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Sewage sludge composting simulation as carbon/nitrogen concentration change

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Abstract

Available composting models do not describe accurately the dynamics of composting processes. Difficulty in modeling composting processes is attributed mainly to the unpredicted change in process rate caused by change in activation energy value (E). This article presented the results of an attempt made to utilize patterns of change in carbon, nitrogen and temperature profiles to model sewage sludge composting process as a multi-stage process. Results of controlled sewage sludge composting experiments were used in the study. All the experiments were carried out as batch experiments in a 300-liter Horizontal Drum Bioreactor (HDB). Analysis of the profiles of carbon, nitrogen and temperature has indicated that there were clear patterns that could be used to develop simple models of the process, the initial C/N ratio was between 7–8 and the final C/N ratio of the compost in most experiments were found to be around 15.0, indicating the compost was fully matured and could be used safely for agricultural purpose. Electrical conductivity of composting material decreased from 1.83 to 1.67 dS/m, after a period, it increased gradually from 2.01 to 2.23 dS/m and remained at around 2.33 dS/m till the end of composting. It is found that change in the concentration of total carbon can reasonably be described by three constant process rate coefficients (k_1, k_2, k_3). It is found that the process starts with a certain process rate coefficient (k_1) and continues until peak temperature is reached, then it reaches lower process (k_2) in the declining phase of the thermophilic stage, and finally it proceeds with a faster process rate (k_3) when maturation is reached. Change in the concentration of total nitrogen has shown to have the same patterns of change as carbon.

Key words: composting; sewage sludge; HDB; modeling; reaction rate

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Introduction

Composting is usually defined as a biological process that converts organic matter into humus-like substances and at the same time destroys pathogenic organisms (Haug, 1980; Polprasert, 1996). Wastewater treatment authorities are often confronted by the challenge of finding an economical and sustainable management method for sewage sludge. In wastewater treatment plants there are usually huge amounts of sewage sludge that need to be treated and disposed in an economical and environmentally way. The methods commonly used for sewage sludge treatment and disposal is anaerobic digestion, incineration, composting and land treatment.

Composting is the cost-effective and environmentally sound method that can be used for sewage sludge treatment and disposal (Das and Keener, 1996; MetCalf and Eddy, 2003). Composting is usually the method that enables the reuse of the valuable nutrients (P, K, Ca, trace elements) in sewage sludge as fertilizers or soil conditioners for crops and soils, respectively.

In contrast to other biological processes, however, composting process is extremely complex and highly dynamic. A composting system is usually subject to varieties of physical and biochemical reactions that take place under large magnitude of disturbances caused by changes in the surrounding environment. Difficulty in modeling such a system is often due to nonlinearities and uncertainties (Hall, 1998). However, the unpredicted change in the process rate caused by the change in activation energy value (E) is believed to complicate further the modeling of the system (Hamelers, 2004). So far, all attempts made in modeling composting processes have resulted mainly in the development of complex empirical models, which have large numbers of states and unidentifiable parameters (Lin, 2006). Despite complexity, however, these models do not predict accurately the system dynamics (Mason, 2006). In order to facilitate the operation and control of the composting process, there is a need for simple models that can accurately describe the dynamics of system.

This article presents results of an attempt undertaken to identify and utilize change patterns in carbon, nitrogen and composting temperature to develop a simple but yet an accurate model that can be used to simulate sewage sludge composting experiments carried out in a batch mode.

1 Materials and methods

1.1 Plant material and growth conditions

This study used the results obtained by Kabbashi (2002). Six controlled experiment was carried out to study the effect of the operating parameters on the progress of sewage sludge composting process. All the experiments were batch experiments conducted in a 300 - L Horizontal Drum Bioreactor (HDB). In these experiments, sewage sludge samples were amended with sawdust to adjust C/N ratio and moisture content. Different types of inoculums were used in the experiments. Inoculums used in experiments 1 to 6 were as follows: commercial compost (Organi Gro), *P. chrysosporium*, *T. harzianum*, and mixture of *P. chrysosporium* and *T. harzianum*, *M. hiemalis*, and mixture of *P. chrysosporium* and *M. hiemalis* alone, respectively. During all the experiments, air was supplied through a compressor at a rate of 0.2–1 L/(min·kg) for every 4 hr. Moisture content and process variables were monitored throughout the composting periods. Table 1 presents initial values of process variables. Notice that results obtained for experiments 1 to 5 were the only results used in this study, as experiment 6 failed.

The analysis of carbon, nitrogen and composting temperature profiles was carried out in composting. Firstly, times taken in each experiment to reach maximum composting and maturation temperature were determined and known as the C/N ratio reached the stability 15. Then, visual inspection was also used to detect any pattern during the three main stages of composting that is by the color and the odor of the compost. These three main stages were assumed to be: (1) starting point to peak temperature, (2) peak temperature to maturation temperature (32°C), (3) and maturation temperature to process end point. The main aim was to find out how process rate can be expressed during these various stages, in order to develop a multiphase model for the process. The developed multi-phase model for total carbon (Eqs. (1) and (2)) was then used in a MATLAB/SIMULINK environment to simulate total carbon removal in experiment 5 because it shows optimum paprameters in composting process as C/N ratio 15, temperature 49°C, and pH 6.5. The results obtained were compared with results obtained for the second modeling approach (Eqs. (3) and (4)). Notice that Arrhenius temperature correction method was used in the second approach, while there was temperature correction is used in the first approach. Also the measured composting temperature (T) was used as model in put.

$$\frac{\mathrm{d}S(t)}{\mathrm{d}t} = -k(t) \tag{1}$$

$\mathrm{d}S(t)/\mathrm{d}t$ is dynamic of electrical conductivity,

$$\text{where, } k(t) = \begin{cases} k_1, & 1 < t \leqslant 6; \\ k_2, & 6 < t \leqslant 18; \\ k_3, & 18 < t \leqslant 33; \end{cases} \tag{2}$$

k is process rate coefficient, and t is date.

$$\frac{\mathrm{d}S(t)}{\mathrm{d}t} = -k(T) \tag{3}$$

$$\text{where, } k(T) = k_{20} \times \theta^{(T-20)} \tag{4}$$

where, T is temperature, k_{20} is process rate coefficient for 20 days; θ is process rate.

2 Results and discussion

As can be seen from Table 2, maximum composting temperature is attained on day 6, while maturation temperature is reached either on day 18 or 21. This indicates that despite the difference in the type of inoculm used and the difference in initial conditions (mainly pH and total carbon, Table 1), all composting experiments had reached maximum temperature and completed the various composting stages as pH, temperature and C/N ratio in almost the same time. Further, almost the same magnitude of maximum temperature (46–49°C) was reached (excluding 42°C for experiment 1, Table 2). It is noticed that the experiments were carried out under controlled conditions, which are aeration and moisture content. These results and the patterns of changes carbon and nitrogen concentration were calculated and noticed.

Visual analysis of carbon and nitrogen profiles (Fig. 1) indicates that the total carbon and nitrogen is almost constant until peak temperature is reached (Table 2). It also shows that after peak temperature is reached the process proceed with an almost constant new rate of change until

Table 1 Values of the monitored variables at the beginning of the experiments

Experiment	1	2	3	4	5	6
Temperature (°C)	24	23	24	23	24	23
Moisture content (%)	80.2	82	80.2	82	82	80
pH	4.29	7.27	4.29	7.27	4.29	6.6
EC (dS/m)	1.8	1.83	1.8	1.83	1.8	1.78
Total carbon (%)	52.47	40.39	52.47	40.39	52.47	50.1
Total nitrogen (%)	6.2	5.6	6.2	5.6	6.2	5.9
C/N ratio	8.46	7.21	8.46	7.21	8.46	8.49

EC: electrical conductivity

Table 2 Maximum and maturation temperatures and time needed to reach them

Experimental number	Peak temperature (°C)	t_{max} (day)	Maturation temperature (°C)	t_{max} (day)
1	42	6	32	21
2	46	6	32	21
3	47	6	32	18
4	48	6	32	18
5	49	6	32	21

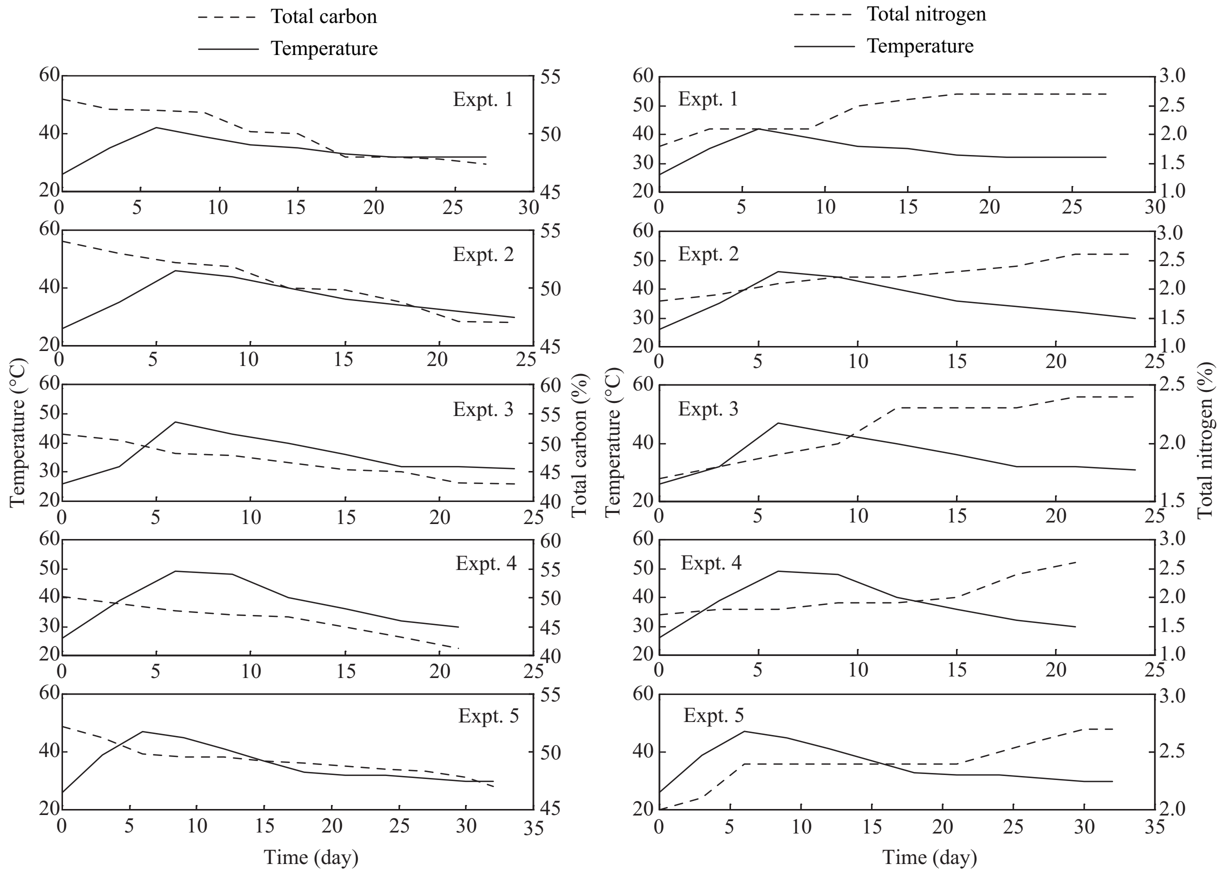

Fig. 1 Profiles of composting temperature and total carbon or total nitrogen of the experiments.

maturation is reached (32/33°C). From maturation to the end of the process there is also another constant rate of change. All these hint that there are patterns of change in the process rate during the three mentioned stages of the process.

Figure 2a shows the results of MATLAB/SIMULINK simulations of experiment 5, using the multi-stage modeling approach (Eqs. (1)–(2)). As can be seen, the model proved to predict very well measured values, except slight deviations during day 6 to day 12, which are corresponding to temperature-declining in the thermophilic phase (Fig. 1). This is confirmed by the very small magnitude of maximum residual error (about 0.2%). Estimates of the three process rate coefficients (k_1, k_2, k_3) used in this approach were found to be 0.0075, 0.0013, and 0.0077, respectively. In contrast, Fig. 2b shows the best fit, which obtained at k_{20} = 0.0008 and θ =1.0799, when the second modeling approach was used. It is clear that obtained

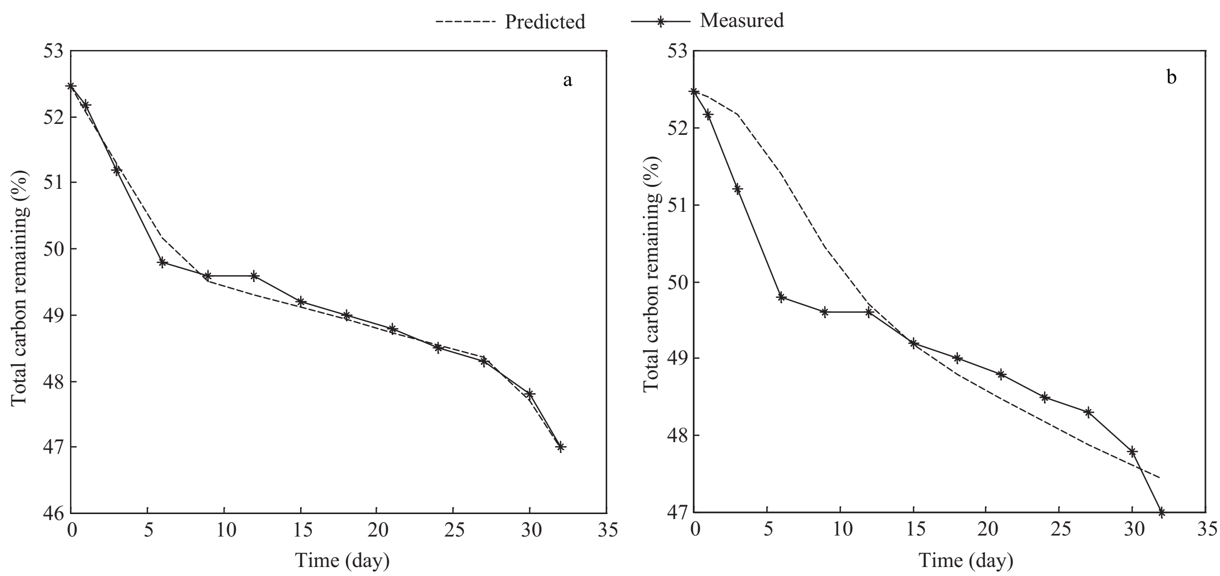

Fig. 2 Measured vs. predicted remaining total carbon using three process rates without temperature correction (multi-stage model) (a), and using single first-order process rates without temperature correction (single-stage model) (b).

results accurately describing the system dynamics.

Although the multi-stage modeling approach seemed to be more appropriate for modeling the dynamics of the composting system, it has limitations that need to be taken into account. The major limitation is that the information about the time needed to reach peak and maturation temperatures must be known a priori. Exact information about peak temperature time is always not available. However, approximate information about when peak temperature will be reached can be obtained from literature (Keener and Marugg, 1992; Marugg et al., 1993) and from previous experiences with the composting material and the composting system. If composting temperature will be measured on-line, maturation time can be assigned to time when composting temperature drops to 32/33°C. However, before applying the second modeling approach, the patterns detected here need to be verified and confirmed. Besides, the conditions of the experiments which the formulation based on are limited, and the results maybe different from the real operations.

3 Conclusions

Modeling of sewage sludge process as a multi-stage process was found can accurately describe the composting process, where the final C/N ratios of the compost in most experiments were found to be around 15.0, indicating the compost is fully matured and can be used safely for agricultural purpose. During composting, the heavy metal content also decreased below the acceptable limit. The pH decreased to 6.5. A slight increase in pH to 7.1 occurred as soon as the temperature of the compost increased to 49°C. Electrical conductivity of composting material decreased from 1.83 to 1.67 dS/m, after a period, it increased gradually from 2.01 to 2.23 dS/m and remained at around 2.33 dS/m till the end of composting. Important stages in dynamic modeling of sewage sludge composting process seem to be the following: (i) process starting point to peak temperature, (ii) peak temperature to begin of the maturation phase (32/33°C), and (iii) begin of the maturation phase to process end.

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