DESIGN, CONSTRUCTION AND MONITORING OF A COMPOSTING SYSTEM USING ARDUINO AND PYTHON

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Abstract. Was developed a mathematical model for the study of the growth of bacteria in the compost process, this mathematical model was solved numerically and found that temperature plays an important role in the growth in the composting process. An increase in temperature benefits bacteria involved in decomposition of organic matter, while it decreases the population of pathogenic bacteria, which inhibit the process of composting.

Key words: *Compost, Jacketed reactor, Matter balances, Energy balance, System of nonlinear ordinary differential equations, Microbial growth equation.*

INTRODUCTION

It is known that the composting offers an excellent alternative to minimize problems of, combined with a culture of waste sorting, simple and practical treatment may become to convert the non-usable organic matter in perfect pass and used in various applications in the area of agriculture or to remediate soils. Compost has a high content of organic matter, these materials begin a process of decomposition or mineralization, and change its organic form (living things) to inorganic forms (mineral, soluble or insoluble).These minerals flow through the soil solution and finally are used by plants and organisms, or stabilized into humus, through the process of humification. It is recommended, before making applications of compost or organic matter, such as mineral fertilizers, perform soil analysis to control the levels of nutrients. The necessary nutrients for the growth of the plant come from air, water and soil, the soil solution being the means of transport of nutrients [1]. The composting process is necessary for the reduction and use of solid organic waste, ensuring correct application and use. It may help farmers to have a better profitability in their processes of crops or it can be commercialized.

METHODOLOGY

Theoretical methodology.

A system of ordinary differential equations which is obtained from the material balance of the system for the concentration of bacteria and organic matter concentration was used to model the dynamics of the composting system.

Balance of matter.

The proposed mathematical model considers the competition of two species of bacteria (pathogenic bacteria and bacteria useful for the composting process or encouraging) and the use of a substrate by both bacteria. The proposed model obtained through the bioreactor material balance is as follows:

$$\frac{dC_s}{dt} = \frac{C_{s_0}}{V} - \frac{C_s}{V} - Ys_{/c_1} f_{1n}(k_s, C_s, r_{\max})C_x - Ys_{/c_2} f_{2n}(k_s, C_s, r_{\max})C_y - m_1 C_x - m_2 C_y,$$

$$\frac{dC_x}{dt} = \frac{C_{x_0}}{V} - \frac{C_x}{V} + f_{n1}(k_s, C_s, r_{max})C_x - \alpha_1 C_x C_y, \quad (1)$$

$$\frac{dC_y}{dt} = \frac{C_{y_0}}{V} - \frac{C_y}{V} + f_{n2}(k_s, C_s, r_{\max})C_y - \alpha_2 C_x C_y,$$

where C_s y C_x y C_y are the concentration of substrate, which promote bacteria and pathogenic bacteria, respectively. Parameters of the system are: V volume of system and f is some function that represents the rate of bacterial growth [1-4].

Parameters V, volume of bioreactor, $Ys_{/c_1}$ and $Ys_{/c_2}$ are the factors of performance of the substrate for both beneficial and pathogenic bacteria, respectively. The factors K_s, k, $r_{máx}$ and n are parameters associated with the bacterial growth rates.

If we consider that C_s, C_x, C_y, C_{s_0}, C_{x_0} y C_{y_0} are zero due to the intermittent operation and adds a bacterial natural death rate, the equations are converted in:

$$\frac{dC_s}{dt} = -Y_{s/c_1} f_{1n}(k_s, C_s, r_{\max}) C_x - Y_{s/c_2} f_{2n}(k_s, C_s, r_{\max}) C_y - m_1 C_x - m_2 C_y,$$

$$\frac{dC_x}{dt} = f_{n1}(k_s, C_s, r_{max}) C_x - \alpha_1 C_x + \beta C_x C_y, \qquad (2)$$

$$\frac{dC_y}{dt} = f_{n2}(k_s, C_s, r_{max}) C_y - \alpha_2 C_y - \gamma C_x C_y,$$

where parameter α_i is associated with the influence of temperature on bacterial growth rates and parameters β y γ are associated with the natural death rates in flattering and pathogenic bacteria, respectively. Parameter α is directly related to the temperature of the system and as it was discussed in the previous section, the increase in temperature decreases the population of pathogenic bacteria and benefits the increase of the population of thermophilic bacteria, the latter they are responsible for the decomposition of organic matter for the obtaining of the compost.

Balance of energy.

When there is no spatial in the system volume variations, and changes over time with respect to the product of the total pressure by volume (pv) are negligible, the energy balance, in the case where there are no phase change [1, 2, 5, 6]:

$$\frac{dT}{dt} = \frac{\dot{Q} - \dot{W}_S - \sum F_o Cp_i (T - T_o) + [-\Delta H_{rxn}(T)](-r_A V)}{\sum N_i Cp_i} . \qquad (3)$$

Equation (3) is applicable to a semi-continuous reactor and also a CSTR in unsteady-state operation [1, 2, 6, 7].

An intermittent reactor tends to be well mixed, so that it is possible to despise variations give the temperature and concentration of species. The balance of power for intermittent reactors is matching $\sum F_o$ to zero in the equation (3), to obtain [1, 6, 8]:

$$\frac{dT}{dt} = \frac{\dot{Q} - \dot{W}_S + [-\Delta H_{rxn}(T)](-r_A V)}{\sum N_i Cp_i} . \qquad (4)$$

Often used intermittent reactors operating adiabatically to determine the reaction orders, activation energies and the specific rate of reaction for exothermic reactions, monitoring temperature against time paths for different initial conditions. For the operation of an intermittent reactor ($F_o = 0$) and when the work done by the stirrer is negligible $(\dot{W}_S \cong 0)$, equation (4) can be written as follows [2, 5-9]:

$$\frac{dT}{dt} = \frac{[-\Delta H_{rxn}(T)](-r_A V)}{\sum N_i Cp_i} \qquad (5)$$

with:

$$\sum N_i C_{p_i} = \Delta C_{p_i} , \qquad (6)$$

where the sum of M_i is the total mass and $C\tilde{p}_i$ is the heat capacity at constant pressure average of each species. In the case of an intermittent reactor, with a bacterial growth following the Monod equation, whereas encouraging bacteria and pathogenic bacteria, combining the equation 5 and the bacterial growth equation we obtain [1-4, 8, 10]:

$$\frac{dT}{dt} = \frac{\mu_{máx}[Cs]}{k_\mu + [Cs]} V C_x \frac{\Delta H_{rxn}}{\Delta C_{\tilde{p}}} + \frac{\mu_{máx}[Cs]}{k_\mu + [Cs]} V C_y \frac{\Delta H_{rxn}}{\Delta C_{\tilde{p}}} , \qquad (7)$$

where $\frac{dT}{dt}$ is the temperature differential time representing each stage according to the temperature change during the time in which the process takes place, $C_{\tilde{p}}$ the average capacity at constant pressure of a kind used, V is the total volume of the system and ΔH_{rxn} is the heat of reaction.

Experimental methodology.

1. It was built a composting system using an intermittent jacketed reactor of glass that allowed to install sensors with open system (Fig. 1a).

2. It was selected the organic matter and it was placed inside the jacketed reactor, which was obtained from household waste (Fig. 1b and 1c). The organic matter was selected and weighed.

Figure 1. a. Jacketed glass reactor, b. Weighing of the substrate and c. Reactor substrate

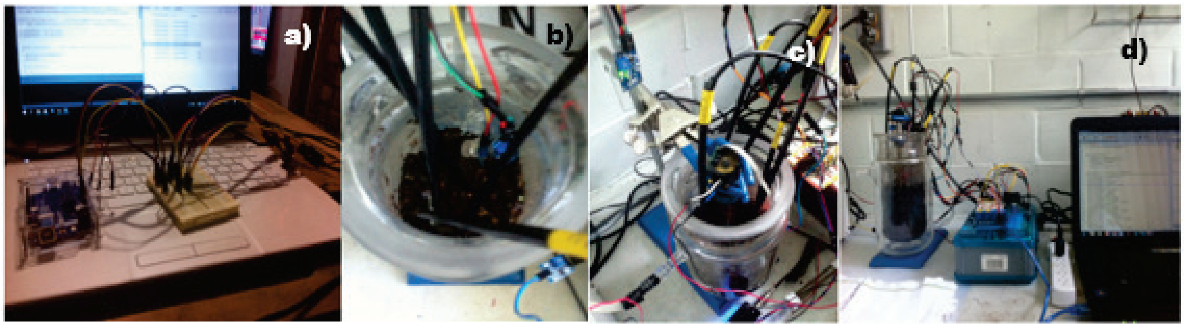

Figure 2.a) connection of the sensors to Arduino card, b) location and tests of the sensors in the reactor, c) testing sensors and agitator and d) installed sensors

RESULTS

Implemented the general equation of balance for both considering both the bacterial growth, such as intermittent operation, the model is transcribed and resolved to observe the quantitative and qualitative response to the Python programming language. A way of expressing the quantitative response is by means of graphs of numerical data that yielded the solution of the model, as shown in Figures 3 and 4.

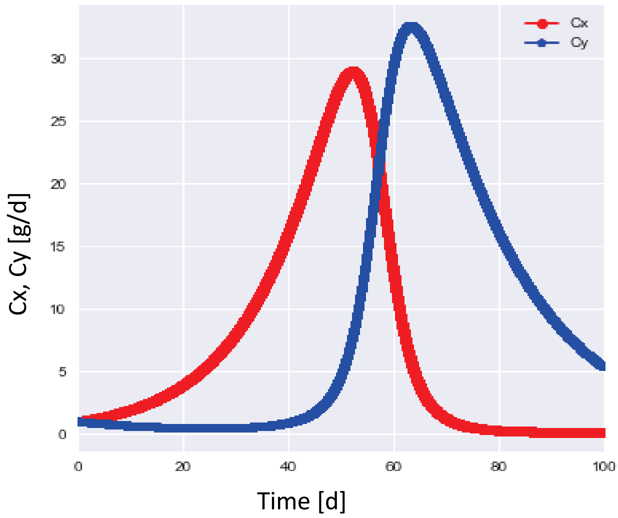

Figure 3. Population of microorganisms. You can see the interaction between the population of beneficial bacteria (Cy) and the population of pathogenic bacteria (Cx) with respect to time. The parameters used were consulted in the literature

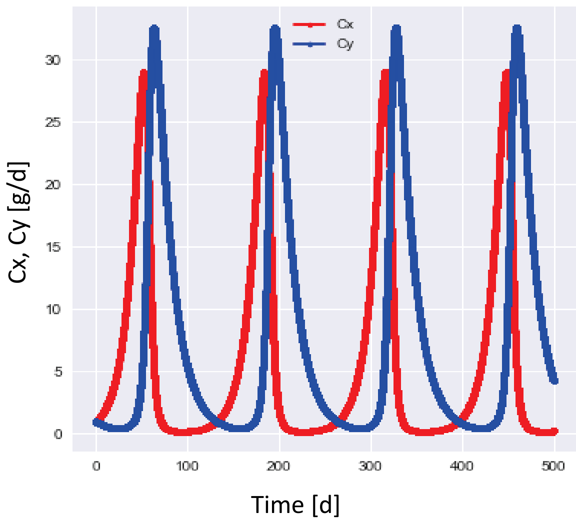

Figure 4. Population of microorganisms. According to the dynamic that occurs during the time of conversion to humus the organic matter, the behavior among the population of beneficial bacteria (Cy) and the population of pathogenic bacteria (Cx) ranges, due to the conditions and the growth cycle microbial as shown in graph 2

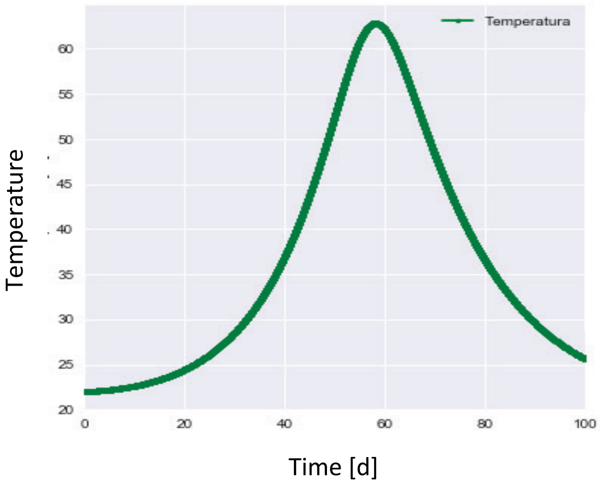

Figure 5. Temperature. According to the characteristic phases of composting time, a temperature is reached maximum of 65 to 70°C to ensure the sanitation of the final product, this figure is observed such behavior, which was described with the energy balance

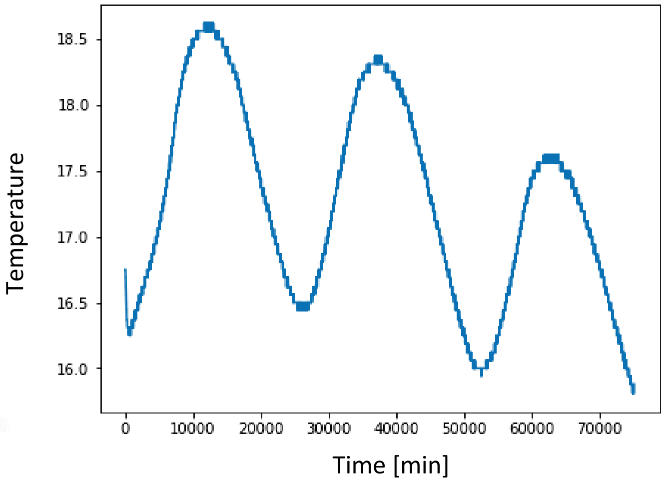

Figure 6. Temperature. This graph shows three days of monitoring, and you can appreciate the same way that threw the model

Monitoring.

It can be compare the graphs of the results thrown by the Python software and with the data obtained from the monitoring plotted, as seen in the Figure 6.

CONCLUTIONS

1. Temperature is an important factor for the growth of thermophilic bacteria, which is responsible of the decomposition of organic matter in the compost.
2. The temperature increase allows the decrease in the population of pathogenic bacteria in compost (which inhibit the composting process).
3. The Monod model in combination with the 2 equations is a good approximation for understanding the dynamics of populations of bacteria in a composting process.
4. It is necessary to introduce the effect of temperature and humidity in the mathematical model to explain in more detail the dynamics of the system.

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