(074) DESIGN AND CONSTRUCTION OF A REPLICATED COMPOSTING SYSTEM AT LABORATORY SCALE: TECHNICAL CHARACTERISTICS AND FIRST HOMOGENEITY TEST

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EXECUTIVE SUMMARY

Composting is one of the most popular methods to treat those organic wastes which could be transformed into an useful compost. Due to this, the number of scientific and technical studies about composting is increasing every year. However, on most of those works only the initial and final products are analysed, due to the impossibility of taking homogeneous samples from the composting matrix without disturbing it, especially on closed composting systems like bioreactors. This work shows the technical and operational characteristics of a laboratory scale composting system composed of replicated bioreactors, designed with the aim of allowing destructive sampling through the process, thus obtaining useful data without disturbing the composting matrix or process. The results obtained with the first on-load trials are also show.

The system consist of 12 identical bioreactors, 30 litres capacity each one. All of them are connected to a ventilation system equipped with 24 electrovalves to control which bioreactor will be ventilated. A single air compressor, fitted with a 100 litres tank, supply a constant amount of air to this system, being controlled the air flow by an analog electrovalve and a mass flow meter. The control and monitoring of all the system is made by a Siemens Microbox 340, connected by Profibus to the input / output modules. This control system registers all the data from the sensors (temperature, oxygen, carbon dioxide, ammonia and air flow from each bioreactor), and controls all the electrovalves. The control program allows to fix a constant air flow rate, which will be maintained during all the composting process if ventilation is activated, regulated by a PID control of the analog electrovalve. The ventilation will be activated automatically if the set points for the maximum temperature or the minimum oxygen concentration are achieved (those set points are determined by the operator). A queue control system have been programmed to organize the order and way of ventilating the bioreactors connected to the system.
The on-load trials were developed with fishery sludge mixed with 1 cm bulking agent obtained from garden wastes, on a 1:2 ratio (sludge : bulking volume). 10 Kg of mixture was loaded into each bioreactor, setting as control parameters a maximum temperature of 55ºC, minimum oxygen concentration of 5% and 30 litres per minute of air flow. The trial started with 12 biorreactors. 3 biorreactors were logged off from the system and sampled at several key moments of the composting process: mesophilic – termophilic interphase (45ºC), termophilic phase (55ºC) and final mesophilic phase (35ºC). The material inside each bioreactor was homogenizated and analysed by triplicate for total weight, water content, organic matter, pH, electric conductivity, ammonia and nitrate,.

The temperature and oxygen uptake evolution was homogeneous for all the bioreactors, reaching all of them the thermophilic phase during the first 30 hours of the trial. The queue control system worked as expected, not being detected any bioreactor which suffered thermic or oxygen process inhibition due to being not ventilated when needed. Due to the sludge used, a high level of ammonia, which caused high electric conductivity values, was detected. The standard deviation detected for all the measured parameters were small, and all of them evolved within the limits considered correct for the composting process.

Both the continuous measured parameters and the results obtained from the matrix analysis of bioreactors logged off at the same time shows an homogeneity enough to consider them as “replicates”. For this reason, this composting system allow to sample in a destructive way during the composting process.

1 INTRODUCTION

Composting is one of the most popular methods to treat organic wastes, transforming them into useful compost to use as a organic amendment. It’s a natural method which takes places spontaneously when the correct conditions are held, so it was used to recycle organic wastes almost since the start of the agriculture, dating even from the middle ages the first wrote about composting techniques. But perhaps this robustness was also the main problem for the composting process,

not encouraging the realization of deep and scientific investigations on how the composting takes places until some decades ago.

Nowadays, there is a huge amount of scientific and applied work related to the composting process, to understand and know how the organic matter is transformed into compost by the microbial activity. When the composting system analysed is a dynamic one (with turns over to mix and homogenize the material), usually the sampling is made just after the turn over, so the sample will be easier to take and more representative. But, if the process technology studied is a closed one (like tunnels or bioreactors), where the material is kept still all along the process, the fact of taking a representative sampling interfere with the correct development of the process due to the effects the sampling process has over the organic matrix, composting atmosphere, etc.

1.1 Research objectives

The main objective of the present work is to design, built and test a laboratory scale composting systems with several reaction vessels. The process evolution and control should be keep stable and homogeneous between the bioreactors, thus allowing to consider them replicates so destructive sampling techniques could be used.

2 METHODOLOGY

We have tried to keep as many common elements as possible on the design of this replicated bioreactor system, thus to avoid differences caused by the utilization of different models or brands for each unit. This required the design and development of a control software capable of administering on a correct way the common elements, so that the composting process evolve on a correct way into all the individuals bioreactors, and the control system must be also homogeneous for all of them, thus minimizing the differences.

2.1 Description of the replicated composting system

The system consist of 12 individual bioreactors, 30 liters capacity each, designed as stated in Mato *et al* (1994). Each bioreactor is made of a PVC cylinder. The air entry is located at the bottom, through a perforated pipe system located on the “plenum” chamber (Figure 1). This chamber allows to distribute the fresh air homogeneously through the composting matrix, and also works as a reservoir in case any leachate would be produced, separating them from the lower layers of organic waste and thus avoiding the anoxic conditions due to flooding of that material. Into this plenum chamber there are also 4 plastic pieces, 3 centimetres high, which held a metallic mesh which works as support for a plastic mesh with 2 millimetres perforations. This thin mesh keeps the organic material from falling into the plenum chamber, thus collapsing it, while allowing the leachates to fall and the air to go through it. To achieve a good thermal isolation of the bioreactor a 3 centimetres wide rockwool layer have been arranged. The cylinder screw top lid can be closed with enough pressure to assure a hermetic closing, thanks to a plastic joint between the lid and the bioreactor body.

This lid is equipped with 3 perforations, closed with pressure joints. Two of them are devoted to allow the introduction of the thermal probes, 3 wires PT-100 of two different length into each bioreactor (20 and 40 centimetres long). The third pressure joint is equipped to allow the conection of the pipe for the evacuation of the air inside the composting matrix (Figure 1).

The air for the composting system is supplied by a compression engine equipped with a 100 litres reservoir, were the air is storaged up to 8 bar pressure. This allows a continuous flow of air when needed, minimizing the variations caused by the turn on and off of the ventilation engine (which are even more intense when a centrifugal fan is used, as in most composting facilities). At the air reservoir exit there is located a water and oil filter, which cleans the air before sending it towards the mass flow meter which will control the air volume allowed to enter the composting system. This flow meter is equipped with a built-in analogic eletrovalve and PID control, and allows to keep a stable air flow at any value between 0 and 50 litres per minute.

Behind the mass flow meter there is a common tube, from which the 12 derivations towards the bioreactors goes out. Each derivation is closed by a digital electrovalve, in such way only one of those valves can be open at a given time so the air can enter only a single bioreactor. Thus, is possible to know how much air have been used to ventilate each bioreactor. A second tube takes the exhaust air from the bioreactors and leads it towards a Y junction, where one of the branches directs a sample of the air to the gas analyzers and the other drives the remaining amount of air to the atmosphere. There is a second digital electrovalve on the air exhaust of each bioreactor, so only the one belonging to the bioreactor which is being ventilated is opened at a given time. This has a double function: to avoid that the air from the ventilated bioreactor could enter another one, and also to avoid the Venturi effect, which could imply a suction of the

air from the other bioreactors. Thus, we can be sure that only the air from a single bioreactor will be driven to the gas analyzers each time.

The gas analyzer system is composed of a pre-treatment system, which cools the air up to ambient temperature and retains the moisture content. Then a air sample (about 2 millilitres per minute) is driven to a electrochemical oxygen detector and to a infrared carbon dioxigen detector. There is only a single gas analyzer device for the whole composting system, so only one sample from a single bioreactor can be analysed at a time.

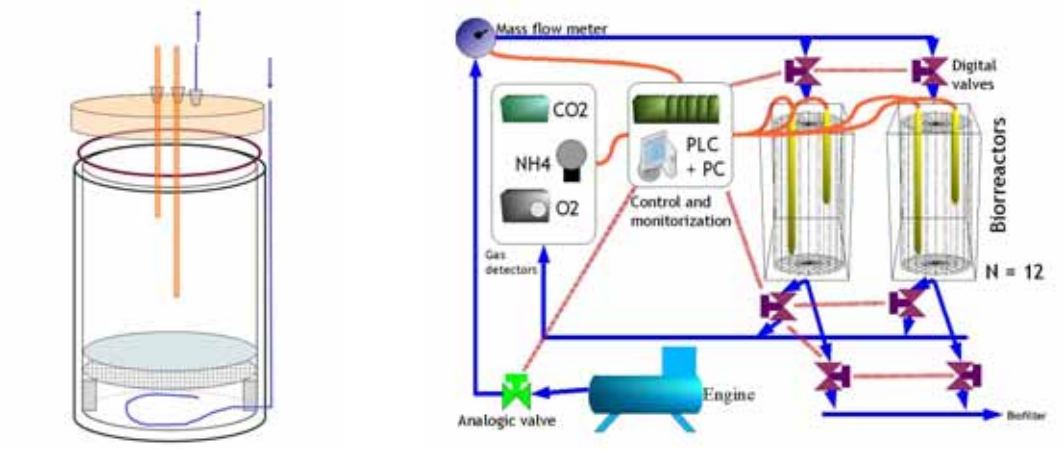

FIGURE 1 Schemes of a single bioreactor and the composting system

The monitorization and control of the whole system is based on a Siemens Simatic Microbox 420, equipped with Profibus field bus and connected to the input / output modules (figure 2). The PLC software have been developed on Step 7, and the HMI interface and control SCADA with WinCC.

FIGURE 2 General view of the composting system (left) and control and monitoring system

The goal of this control software is to keep the operation conditions within the limits consider optimal for the composting process, avoiding that the temperature rise goes over a chosen value, or that the oxygen concentration into the composting matrix could be reduced to anoxic values. Those conditions and control parameters will be always identical for all the bioreactors active connected to this system, although the fact some control equipments are common for all the system (mass flow controller, gas analyzers, air reservoir), prevent that more than a single bioreactor can be ventilated at the same time.

When none of the bioreactors connected to the system presents a temperature over the maximum assigned value, or a oxygen concentration below the set limit, it's consider that the system is on "operation mode". In this situation a small amount of air flow is flowing constantly into the system (this is denominated "process flow"), which helps that a sample of the inner atmosphere from inside the composting matrix reach the gas analyzers on

a suitable amount of time. It's important that this volume of air flow doesn't interfere on the correct development of the composting temperature evolution, above all on critical stages like the initial mesophillic to termophillic transition. Only the air sample from a single bioreactor can be sent towards the gas analyzers at a time, so the entry and exhaust digital electrovalves of each bioreactor opens in turns one after another. This means that, once a bioreactor air has been analysed, that same bioreactor won't be analysed again until all the remaining bioreactors have also been. This made basic for a fast response this "operational air flow", which allows to measure the inner atmosphere of each bioreactors on the less time possible and frequently.

To control the gas monitorization two counters have been programmed on the PLC. The counter denominated "purge" allows the operation air flow to pass trough the bioreactor but no data is recorded, because the presence into the system of remaining air from the last measured bioreactor could interfere with the measure. Once the tubes and gas analyzers have been purged, the "measure" counter is started, being recorded the data loaded from the gas sensors and associated into the SQL database to the bioreactor number which is being analysed.

When the control devices detect a temperature excess or a oxygen concentration below the chosen value, the systems enters the "alarm state". During this stage the gas analysing cycle is stopped and the systems vents the bioreactor which is "in alarm", blowing air at the "alarm flow rate", which should be much higher than the "operation flow rate" because it's objective is to cool and oxygenate the compost matrix on the less time possible, but without committing an excess that could affect the evolution of the composting process. The air flow will be maintained as long as the "alarm condition" is on. If any other bioreactor enters the alarm condition while another one is ventilated, it will be situated on the "alarm queue" and will be ventilated as soon as the prior one is controlled and out of the alarm state. Once all the alarm reactors are controlled, the systems goes back to the "operational mode" and resume the gas analysing cycle on the same bioreactor it was stopped when the alarm got started.

This means that it's crucial for the correct development of the composting process, and to avoid differences between bioreactors, that the waiting time on the "alarm queue" would be the less possible. In such way, when a bioreactor enters the alarm state it should be attended on the less time possible.

The control software developed allows to take out from the systems any bioreactor during a experimental run (Figure 3). It could be to destroy that unit and proceed to it's analysis, or just to check some parameters and incorporate it again later. When a bioreactor is marked as "retired", the system stops registering it's temperature values on the SQL database, likewise that unit is not taken into account for the gas analysing cycle, "jumping" over it to the next active bioreactor. This is the cause that the gas analysing cycle will be shorter as more bioreactors are taken out from the system, improving the gas monitoring efectivity.

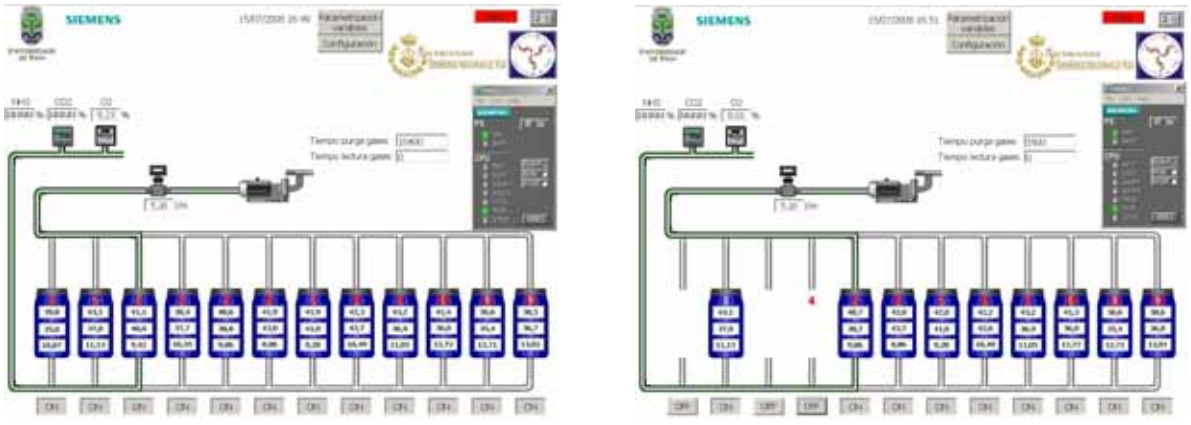

FIGURE 3 Control screen. With the 12 bioreactors active (left) and with some retired from the system (right)

2.2 First "on load" test

For the first test a wastewater sludge obtained from a fishery cooking industrial facility was chosen, which is characterised by a high level of labile organic matter and absence of recalcitrant contaminants like heavy metals. This same sludge have been used on several composting trials before at our facilities (Perez, D. *et al* 2006).

The table 1 shows the analytical results for the sludge used.

TABLE 1 Analysis results for wastewater sludge

	Sludge
Moisture content (%)	71.09
Volatile Solids (%)	94.38
pH	4.1
Electric conductivity (mS . cm^{-1})	0.60
N-NH_4^+ (mg . Kg^{-1})	290.48
N-NO_3^- (mg . Kg^{-1})	55.53

This sludge was mixed with green waste from city gardens cleanings minced to less than 1 centimetre pieces, which will work as bulking agent to achieve a proper pore structure. The mixture was made on a proportion of 2 volumes of bulking agent for each volume of sludge. Only a mixture was made, with enough amount to fill the 12 bioreactors to be used on the test, so the homogeneity of the mixture between the bioreactors would be the higher possible. Each bioreactor was filled with 10 Kg (fresh weight) of mixture and logged on to the system immediately.

The operation and control conditions set for this test were:

- Operation air flow: 5 litres per minute
- Alarm air flow: 30 litres per minute
- Maxim temperature: 55ºC
- Control thermal probe: the one with the highest value
- Minimum oxygen concentration: 5%
- Air purge time: 30 seconds
- Air measure time: 10 seconds

Four keys moments of the composting time were selected to destroy bioreactors from the system and analysing them:

- Mesophillic to termophillic interphase (around 45ºC)
- Start of the mesophillic plateau, when the bioreactors reach the 55ºC temperature.
- End of the meshophillic plateau, when the material inside the bioreactors can't achieve again the 55ºC temperature after being cooled by the aeration system, thus starting the temperature descent towards mesophillic conditions.
- End of the composting process at mesophillic temperatures.

On each of those moments 3 bioreactors were randomly selected, disconnected from the system and destroyed to be analysed. The parameters analysed on each bioreactor were: total fresh weight, leachate volume (if any), moisture content, volatile solids, pH, electric conductivity, ammonia and nitrates.

3 RESULTS AND DISCUSSION

The results obtained shows that the evolution of both temperatures were very similar on all the 12 bioreactors. Figure 4 shows the evolution of the upper layer temperatures obtained during the test. To make easier to read the bioreactors were separated according to the moment they were destroyed. Thus, graphic A shows the temperature evolution for the bioreactors destroyed at the mesophillic – termophillic interphase, graphic B shows the temperature evolution on the bioreactors destroyed at the start of the thermophillic plateau, graphic C the bioreactors destroyed at the end of the thermophillic plateau and graphic D the bioreactors maintained until the final of the composting process.

The stardard desviation between the different temperatures is low, ranging from 0 to 3 degrees. Only at the end of the process (hour 160, figure 4 – D) a higher difference was detected between reactor number 11 and the reactors 7 and 4. This different was caused, most probably, by a power failure happened during the night (empty space on the graphic). After this power failure a lower temperature was detected on all 3 remaining bioreactors, and even after resuming the surveillance and control of the system all 3 units kept loosing temperature. However, bioreactors 7 and 4 resumed a high rate of microbiological activity about 50 hours later after the power failure, reaching again the termophillic plateau, while bioreactor 11 wasn't able to recover from the initial loss of temperature.

The evolution of the temperature on the lower layer of the bioreactors were also homogeneus (figure 5), being this the layer most subjected to sudden changes due to be closer to the fresh air entrance. However, the standard deviation detected between those temperatures ranged from 0 to 4 ºC during most of the test, being only higher on the last phase of the composting process due to the different behaviour of the bioreactor number 11.

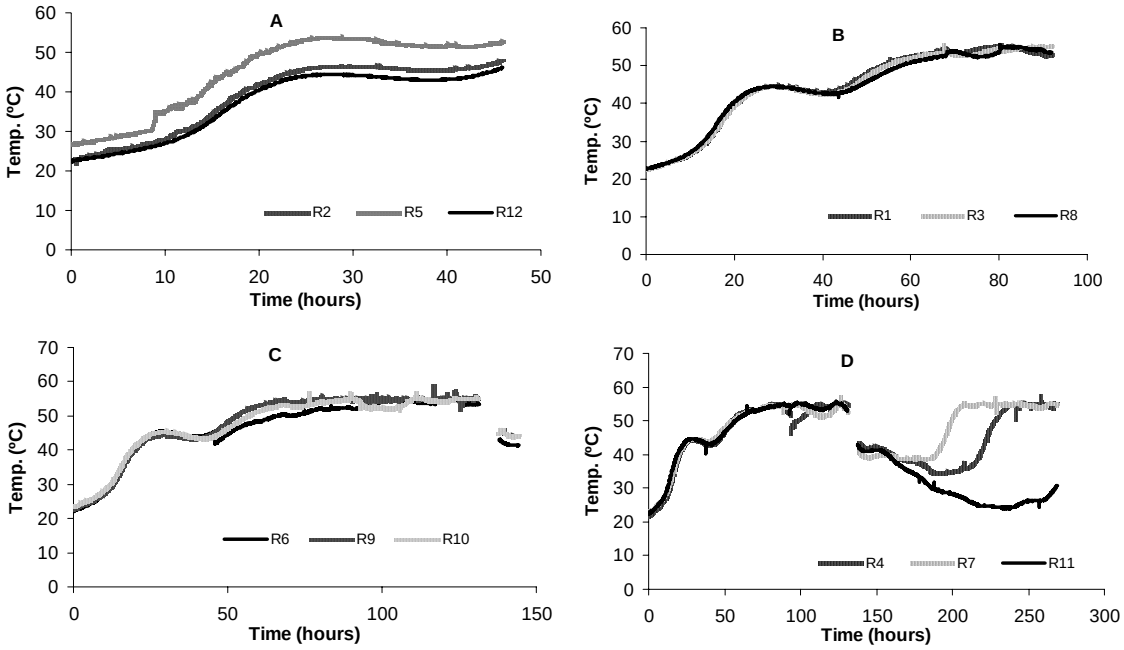

FIGURE 4 Evolution of the upper temperature on the bioreactors

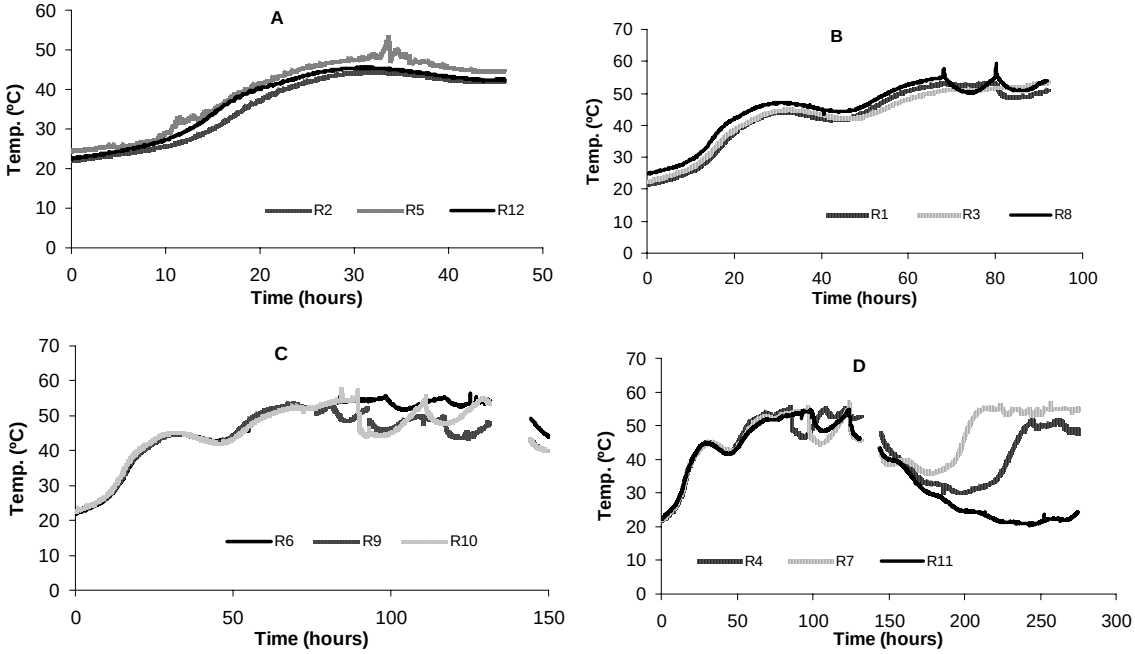

FIGURE 5 Evolution of the lower temperature on the bioreactors

Both air flow selected worked as expected. The operation air flow allowed an accurate measure of the oxygen concentration into each bioreactor, being obtained stables measures. The alarm air flow, of 30 litres per minute, were enough to control both the anoxic conditions and the temperature raising easily. The average time an alarm condition needed to be controlled were of 1.2 minutes, thus not being needed the "alarm queue" because each bioreactor was controlled fast enough. This implies all the bioreactors were attended immediately when the alarm conditions were reached, so none bioreactor reached a temperature over 60ºC or anoxic conditions.

Also, a need to introduce on the program a hysteresis parameter for temperature was detected. Meanwhile the oxygen value had some inertia, so when a bioreactor was ventilated due to a lack of oxygen usually the final value went beyond the alarm "set point", with the temperature things evolved on a different way. Once a bioreactor reached 55ºC the

system started to introduce fresh air to cool it, until it reached just below 55ºC. Just then, the system went back to "operation mode", but it was only a matter of seconds for the bioreactor to reach 55ºC again, shooting the alarm state again. This caused that the gas measurement cycle took a lot longer to be completed, due to the frequent stops the systems should made to attend the bioreactors on alarm state.

Having a hysteresis value of 1ºC for temperature control would mean that, once a bioreactor reach the 55ºC, the system will cool it until 54ºC, thus separating it from the high temperature set point. The time the microbial biomass activity inside that bioreactor will need to rise the temperature to 55ºC again will be enough, then, to perform a gas analysing cycle on the remaining bioreactors, thus allowing to control their oxygen level in a more accurate way.

The result obtained from the analysis performed to the material showed the high level of degradation achieved by this material. Figure 6 shows the results obtained for the net weight of total and volatile solids. On both graphics a continuous degradation through all the process is detected, with small standard deviations between each replicate.

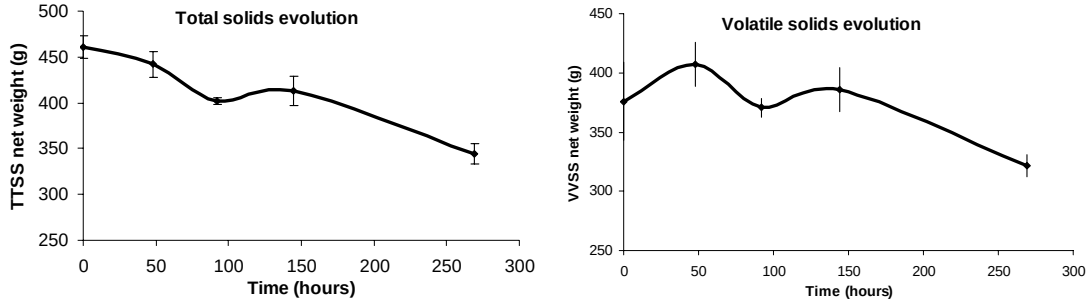

FIGURE 6 Total and volatile solids evolution

On figure 7, the ammonia concentration evolution is shown. This increase on the ammonia levels can be explained by the high protein concentration on this sludge. Most of this ammonia produced will be retained by the moisture content of the composting matrix, thus increasing the electric conductivity of the material as show on figure 7 also.

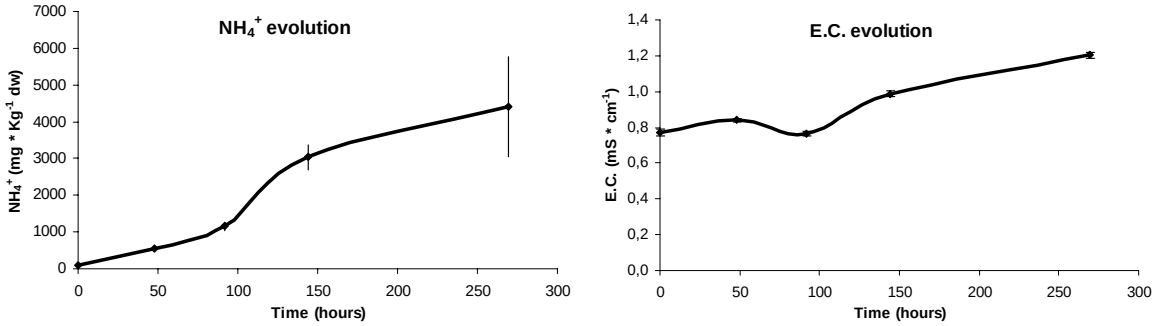

FIGURE 7 Ammonia and electric conductivity evolution

Also, as a indicator of the correct evolution of the composting process inside those bioreactors, a constant production of nitrate have been detected, as show on figure 8.

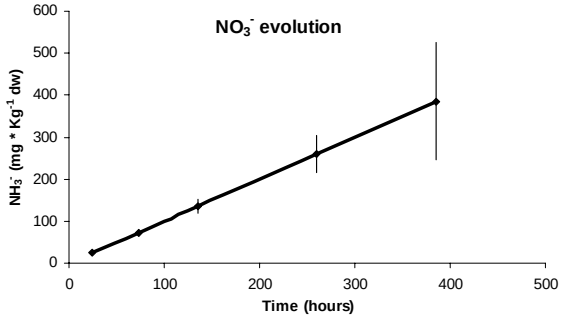

FIGURE 8 Nitrate evolution

The evolution of all the parameters measured on this first "on-load" test is within the limits of what is considered accurate for a correct developed composting process, being the standard deviation detected between replicates small, except for the final values of ammonia and nitrate.

4 CONCLUSIONS

The results obtained shown that the evolution of both the "on-line" measured parameters (temperature and oxygen), and the parameters analysed on the destructive sampling is homogeneous, progressing all the bioreactors on the same way along the composting process.

The control software developed for this system can control the process evolution, so no differences are detected between the vessels and the temperature and oxygen concentrations evolves on all of them correctly.

This system can be useful to carry out composting trials with destructive sampling, thus allowing to sample and analyse the organic matrix without disturbing the process.

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