IMPROVING COMPOSTING TREATMENT THROUGH MODELLING: CONCEPTION OF AN IN-VESSEL COMPOSTING MODEL

A. Tremier[1], A. de Guardia[2], J.L. Martel[1]
[1]Suez Environnement, 38 rue du Président Wilson, 78230 Le Pecq, France Cemagref,*
[2]17 av. de Cucillé, CS 64427, 35044 Rennes Cedex, France; anne.tremier@cemagref.fr

ABSTRACT

An in-vessel 300-litre pilot composting treatment was studied. Three steps were considered to set up the composting model. First, the biological reactions were studied thanks to a respirometric method and modelled. Second, the gas hydrodynamics was studied in the composting pilot by using a gas tracing method, and the gas flow pattern model was then used to propose heat and mass transfers models within the composting pilot. Third, the biological and transfers models were compiled in a one-dimension composting model, programmed and solved with a Scilab software. The model allows to predict the biodegradable organic matter fractions content, the temperature, the oxygen content and the compost water content through the composting mass all along the treatment. First results were obtained with initial experimental data and non-calibrated parameters. The model has now to be well calibrated and further validated on complementary experiments. This study was led in the frame of a PhD work funded by Suez-Environment, the Cemagref laboratories (French agricultural and environmental engineering research institute) and ADEME (French agency for environment and energy management).
Keywords: *composting, modelling, pilot reactor, sludge.*

INTRODUCTION

Composting processes are an interesting way to treat organic wastes, which leads to obtain materials that may be used as soil conditioners or organic fertilizers. Nevertheless, the composting end product's quality largely depends on the way to formulate the initial mixture and to manage the reactions occurring during the treatment. As composting is based on numerous interdependent biological, physical, chemical and thermal phenomena, this treatment is quite difficult to understand on the sole experimental way. Thus, modelling each phenomenon and the phenomena interferences should allow a better understanding and the optimization of the composting treatments.

The composting modelling has been studied for approximately twenty years (Das and Keener, 1997 ; Haug, 1993 ; Kaiser, 1996 ; Nakasaki et al., 1987 ; Seki, 2002 ; VanderGheynst et al., 1997). Nevertheless, few of these models describe the organic matter biodegradation as a metabolic kinetics and none of them characterized the gas flow within the studied composting reactor in order to precisely traduce its influence on heat and mass transfers. Thus, the aim of this study was to propose a model, applied to the active phase of a pilot composting treatment. It describes microbiological phenomena, and also all mass and thermal phenomena. Each phenomenon was first specifically studied and then they were coupled to design the global composting model.

MATERIALS AND METHODS

The composting pilot reactor and the composting trials

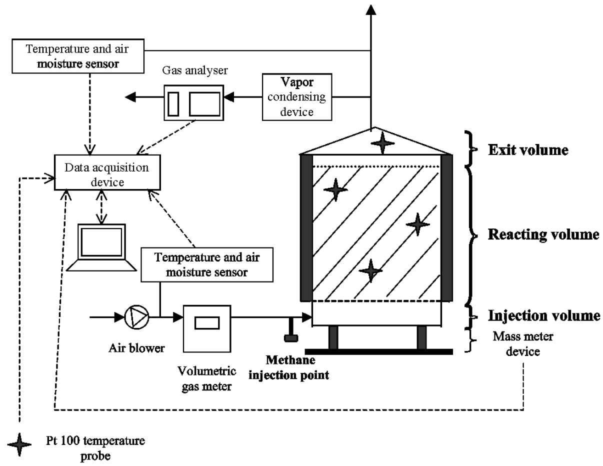

Figure 1. *Scheme of the composting pilot.*

The composting pilot reactor (Figure 1), consisted in an airtight 300-litre stainless steel cylindrical chamber (Reacting volume), which sides were insulated by a layer of polyurethane. Aeration was supplied via an air blower, from the bottom (Injection volume) through the material, and gases were collected at the top (Exit volume) in order to analyse them. Parameters monitored during experimental trials were the following: (1) gas flow rate via a volumetric gas meter, (2) mass loss thanks to a continuous mass monitoring device, (3) temperature of the matter and gas in the reactor with Pt 100 temperature probes, (4) entering and exhaust gas temperature and humidity. Four composting trials with a sludge/pine barks mixture were managed in the composting pilot. Three were led at constant airflow rate (1000, 750 and 550 L/h), and one at varying airflow rate (Q=f (Temperature)).

The modelling strategy and the model design

The composting model was designed by using a three steps strategy. The first step of the model design consisted in studying the biological reactions included in the composting process. A specific respirometric method was set up, and it was interpreted through a biological model to determine the biodegradation kinetics and to quantify the biomass content, the easily biodegradable organic matter content and the slowly biodegradable organic matter content of the solid waste (Tremier et al., 2004). The second step consisted in studying the mass and heat transfer phenomena through the gas flow. A gas tracing method (using methane as gas tracer) was then used to characterize the retention time distribution (RTD) of the gas flow within the composting reactor. The experimental RTD curves were modelled and a dispersed-plug flow was found in the reaction volume. Thus, the heat and mass transfers modelling equations traduced the characteristics of the gas flow within the composting media by developing one dispersion term and one convective term. The resulting composting model, combining the previous results, was based on the following assumptions: (1) The waste to be composted is considered as a three-phase matrix: a dry solid phase, an aqueous phase and a gaseous phase ; (2) The organic matter is divided in three fractions: easily biodegradable, slowly biodegradable and inert ; (3) The gaseous phase is charac-

Table 1. *Initial characteristics of the sludge and pine barks mixtures.*

	1000 L/h	750 L/h	550 L/h	Q=f (T)
Total dry mass (kg)	51.0	49.5	46.0	50.3
Total sludge dry mass (kg)	8.2	14.0	7.8	14.0
Total pine barks dry mass (kg)	42.8	35.5	38.2	36.3
Ratio sludge dry mass / total dry mass	0.16	0.28	0.17	0.28

terized by a dispersed-plug flow, inducing vertical gradients concerning the temperature and the gaseous concentrations. There is no horizontal gradient ; (4) There is no vertical transfer of biomass and organic matter within the reactor and no liquid water flows out the composting reactor; (5) The porosity and the waste height in the reactor are supposed constant during composting.

The composting model is a mono-dimension model in which mass terms and heat terms are coupled in the heat balance equation. Ten outputs are modelled: the biomass content, the slowly biodegradable organic matter content, the easily biodegradable organic matter content, the inert organic matter content, the dry matter content and the water content of the substrate, and also the oxygen content, the carbon dioxide content and the water content of the gaseous phase. A semi spatial discretization method was used to solve the coupled partial differential equations thanks to a Scilab program. In the following examples, the reactor was discretized in five layers. The initial variable values were obtained from the chemical and respirometric analysis of the sludge and pine barks mixture, and from the gas initial characteristics. The kinetic, physical and thermal parameter values were obtained from the respirometric method, from the RDT mesurement and from the literature. They were not optimized.

RESULTS AND DISCUSSION

The experimental temperature evolution during composting

The upper temperatures (Figure 2) reached within the reactor were higher for the trials at 750 L/h and at varying airflow rate (between 60 and 70°C) than for the trials at 1000 and 550 L/h

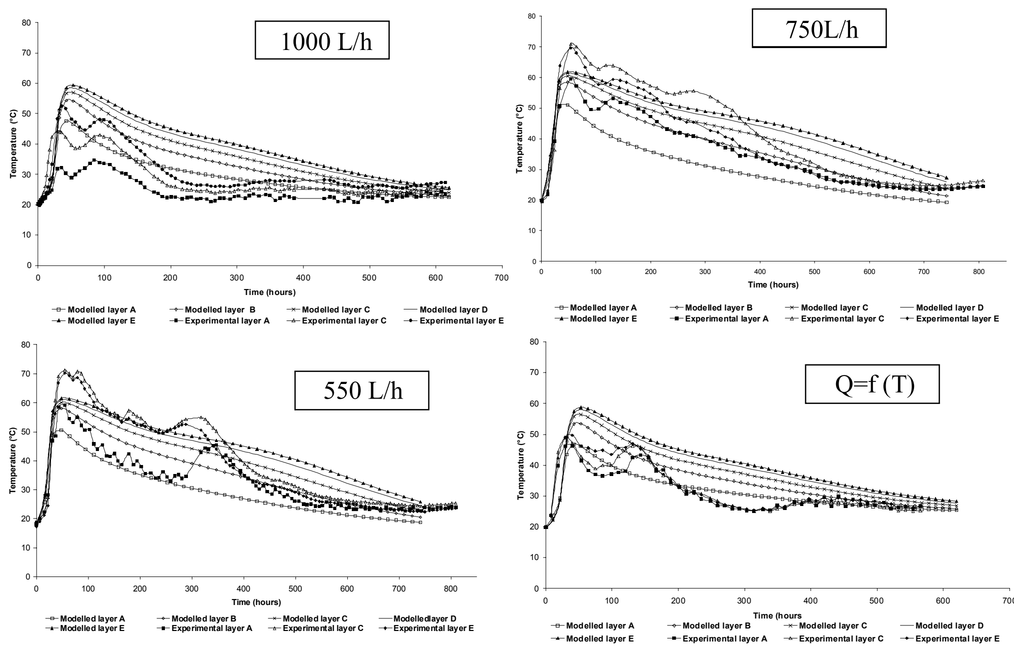

Figure 2. *Evolution and distribution of the experimental and modelled temperatures*

(between 40 and 50°C). As shown in table 1, the initial weight of mixture contained approximately two times more sludge dry matter at 750 L/h and at varying airflow rate than at 1000 and

550 L/h. Therefore, more biodegradable matter was available during the trials at 750 L/h and at varying airflow rate, involving more biological heat release.

On a spatial point of view, it must be noticed that the temperature distribution evolved differently depending on the airflow rate (figure 2). At 1000 L/h, the temperature regularly increased from the bottom to the top of the reactor. At 750 L/h, the temperatures in the middle and at the top of the reactor were quite homogeneous, but the temperature at the bottom was much lower. At 550 L/h, the three measured temperatures were close. Then it seemed that the axial temperature heterogeneity increased with an increasing flow rate. It was quite well confirmed by the trial with varying airflow rate, in which heterogeneity seemed also to decrease with the decreasing flow rate (airflow rate decreased with temperature).

Comparison of the modelled and the experimental temperature evolution

The figures 2 shows the modelling results obtained respectively for the trials at an airflow rate of 1000, 550, 750 L/h and at varying airflow rate. The temperatures of the five modelled layers (from the A layer at the back of the reactor to the E layer at the top of the reactor are represented. The experimental results for the A, C and E layers are also presented on these figures. The qualitative evolution of the modelled temperatures is coherent with the experimental one. The spatial distribution of the temperature is well represented. Nevertheless, the modelled results are not quantitatively representative from the experimental ones. The model parameters have to be calibrated and validated to improve the modelling.

CONCLUSIONS

As the modelling results concerning the temperature evolution, obtained on the basis of the four composting trials, are globally coherent with the experimental ones, they give us a first validation of our modelling concept. The model parameters have now to be calibrated in order to increase the precision of the simulations and the model has to be validated by comparing more modelled variables with other experimental values. The validated model will represent a useful tool for testing the influence of the mixture initial characteristics and the way to manage composting parameters (airflow rate, moisture, etc.), on the composting treatment progress.

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