved in the treatment of organic wastes—sludge mixed with pine barks—by composting. Oxygen consumption rates of this type of mixture were monitored during 10–20 days, using a 10 l respirometric cell kept at constant temperature and moisture. Oxygen consumption kinetics were modelled and organic matter composition was characterised as biomass, easily-biodegradable, slowly-biodegradable and non-biodegradable organic matter. The influence of temperature on kinetics was tested. Results show that this respirometric method is a useful tool for the characterisation of solid organic matter biodegradability and for the modelling of the biological kinetics of the composting process.

Keywords: Composting; Sludge; Respirometry; Organic matter characterisation; Biodegradation kinetics; Modelling; Biodegradability

1. Introduction

Composting, or aerobic biological treatment of organic wastes, is an ancestral way to reduce wastes and to reuse organic matter. Among the range of existing organic wastes, sewage sludge composting with the use of woody bulking agents, such as pine barks, enables the production of a quality product that may be used as a soil conditioner or as an organic fertiliser. However, the quality of the end-product largely depends on the way to perform the initial mixture and to manage reactions occurring during the composting treatment.

The composting process includes two major phases. The first one, called the "active phase", mainly develops degrading reactions: dissolved organic matter is used as carbon and energy source by microorganisms for their metabolism. During the second phase of the composting process, called the "curing phase", organic macromolecules such as humic substances are synthesised. As we already mentioned, degrading reactions form the central phenomena of the "active phase" of the treatment. These reactions, based on numerous biological, thermal and physico-chemical phenomena, involve oxygen consumption, as well as heat, water and carbon dioxide production. As all the above phenomena interfere with one another, they are quite difficult to characterise on the sole experimental basis obtained from composting trials. Thus, describing each phenomenon and all the phenomena interferences, thanks to mathematical equations and, particularly, modelling the biological reactions of the active phase of composting, should lead to a simulation of the behaviour of the substrates treated by this process and then should allow a better understanding and optimisation of the composting treatments.

Knowing the kinetics of biological reactions and the influencing environmental parameters is essential to

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reach the objective of simulating biological degradation of organic matter, without consideration of any mass transfer limitation. In such a case, the kinetics of the organic matter degradation and the quantity of degraded matter are directly linked with biomass growth kinetics (Bailey and Ollis, 1986):

$$r_X = \mu X \quad \text{and} \quad r_S = \frac{1}{Y_{X/S}}\mu X$$

with r_X: biomass growth kinetics (mol O_2/kg/h), μ: biomass specific growth rate (h^{-1}), X: microorganisms concentration (mol O_2/kg), r_S: substrate degradation kinetics (mol O_2/kg/h), $Y_{X/S}$: biomass growth yield (–).

There is also a relationship between biomass growth, substrate degradation and oxygen consumption:

$$r_{O_2} = (1 - Y_{X/S})r_S = [(1 - Y_{X/S})/Y_{X/S}]r_X$$

with r_{O_2}: oxygen consumption rate (mol O_2/kg/h).

As biomass or substrate concentrations are difficult to measure, biological reactions can be studied through respirometric methods by monitoring instantaneous oxygen consumption rate and by knowing the biomass growth yield. Indeed, respirometry is the measurement and interpretation of the biological oxygen consumption under well-defined experimental conditions (Spanjers et al., 1998). Numerous respirometric methods are used to characterise organic matter composition and biodegradation in liquid effluents (wastewater, slurries, etc.).

Such methods have also been developed to study organic solid wastes, in order to provide a maturity or stability index. Ianotti-Frost et al. (1992), Ianotti et al. (1994) evaluated compost stability through a gaseous dissolved oxygen measurement in a closed bottle. The AT4 (German index for respiration activity in 4 days) evaluates stability with regard to the cumulative quantity of consumed oxygen measured for 96 h (Binner and Zach, 1999). The DRI (Dynamic Respiration Index), proposed by Adani et al. (2001, 2002), considers, as a stability index, the average instantaneous oxygen consumption kinetics, measured on a sample for 24 h after the maximum respirometric activity has been reached. Finally, stability has been studied by Lasaridi and Stentiford (1998) and Stentiford (2002), by placing compost in a liquid medium and by measuring the maximal oxygen uptake rate (SOUR). Some authors, such as Lasaridi et al. (1996), have also applied a respirometric method to solid wastes so as to study organic matter biodegradation kinetics as a function of environmental parameters such as temperature.

The most important limit concerning the previous methods was the measurement of oxygen consumption on small quantities of solid sample (30–100 g). Moreover, these samples were often ground and sometimes they were suspended in aqueous solution before measurement. As a consequence, the result concerning stability level or biodegradation kinetics would not take into account the influence of the solid matrix characteristics of the substrate (moisture, granulometry, etc.). Thus, the results of stabilisation or biodegradation kinetics might be quite different when considering the treatment of a real waste.

The first aim of this study was to develop a respirometric method respectful of the real physical structure of samples and to apply it to the special case of a solid mixture of sludge and bulking agent, in which homogeneous oxygen supply might be a problem. While using this method, two objectives were pursued: (1) To characterise the initial organic composition of the mixture as biomass concentration and as easily-biodegradable organic matter concentration, as well as slowly-biodegradable and non-biodegradable organic matter concentration, thanks to the validation of a kinetic model simulating the oxygen uptake rate by considering biomass growth and organic matter hydrolysis limitation; (2) To study the influence of temperature on the biodegradation kinetics at constant moisture.

2. Methods

2.1. Respirometric device design

The respirometric device (Fig. 1) was set up on the basis of Aguilar-Juarez (2000). In order to model household wastes biodegradation kinetics during the aerobic phase of a landfill cell exploitation period, Aguilar-Juarez developed a 1.8-l closed respirometric cell. This cell, filled with a representative sample of household wastes, was continuously aerated and the oxygen consumption rate within the substrate was recorded.

Considering the specificity of the studied substrate (sludge and bulking agent), the respirometric device developed in this study was bigger than Aguilar-Juarez's device so that the reacting medium would be comparable to a composting one. The proposed respirometer consisted of a 10-l hermetically-closed glass cell, filled with the substrate mixture placed on a grid. Ambient air was blown into the mixture through a pipe placed at the bottom of the cell. The flow rate (Q) was maintained constant and precisely measured through a volumetric gas counter. In order to provide homogeneous aeration conditions, a rapid recirculation of the gas in the cell was carried out. So, considering the solid organic substrate, this device was a closed vessel reactor. Considering the gas phase, the respirometric device could be used as an open reactor (continuous injection of ambient air and continuous air exit) or as a closed reactor (only recirculation of the initial gas volume).

Temperature and moisture were kept constant during each experiment, by placing the respirometric cell in a thermostatic water bath and by humidifying the incoming air and condensing the water in the exhaust