Degradation dynamics of several organic matter pools in food processing sludge at different composting temperatures

D. PEREZ*; F. SOLE**; A. RODRIGUEZ*; L. SAMPEDRO****; X. FLOTATS*** & S. MATO*.

**Universidad de Vigo; **Universidad de Lleida; ***GIRO CT.; ****Centro de Investigaciones Forestales de Lourizan. SPAIN*

SUMMARY: Hydrolysis has been proved as a key factor on biological treatment process like anaerobic digestion or water purification facilities. Regarding to composting, some previous works made with vegetable fibres has demonstrated the slow speed of this process for this pool of organic matter (Tuomela et al, 2000), neverless, the experiences related to this process are only a few (Komilis, 2006). The present work deals with the study of the hydrolysis process into the composting by the following of the degradation of several organic matter pools at four key temperatures of the composting process (20, 37, 50 and 60ºC). The waste used in this work was a mixture which contained all the main groups in which the organic matter can be divided, this means several kinds of carbohydrates, proteins and lipids; this was the reason a sewage sludge from a fish processing factory was chosen, with poplar bark as bulking agent. The mixture was introduced into independent experimental containers (N=15), which were maintained at the different temperature treatments during 15 days. A destructive sampling was made at the 1, 3, 6, 10 and 15 days of the process. This experimental design showed to be rather adequate to the process study, being obtained useful data which shows that the degradation of each component of the organic matter took place at different process moments, and not as a homogeneous whole.

Composting, organic matter degradation dynamics, fishery sludge.

1 Introduction

Composting has been defined as a controlled bio-oxidative process, were a heterogeneous organic substrate on solid state achieve a thermophilic stage and a transitory phytotoxin liberation, being obtained as a result carbon dioxide, minerals and a stabilized organic matter denominated “compost” (Zucconi and De Bertoldi, 1986).

At the present, composting is taking into account as an optimal solution for all those organics wastes which doesn’t present any recalcitrant contaminant which could impede the agronomic use of the obtained compost. For this reason, each year new industrial facilities, devoted to organic waste composting, are built. Factories designed to work on a continuous basis and with the retention times optimized to achieve a minimal cost for each amount of waste treated. In this juncture, a deep knowledge of the process, and to have at one’s disposal the proper “know-how” and techniques necessary to handle the composting process, are key aspects.

Usually, the works related to composting only showed the initial and final values, due to the impossibility to obtain a sample from the interior of the composting matrix without perturbing it atmosphere and structure, interfering with the normal development of the process. It is possible to suppose that the degradation detected didn’t took place in an homogeneous and continuous way, being instead a process where each substance had been degraded at a different rate, on a different moment and by some particular microbial populations among all which takes place on the composting process. A deep knowledge of those kinetics would allow to adapt the process handle to each stage, achieving an optimization of the necessary time to develop the final compost and, with that, of the cost of the whole process.

The objective of the present work was the study of the hydrolysis rate of several pools of organic matter during the composting process. A innovative experimental design is presented, based on independent batch reactors which allows destructive sampling along the time and the study of the process taking into account independent variables as time and temperature. The obtained data could allow a future study of the hydrolysis kinetics on the composting process.

2 Material and methods

One of the key characteristics this experimental design should comply, to be able to provide useful data, was the characteristic of being able to be sampled along time without interfering on the process. Under that idea, a system with 15 different experimental units was designed, allowing to destroy 3 independent units at each sampling time.

Each unit consisted of a glass container, about 500 ml capacity, enough to contain the sample needed for all the analysis planned. Composting is an aerobic process, which means that a enough amount of oxygen must be kept into the matrix, it was necessary to design a system which would allow the oxygen flow trough the mass but without affecting its temperature. So, a passive ventilation system was developed, in a way the heat within the matrix would be the responsible of its ventilation. The upper part of the glass container were closed with a Parafilm layer, which were adhere hermetically to the container's edges, and over that layer a second coat of aluminium foil was placed, to act as support for the Parafilm layer. Two holes were made on those layers, one on the centre and another next to the edge. By this last hole a cannula, with the bottom end cut on a bevelled edge, was introduced to the bottom area of the container. This design is showed on figure 1.

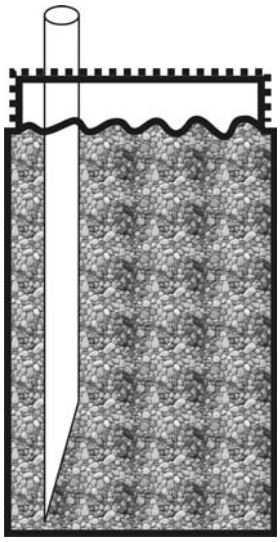

Figure 1 Experimental unit scheme

This way, the hot air from the interior of the matrix tend to go up and out by the central perforation, which worked as a "chimney". This movement induced a void on the bottom part of the mass, which forced the entry of fresh air by the cannula to the interior of the container.

Into each container 150 g (fresh weight) of the mixture were introduced, which consisted of 100 g (fresh weight) of fishery sludge and 50 g (fresh weight) of poplar bark minced and screened to less than 1 cm, which would be the bulking agent to produce a porous matrix which would allow the air flow. This proportion was chosen because the final moisture content was of 60%, an optimum value to start the composting process (Finstein and Miller, 1985). The chemical characterization of both products are show on table 1.

Four key temperatures from the composting process were selected: 20ºC (low mesophilic), 37ºC (optimum mesophilic), 50ºC (optimum thermophilic) and 60ºC (high thermophilic). The activity rate of the microbial populations which takes places into the composting process would be different at each temperature, allowing this to detect the influence of each microorganism on the hydrolysis process at each temperature.

To keep the temperatures stable the experimental units were introduced into thermostatic water baths, so the water level would be just one centimetre below the units upper edge, covering all the matrix but without entering the experimental vessels. A water reservoir with a constant supply of water, connected by tubes to the experimental bath, will maintain the water level constant during all the experimental time, regardless of possible water leakages due to evaporation or caused by the removing of experimental units at the sampling times. Also, several thermometers situated on different points into the water baths assured a correct and homogeneous temperature along the bath surface, avoiding the possible differences caused by the situation of the experimental unit into the bath.

Table 1 Initial characterization

	Sludge	Poplar bark
Moisture (%)	65,06	11,17
Volatile solids (%)	99,25	97,20
pH	3,52	6,72
Electric conductivity (mS cm^{-1})	0,14	0,10
Ammonia (ug g^{-1})	54,90	24,46
Nitrate (ug g^{-1})	214,95	30,23
Dissolved organic nitrogen (ug g^{-1})	477,37	78,88
Dissolved organic carbon (ug g^{-1})	26083,96	548,89
Microbial biomass (ug DON g^{-1})	31,69	Not detected
Protein (ug g^{-1})	10258,16	1013,28
Lipids (ug g^{-1})	188414,83	7719,57
Total fiber (%)	3,36	78,42

The destructive sampling took place at 1, 3, 6, 10 and 15 days from the beginning; on each sampling time 3 experimental units were removed from each bath. The experimental units were randomly chosen with the use of dices.

After being removed from the bath, each unit was processed immediately. First, the whole volume of air into the matrix was suctioned by the cannula by the use of a pump, being that air sent to a oxygen analyzer Servimax 6000 to check the presence of enough oxygen into the matrix to a correct development of the composting process. Once this measure was made, the experimental unit was opened and the total mass weighted, homogenized, and separated into several fractions to proceed to the different analysis.

The analysis made were: moisture content (dry at 105ºC until constant weight), volatile solids (calcination at 550ºC until constant weight), dissolved organic carbon (Springer-klee method), hot water extractable carbon (Springer-Klee method), cellulose, hemicellulose and lignin (Van Soest fractionation), ammonia, nitrate and dissolved organic nitrogen (Sims et al, 1985), microbial biomass (measured as microbial dissolved organic nitrogen), lipids (vainillin reagent method), total carbon and nitrogen (combustion and infra-red spectrometry LECO CN 2000) and proteins (Lowry method).

3 Results and discussion

The minimum oxygen concentration detected within the experimental units was of 13,5%, corresponding to the 10^{th} day and the 20ºC treatment. This shows that the ventilation rate was enough into the experimental vessels, not being caused by a lack of oxygen any of the results obtained.

The figure 2 shows the evolution of the moisture content into the four treatments. We would like to point that on the 60ºC treatment a progressive descent of the moisture content was detected, passing from a value of 48,85% to 21,97% between the 6^{th} and the 10^{th} day. Is considered that a moisture content below 40% is already limiting to the correct development of the microbial activity of the composting process (Finstein and Miller, 1985), but other authors had signalled that, if the waste is widely colonized, the microbial activity could take place even with moisture contents below 30% (Miller, 1989). But our results regarding microbial biomass shows that the material under 60ºC was the less colonized, so it can be supposed this moisture deficit detected had affected the metabolic activity of the microorganisms.

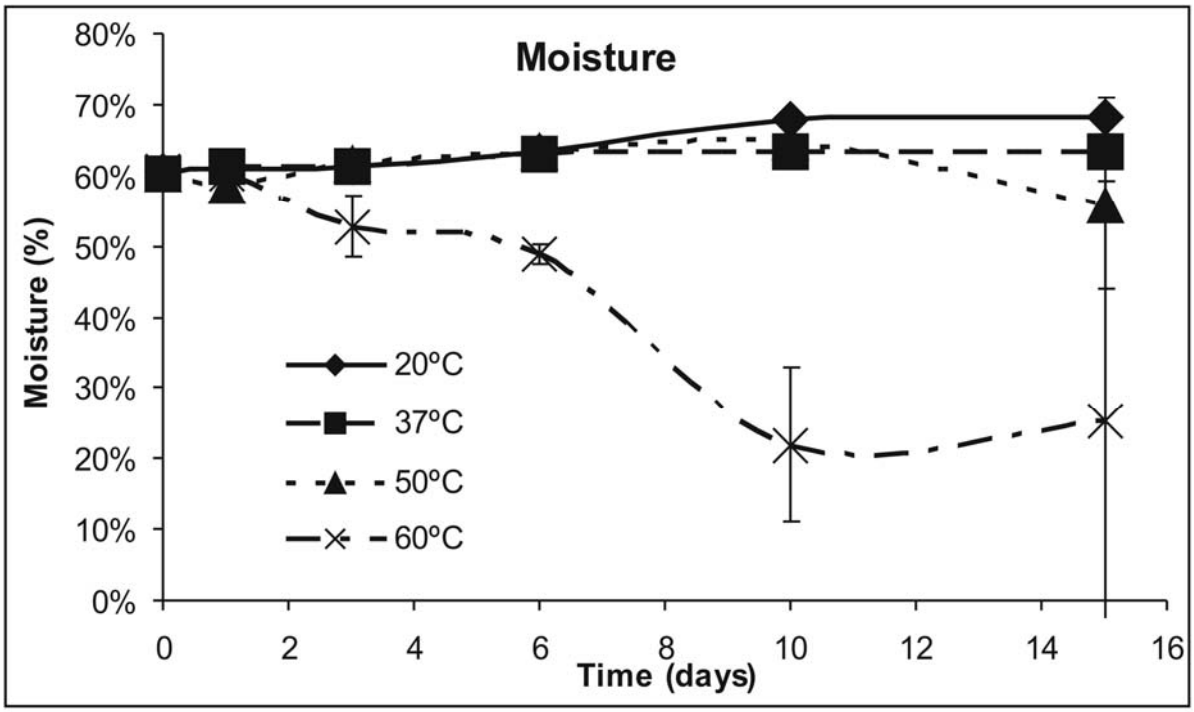

Figure 2 Moisture content

The figure 3 shows the microbial biomass evolution (measured as microbial dissolved organic nitrogen) along the experimental time for each treatment. It is possible to check that the 60ºC treatment was where a less microbial development was achieved, being almost null along all the experimental process.

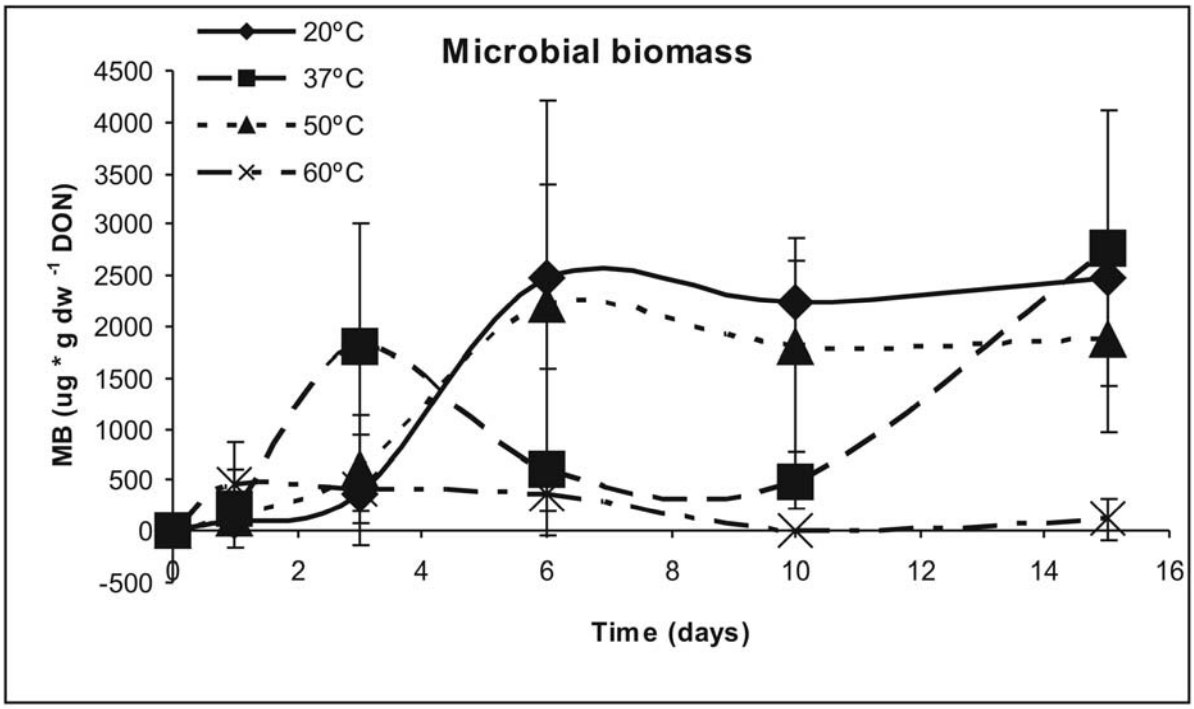

Figure 3 Microbial biomass evolution

This result agreed with the volatile solids evolution, showed on figure 4, where only the 60ºC treatment doesn't present a clear loss of organic matter, being detected a progressive reduction on the other three treatments.

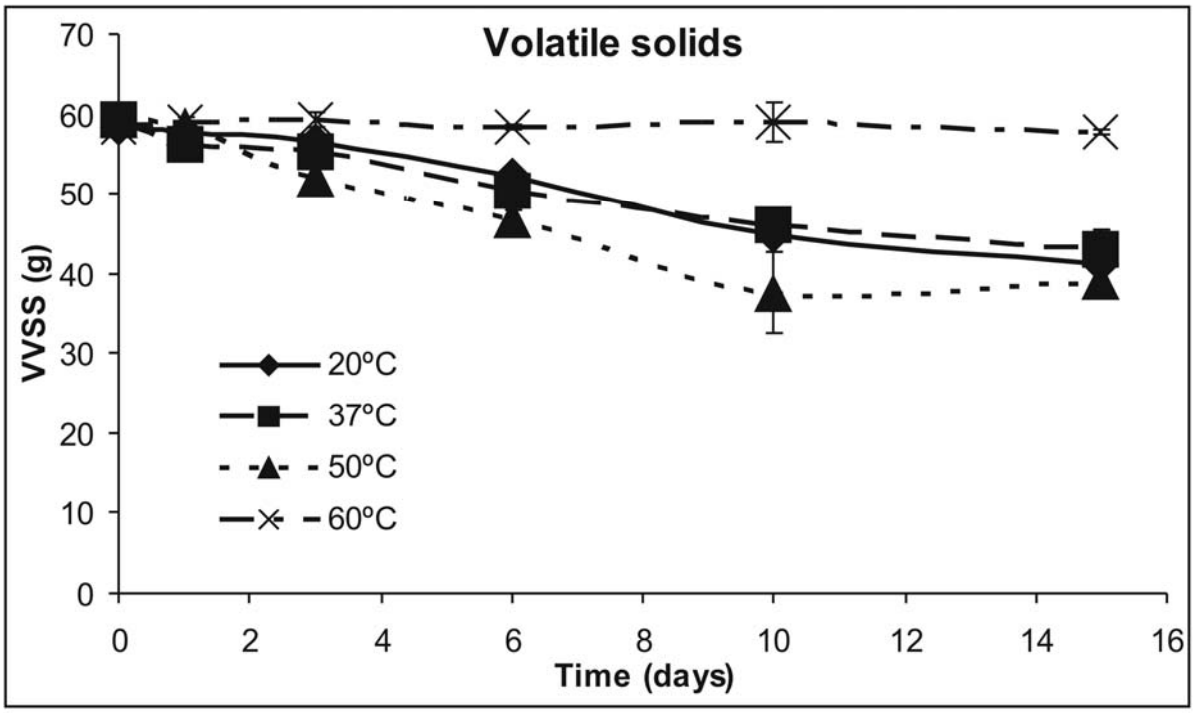

Figure 4 Volatile solids evolution

The figure 5 shows the aspect after the whole process of two experimental vessels from different treatments. The vessel on the right belong to the 20ºC treatment, while the vessel on the left belongs to the 60ºC treatment. It is possible to observe a clear difference on the microbial colonization and the development of fungi structures, being almost all the free space of the 20ºC matrix occupied by those structures and the 60ºC matrix completely empty.

Figure 5 Comparison between 20ºC and 60ºC vessels after 15 days

The rest of the analysed parameters are show on table 2. The results from the 60ºC treatment have not been included, mainly, to simplify the reading, and also due to the fact of being the only treatment which suffered an hydric deficit which had a great influence over the degradation process. Due to this fact, the analised parameters doesn't show differences on the 60ºC treatment, repeating the evolution show on figures 3 and 4.

Table 2 Physical, chemical and biological parameters analised

		Initial	Day 1	Day 3	Day 6	Day 10	Day 15
Lignin (%)	20ºC	10,79	19,89	11,04	12,52	16,53	18,37
	37ºC	9,10	11,18	13,69	12,96	14,09	15,13
	50ºC	9,10	10,79	11,93	14,12	12,92	15,23
Cellulose (%)	20ºC	28,24	29,22	29,72	34,07	37,07	43,05
	37ºC	28,33	29,63	31,11	36,42	35,10	36,17
	50ºC	28,33	234,69	32,99	35,33	37,52	43,84
Hemicellulose (%)	20ºC	14,26	13,84	15,75	15,93	23,93	16,01
	37ºC	13,88	20,97	24,51	17,20	24,42	18,70
	50ºC	13,88	20,66	19,89	18,23	18,94	14,51
Ammonia (ug g^{-1} dw)	20ºC	420,15	421,10	348,01	1080,46	7198,05	13151,70
	37ºC	1719,18	564,26	1476,88	3623,97	4134,36	3607,53
	50ºC	1719,18	572,51	2435,25	3699,88	3983,24	2955,04
Lipids (ug g^{-1} dw)	20ºC	51069,19	69557,10	68677,93	81101,65	85782,53	47709,58
	37ºC	7736,17	4949,87	7141,36	8616,85	4018,71	1687,93
	50ºC	7736,17	5919,62	6937,94	6449,51	2704,57	2167,53
Total carbon (%)	20ºC	47,67	47,73	47,20	48,13	48,22	47,32
	37ºC	48,60	49,36	48,89	49,31	48,75	48,84
	50ºC	48,60	47,94	48,75	48,86	47,67	47,51
Total nitrogen (%)	20ºC	1,53	1,46	1,51	1,58	1,50	1,29
	37ºC	1,65	1,79	1,48	1,14	1,35	1,47
	50ºC	1,65	1,69	1,65	1,51	1,83	1,58
Proteins (ug g^{-1} dw)	20ºC	15166,35	15120,93	14656,39	17014,61	35584,37	53628,08
	37ºC	12067,06	16098,96	25168,37	41342,69	40943,18	36763,59
	50ºC	12067,06	16468,54	35346,69	41970,38	49188,92	30889,24

Those data shows a different degradation of lipids and proteins between the 20ºC treatment, on one side, and the 37ºC and 50ºC on the other. Also, it is possible to check that only the hemicellulose, among the three fibre fractions analysed, was lightly degraded.

We must remark that the analysis were made to the mixture used on the experiment, so the results shows not only the sludge degradation but also the bulking agent degradation. Komilis (2006) studied the degradation of several carbon forms into the composting process, concluding that among all the materials he tested, those with a higher concentration of fibres (poles and leaves) were the ones which presented a lower amount of easily hydrolysable carbon , and a higher concentration of recalcitrant carbon.

This allows to suppose that the bulking agent used in the present work didn't took part on the hydrolysis reactions, acting only as a physical agent to achieve a porous structure and as a sponge which helped to kept the moisture content during the process. So, all the degradation detected were suffered by the sludge present into the experimental containers. If this premise is right, the amount of volatile solid reduction became much more important if only the organic matter from the sludge is took into account. A estimation of the percentage of volatile solid reduction over the sewage sludge is show on table 3

Table 3 VVSS reduction over initial sludge

	VVSS reduction (g)	VVSS reduction over initial VVSS sludge (%)
20ºC	17,00	48,65
37ºC	16,26	46,54
50ºC	20,05	57,38
60ºC	0,60	1,72

Also, this effect will explain the increase on the cellulose and lignin concentrations along the time. If other substances from the organic matter are degraded, the recalcitrant ones increase it's concentration over the total organic matter, but not meaning this a "generation" of new fibres, instead just a mathematical effect due to the loss of the more easily degraded substances which conform the organic matter.
So, the effects a recalcitrant material like the bulking agent have over the analytical results must be taken into account before extracting conclusions from this work, and a way of eliminating this bulking agent prior to the analysis (something that would allow to analyse only the product that really is being hydrolysed: the sludge) should be searched for an accurate measurement of the hydrolysis kinetics, without disturbing agents that dilute the results.

4 Conclusions

The degradation of the several pools that conform the organic matter doesn't take place as an homogeneous and continuous whole, being instead each substance degraded at a different ratio and at different moment within the process.

Lipids and some proteins are among the most easily degraded pools, being the vegetable fibres the most recalcitrant components of the organic matter.

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