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M.C. Gutiérrez[a], A. Serrano[a], M.A. Martín[a] & A.F. Chica[a]

[a] Department of Chemical Engineering, University of Cordoba, Campus Universitario de Rabanales, Carretera N-IV, km 396, Edificio Marie Curie, 14071 Córdoba, Spain

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Odour in composting processes at pilot scale: monitoring and biofiltration

M.C. Gutiérrez, A. Serrano, M.A. Martín and A.F. Chica*

Department of Chemical Engineering, University of Cordoba, Campus Universitario de Rabanales, Carretera N-IV, km 396, Edificio Marie Curie, 14071 Córdoba, Spain

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Although odour emissions associated with the composting process, especially during the hydrolytic stage, are widely known, their impact on surrounding areas is not easily quantifiable. For this reason, odour emissions during the first stage of composting were evaluated by dynamic olfactometry at pilot scale in order to obtain results which can be extrapolated to industrial facilities. The composting was carried out in a commercial dynamic respirometer equipped with two biofilters at pilot scale filled with prunings (*Populus*) and mature compost obtained from the organic fraction of municipal solid waste. Given that the highest odour emissions occur in the first stage of the composting process, this stage was carried out in a closed system to better control the odour emissions, whose maximum value was estimated to be 2.78 $\text{ou}_\text{E}\ \text{s}^{-1}$ during the experiments. Odour concentration, the dynamic respiration index and temperature showed the same evolution during composting, thus indicating that odour could be a key variable in the monitoring process. Other variables such as total organic carbon (C_{TOC}) and pH were also found to be significant in this study due to their influence over odour emissions. The efficiency of the biofilters (empty bed residence time of 86 s) was determined by quantifying the odour emissions at the inlet and outlet of both biofilters. The moisture content in the biofilters was found to be an important variable for improving odour removal efficiency, while the minimum moisture percentage to obtain successful results was found to be 55% (odour removal efficiency of 95%).

Keywords: biofilter; dynamic olfactometry; dynamic respirometer; odorous impact; odour concentration

1. Introduction

Composting is the aerobic biodegradation of solid organic materials under controlled conditions. The final compost is a valuable product for agriculture and allows organic waste to be recycled from an environmental point of view. Maturity and stability are two important characteristics of compost. Whereas maturity is primarily related to agriculture, stability can be defined as the extent to which readily biodegradable material has been decomposed.[1]

Respirometric techniques are one of the most widely used methods to measure stability. These techniques are based on either O_2 consumption or CO_2 production by unstable biowaste under aerobic conditions. The respiration index (RI) of biowaste, defined as the oxygen uptake rate, can be measured by different respirometric techniques.[2] Several methods have been proposed to measure compost respiration indices and stability. The static-liquid method developed by Chica et al. [3] uses small compost samples suspended in water in order to measure oxygen consumption with dissolved oxygen probes. Gea et al. [4] and Mari et al. [5] proposed static-solid methods, which use solid sample in-vessel systems to measure oxygen consumption by measuring the decrease in the partial pressure of atmospheric oxygen. Adani et al. [6] and Adani et al. [7] proposed the dynamic-solid method in which air passes through a solid sample and oxygen consumption is measured as the difference between the inlet and outlet oxygen concentrations. The dynamic respiration index (DRI) was found to be the most suitable way to evaluate microbiological activity during composting processes.

Although several methods to indicate compost stability throughout the composting process have been described in the literature, there is no widely accepted and reliable method to quantify all types of compost. Other methods based on physicochemical and biological properties such as temperature, total organic carbon content and the RI have also been proposed.

The second draft of the Biowaste Directive [8] defines the stability of material as the reduction of waste decomposition activity and offensive odours and establishes that the DRI must be less than 1000 ($\text{mg}\,O_2 \cdot \text{kg}^{-1}\text{OM} \cdot \text{h}^{-1}$). The draft of this directive demonstrates the need to evaluate odour emissions and their close relationship with substrate stability.

A large portion of odorous emissions can be prevented by ensuring optimal composting aeration conditions. If biowaste is not well aerated, malodours often occur as a result of partial anaerobic processes. To ensure a sufficient oxygen supply, the aeration rate can be adapted to the composting conditions.[9] Off-site emissions seem to be the

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*Corresponding author. Email: afchica@uco.es main problem at open, outdoor facilities. To avoid such odour emissions, an option could be to enclose such facilities at least in the first stage of the composting process, in which there is a high emission potential due to higher microbiological activity and the degradation of organic matter. Schlegelmilch et al. [10] reported that the increase in odour concentration within the exhaust air during the first days of degradation reaches a maximum level after about a week and slowly starts to decrease during the last two weeks of composting. The advantage to applying this type of system is that it allows controlling the process conditions, as well as gaseous and odorous emissions. The downside, however, is that it requires costly infrastructure.

Although odour emissions can be controlled using in-vessel systems, they must be treated to remove most of the odour. Biofilters are the most often used to control odour and volatile organic compound (VOC) emissions. Biofiltration removes VOCs from gas streams using a bed of biologically active material, such as mature compost or green waste [11] or inorganic material such as ceramic lava rock or activated carbon.[12,13] According to European Standard UNE-EN 13725:2003,[14] dynamic olfactometry is a suitable method for determining odour concentration in terms of European odour units per cubic metre ($\mathrm{ou_E\ m^{-3}}$) from a determined odour focus and is accepted worldwide. This technique was used by other authors to monitor odorous emissions generated in piles composting processes.[15,16]

In this study, the first stage of the composting process is simulated in closed bioreactors (tunnels) by means of a commercial dynamic respirometer at pilot scale.

Given that the main aim of this research study is to demonstrate the close relationship between odour emissions and microbiological activity or substrate stability. Then, the odour concentration ($\mathrm{ou_E\ m^{-3}}$) is an essential variable in monitoring and controlling the first stage of the composting process especially at full scale. For this reason, a novel follow-up assessment was performed of odour emissions quantified through dynamic olfactometry. Odour concentration emissions were also related to other relevant variables in the composting process, such as pH, organic matter content, temperature and respirometric variables to evaluate the maturity and stability of the matter obtained. Furthermore, the simulation of the composting process in vessel systems at pilot scale using a respirometer with a biofiltration system could be a suitable strategy to minimize odour impact at industry scale. To complement this work, the efficiency of two biofilters with different compositions was also tested to minimize odour emissions.

2. Materials and methods

2.1. Raw material

The raw material employed in this study was the organic fraction of municipal solid waste (OFMSW) used by a municipal treatment plant to obtain compost. The plant has a selective collection system and two independent urban waste reception facilities for both organic and inorganic matters. The organic matter is fed into a trommel tube to remove particles larger than 80 mm in diameter. An electromagnet is then used to remove most of the ferrous materials, after which a Foucalt current is used to remove the aluminium. The resulting matter used in this study had an approximate composition of 63% organic matter, 13% glass, 6% plastic, 15% paper-cardboard and 3% of other materials. Although this study was conducted with OFMSW to simulate the first stages of a composting process in tunnels, many other organic substrates can also be used.

2.2. Dynamic respirometer

The process was carried out at pilot scale in a commercial respirometer manufactured by *Costech International* (Respirometer 3022). Scaglia et al. [17] used this method to determine the DRI. The author defines this technique as an effective respirometric method to measure biological stability of municipal solid waste (MSW), which allows testing MSW biological stability under standardized conditions. Respirometric methods are now used for routine analyses.

The respirometer consists of an adiabatic reactor, which is isolated by means of a jacketed reactor (Figure 1). The respirometer has 124 l capacity and measures 800 mm high, with an external diameter of 600 mm and an internal diameter of 486 mm. It has three orifices: an air inlet (ϕ26 mm), an air outlet (ϕ20 mm) and a third orifice which is used to insert the temperature probe. Material is inserted in a container fitted with a removable grid (ϕ2 mm) to filtrate the leachate.

The respirometer is equipped with a computer and a signal conditioning module and has a gas flow regulator on the reactor's inlet. The device has its own software, which has been developed exclusively by Di, Pro, Ve and Costech International for this method to monitor temperature and oxygen concentration and determine microbiological activity by calculating the DRI. The inlet air oxygen concentration, the outlet air concentration, the volatile solid (VS) (%) of the raw material and the experimental time were used to calculate this variable expressed in $\mathrm{mgO_2\ kg\ VS^{-1}\ h^{-1}}$.

Six consecutive experiments were carried out. In each experiment, around 9 kg OFMSW was used to fill the reactor to 80% of its total capacity. Air was introduced into the reactor at a constant airflow rate of $500\ \mathrm{l\ h^{-1}}$ ($1.39\ 10^{-4}\ \mathrm{m^3\ s^{-1}}$), thus maintaining the oxygen concentration in the gas phase at 16–20%. These real operating conditions might not be similar at industrial scale as the oxygen concentration is not normalized.

Although the origin of the OFMSW was always the same, its behaviour varied due to the heterogeneous composition of the substrate.

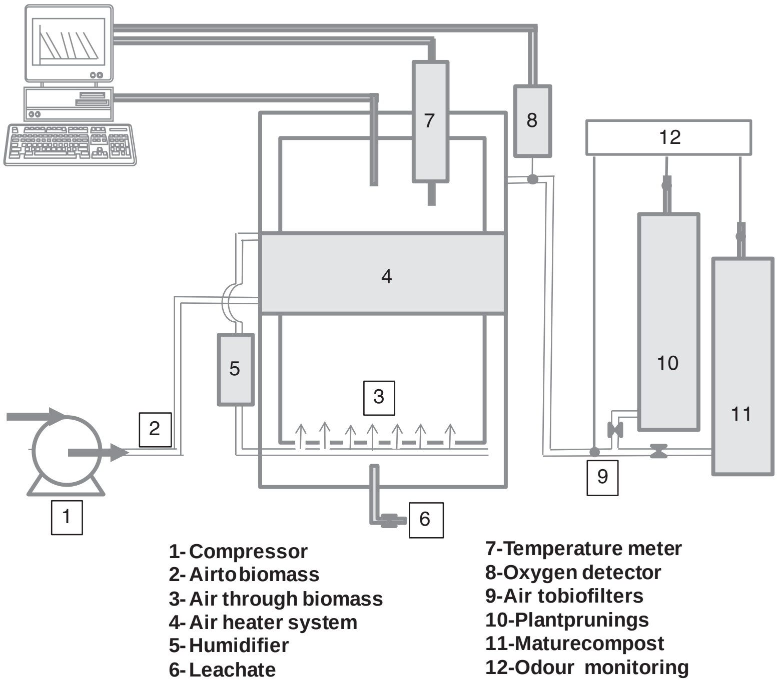

Figure 1. Dynamic respirometer and biofiltration system.

2.3. *Odour emission biofiltration system*

The experimental system comprised two biofilters (Figure 1) to which odour emissions generated during the process in the reactor were redirected. The outlet duct of odour emissions coming from the reactor has a valve to direct the emissions towards one of the biofilters or towards both simultaneously. One of them was filled with *Populus* plant prunings from an industrial biofilter, and the other was filled with partially stabilized compost obtained from OFMSW. The filling volume of each biofilter was 1.18 10^{-2} m^3. The air from the reactor was conducted to one biofilter per experiment, therefore 500 l h^{-1} of malodorous air supported an empty bed residence time (EBRT) of 86 s, which is the same EBRT as reported by Pagans et al.[18] and within the range of 32–94 s studied by Lebrero et al.[19]

The material used to fill the filters (plant prunings and mature compost) was characterized according to its porosity, density, bacteria content and mildew. Porosity and density were determined in accordance with European Guideline EN 13041:2011 [20] and aerobic microorganism content was determined by the horizontal method to count total aerobic microorganisms at 30°C. The initial classification of the filling material is shown in Table 1.

Table 1. Initial characterization of both biofilter filling.

	Pruning biofilter	Compost biofilter
pH	7.0	7.9
Density (g cm^{-3})	1.58	0.59
Porosity (%)	85	70
Macroporosity (%)	48	65
Microporosity (%)	37	5
Total aerobic microorganisms (CFU g^{-1})	10^5	10^7

The moisture content in both biofilters was another variable selected to determine the degree of influence on odour removal. The moisture content in both biofilters was 80% in experiments 1 and 2, 55% throughout experiments 3 and 4 and approximately 20% in experiments 5 and 6. Although the required moisture content depends on the medium used and the temperature, a moisture content of 40–50% is considered optimal in most cases.[21,22] The moisture content was measured at the beginning and end of each experiment, and showed an increase of approximately 10% in all cases due to the moisture content in the air coming from the reactor. The biofilters were irrigated at the beginning of each experiment to obtain the moisture indicated previously. The experiments were carried out under ambient temperature to simulate real conditions and the temperature was always close to 20°C. The biofilters were equipped with an upward air flow system.

A follow-up study of the odour units was carried out during each experiment either on the inlet or outlet of the biofilters of the reactor. The follow-up study pursued a twofold aim: (1) to evaluate odour emissions related to the process and (2) to determine the efficiency of the biofilters. In order to determine the efficiency of each biofilter independently, the airflow was canalized towards the biofilter during the experiment.

2.4. *Odour sampling and analysis*

The maximum duration of each experiment was 240–300 h, during which five gas samples were taken to determine their odour concentration (ou$_E$ m^{-3}). The samples were taken on the reactor outlet using a standard sampling device that consisted of a vacuum container, which is evacuated with a vacuum pump. The sampling point and the standard sampler are connected by a probe. An 8L-Nalophan™ sampling bag lies inside the container, and sucks in the sample air via the probe. Due to the construction of the sampling device, none of its components comes into contact with the sample air.

The dynamic olfactometry sensorial method was used to determine the odour concentration of an odorous air sample, which according to European Standard UNE-EN 13725:2003 [14] is expressed in units per cubic metre (ou$_E$ m^{-3}). A T08 ECOMA GmbH olfactometer based on the 'Yes/No' method was also used in the experiment.[23]

A panel of four members characterized the gas odour samples. The odour concentration was calculated according to the geometric measure of the odour threshold values of each panellist, which was multiplied by a factor that depends on the olfactometer dilution step factor. All odour concentration data were finally expressed in standard temperatures and pressure (STP, 0°C and 1 atm). It was assumed that the results obtained by means of dynamic olfactometry had a confidence level from half to double the value of the odour perception threshold concentration.

2.5. *Physicochemical characterization of OFMSW composting*

The initial and final OFMSWs of each experiment were subjected to physicochemical analyses. The solid fraction was used to determine the following variables: moisture (%), VS, oxidable organic carbon (% C_{OXC}), nitrogen content (as % N-Kjeldahl), ammonia nitrogen (% N-NH_4^+) and phosphorous content (% P-P_2O_5). In aqueous extract (1:25 ratio), the measures were total organic carbon (% C_{TOC}), pH and conductivity (μS/cm) following the methodology proposed by the US Department of Agriculture and the US Composting Council (2002).[24]

Biological activity was determined by two methods, which were carried out in the respirometer at pilot scale and expressed as DRI. A second method was carried out in an aqueous medium using a respirometer at laboratory scale as described by Chica et al.[3]

Biological activity is defined by variables based on the specific oxygen uptake rate (SOUR) and cumulative oxygen demand at 20 h (OD_{20}). Adani et al. [25] compared both methods, as well as one in static conditions (static respiration index) to find similarities. Their results indicated that there was an adequate correlation between both methods and that both could be used to describe the biological stability of the samples.

3. Results and discussion

3.1. *Simulation of tunnel composting process with a respirometer at pilot scale*

The dynamic respirometer continuously registered the oxygen content (%), temperature (°C) and DRI (mgO_2 kg VS^{-1} h^{-1}) by a data acquisition system. The information was saved each hour during the experiment. Figure 2 shows the results obtained by the respirometer during one of the experiments carried out as an example. Oxygen content decreased due to an increase in microbiological activity, resulting in an increase in DRI and temperature. The thermophilic stage (≈ 45°C) was characterized by high oxygen consumption and the release of a high amount of energy due to microbiological activity, thus permitting the sanitation of the final product. In spite of the fact that all the experiments were carried out under similar conditions, each experiment behaved in a slightly different manner, which may have been due to the heterogeneous substrate. The maximum temperature was reached after 100–150 h of the process, obtaining similar values (38–51°C) in the thermophilic range.

The most relevant results of this research study were obtained when the odour emissions were determined through dynamic olfactometry. Monitoring odour emissions allowed us to obtain an adequate relationship between microbiological activity – expressed in DRI – temperature and odour concentrations (Figure 3). The three variables reached their maximum value after 116 ± 3 h. The mean maximum temperature was 46 ± 4°C, the DRI values were $38,000 \pm 7000$ mgO_2 kg VS^{-1} h^{-1} and the highest odour concentration was $22,000 \pm 6000$ ou$_E$ m$^{-3}_{STP}$. Due to the parallel evolution of these variables during the first stage of composting, odour concentration would be appropriate to carry out a follow-up of the compost.

In light of the odour concentrations generated, it is essential to combine a biofilter to the air outlet of the tunnel in order to minimize most of the emissions in this stage of the process.

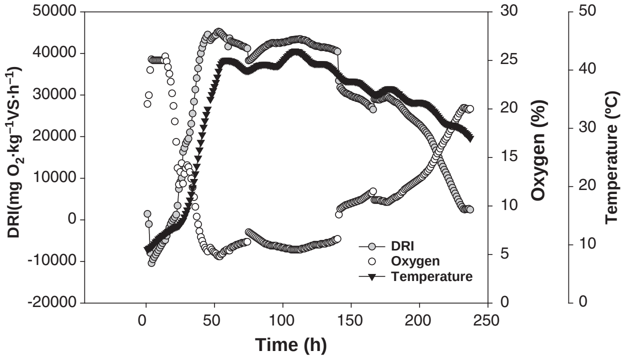

Figure 2. Time course of DRI, oxygen and temperature during experiment 2.

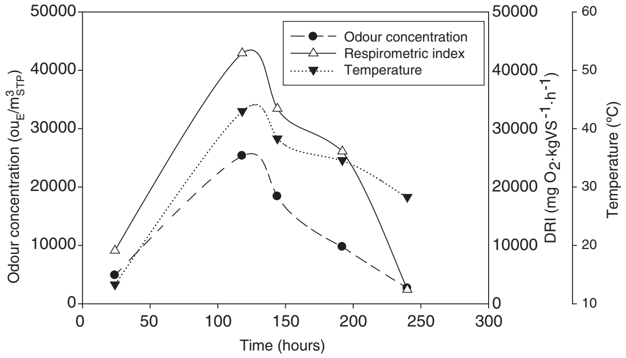

Figure 3. Time course of odour concentration, DRI and temperature during experiment 2.

3.2. *Physicochemical characterization of initial and final OFMSWs*

Given the results obtained in the previous section, it was necessary to find an adequate relationship between odour emissions and the key physicochemical variables to determine compost stability. Therefore, a physicochemical characterization of OFMSW was only conducted at the beginning and at the end of each experiment as the respirometer did not allow samples to be obtained during the experiments. Table 2 shows the mean value of each of the variables in the six experiments carried out.

Table 2 shows a decrease in the organic matter expressed as VS_{dry} and C_{TOC} during composting, which is characteristic of this process (removal efficiency of 13% and 48%, respectively). The low C_{TOC}/N_{NH4+} of the raw material favoured the low emission of ammoniacal nitrogen which is a potential odorous compound. The content in total Kjeldahl nitrogen (N_{TKN}, %) and phosphorus ($P\text{-}P_2O_5$, %) was maintained, thus favouring the characteristics of the final product in the composting process for its subsequent merchandizing as fertilizer. The moisture content was maintained through material aeration with air saturated in water.

The pH is an essential variable to be considered in all composting processes due to microbiological activity. Because the reactivity of some chemical compounds also depends on the pH value, pH affects the odour emissions. For this reason, pH was studied in detail to determine if there is a relationship between this parameter and odour concentration (ou$_E$ m$^{-3}_{STP}$). Table 2 shows that pH tended to increase until it reached a value of 7–8 (basic pH), which is the typical behaviour during composting processes. Figure 4(a) shows the mean value of the initial and final pH during the experiment, as well as the increase in pH throughout the process. The increments in pH varied in some of the experiments, which might be due to the heterogeneity of the substrate.

Despite the differences between the initial and final pH values in the experiments, it was possible to establish a relationship between pH and odour concentration. The odour concentrations only showed significant differences at extreme values (Figure 4(b)). Odour concentration values were considerably higher in acid pH (5–5.5) and lower in basic pH (7.5–8). Additionally, an analysis of variance was realized which demonstrated significant differences between both variables ($P < .001$).

Finally, the evolution of some physicochemical variables was studied at the beginning and the end of the process (Table 2) to determine if the simulation of the hydrolytic stage using the dynamic respirometer at pilot scale could be extrapolated at industrial scale. The study was based on decreasing percentages of the same variables (conductivity,

Table 2. Characterization of initial and final OFMSWs of each experiment and simulated variables at industrial scale. Limit values according to the Royal Decree 506/2013.

Variable	Raw material Initial	Dynamic respirometer (at pilot scale) Final	Tunnel (at industrial scale) Final	Royal decree 506/2013
Physicochemical characterization				
Conductivity (µS/cm)	2503 ± 426	3362 ± 696	2988 ± 352	–
pH	5.7 ± 0.3	7.3 ± 0.4	7.6 ± 0.3	–
Moisture (% w/w)	59.1 ± 8.0	63.4 ± 4.6	34.5 ± 3.6	40[a]
Organic matter (%)	62.0 ± 8.0	55.0 ± 3.0	56.4 ± 4.5	35[b]
C_{OXC} (%)	32.8 ± 5.1	30.3 ± 3.4	29.8 ± 3.2	–
C_{TOC} (%)	4.4 ± 2.2	2.3 ± 1.1	2.7 ± 0.5	–
VS_{dry} (%)	74.4 ± 6.4	64.2 ± 8.1	64.0 ± 6.7	–
$N\text{-}NH_4^+$ (%, dry matter)	0.4 ± 0.1	0.3 ± 0.1	–	–
N_{TKN} (%, dry matter)	2.3 ± 0.3	2.3 ± 0.4	–	–
C_{TOC}/N_{NH4+} N	11.0 ± 0.5	7.7 ± 0.3	–	–
C_{OXC}/N_{TKN}	14.3 ± 0.8	13.2 ± 1.5	–	20[a]
$P\text{-}P_2O_5$ (%, dry matter)	1.0 ± 0.4	1.2 ± 0.2	–	–
$SOUR_{max}$ (mg O_2 gVS_{dry}^{-1} h^{-1})	29 ± 10	5 ± 3	16 ± 2	–
OD_{20} (mg O_2 gVS_{dry}^{-1})	258 ± 90	59 ± 9	158 ± 32	–

[a] Maximum value.
[b] Minimum value.

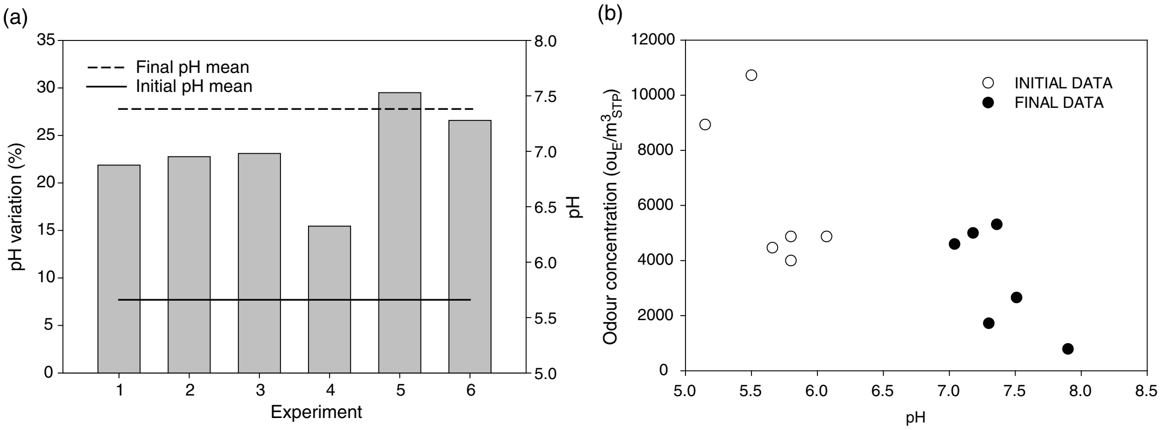

Figure 4. (a) Final, initial and variation of pH for each experiment. (b) Odour concentration versus final and initial pH values.

pH, moisture, C_{TOC}, VS_{dry}, $SOUR_{max}$ and OD_{20}) obtained by Arcos et al.[26] This work evaluated the global variation (%) of these variables during the first stage of composting process in tunnel. The raw material was similar in composition and origin to the raw material used in this work. The results (global variation, %) were applied to the initial characterization of the raw material used in this study to obtain comparative results. Table 2 shows that the final product of the simulation was quite similar at both pilot and industrial scales. However, a higher moisture content and higher microbiological stability were obtained at pilot scale. It might be due to the moisture which is a parameter more difficult to control for industrial scale than for pilot scale, and therefore, a higher moisture content favours the presence and the activity of microorganism.

Moreover, a close relationship was found between biodegradable organic matter in waste and microbiological activity. This was reflected in the initial values of both variables (Figure 5(a)) such that the higher the initial content in organic matter available expressed in C_{TOC} (%), the higher the microbial respiration quantified in DRI (mgO_2 kg VS^{-1} h^{-1}).

As shown in Figure 5(b), microbiological activity expressed in DRI (mg O_2 kg VS^{-1} h^{-1}) was closely related to the odour concentration (ou_E m^{-3}) during the six experiments. The proposed correlation between both variables fits correctly with a r^2 of 0.8706. These results indicate that the higher the microbial activity, the higher the odour concentration value reached.

Figure 5(c) shows the linear correlations between initial and final values of odour concentration and C_{TOC}/N_{NH4+} ratio obtained in the six experiments. An increment in both odour concentration and C_{TOC}/N_{NH4+} ratio was found in the raw material due to the presence of biodegradable carbon whose degradation generates odour. However, the relationship found between them was inversely proportional when the raw material was partially stabilized. The increase in odour concentration and the decrease in C_{TOC}/N_{NH4+} ratio were noticed. It might be due to the presence of partially stabilized carbon in the material and the ammoniacal nitrogen is the main focus of odorous emissions.

The mean results for the characterization of OFMSW in the different experiments (Table 2) showed that the final product did meet the organic matter content and C_{OXC}/N_{TKN} ratio but it was not stabilized. Therefore, this product did not meet quality standards to be used as fertilizer. Although there was a significant decrease in the values of the respirometric variables, such as SOUR (mgO_2 gVS^{-1} h^{-1}) and OD_{20} (mgO_2 gVS^{-1}), the final values indicated that the resulting material of this process was not completely stabilized and a later stage in piles would be required.[27,28] The values obtained were higher than the values corresponding to stabilized compost ($SOUR_{max} < 1$ mgO_2 gVS^{-1} h^{-1}; $OD_{20} < 5$ mgO_2 gVS^{-1}). However, it should be noted that the aim of this research study was not only to obtain stabilized compost, but also to evaluate odour emissions during the hydrolytic stage of composting.

Likewise, due to the relationship established between odour emissions and variables, such as temperature, microbiological activity (expressed as DRI) or pH, odour concentration monitor through dynamic olfactometry allowed the odour emissions to be estimated with basic equipment (a respirometer) at pilot scale. Dynamic olfactometry could also be used in industrial plants where qualified personnel do not have to be so specialized.

3.3. *Biofilter efficiency*

Waste management plants can carry out the composting process in open piles, which result in high odour emissions, or in closed systems where odour emissions are often controlled and reduced by a biofilter.

The different compositions of the two biofilters studied in this research did not vary substantially in terms of their odour removal efficiency despite the different microbiota in both fillings (as shown in Table 1, many differences were observed in two size orders). In contrast, the moisture in the

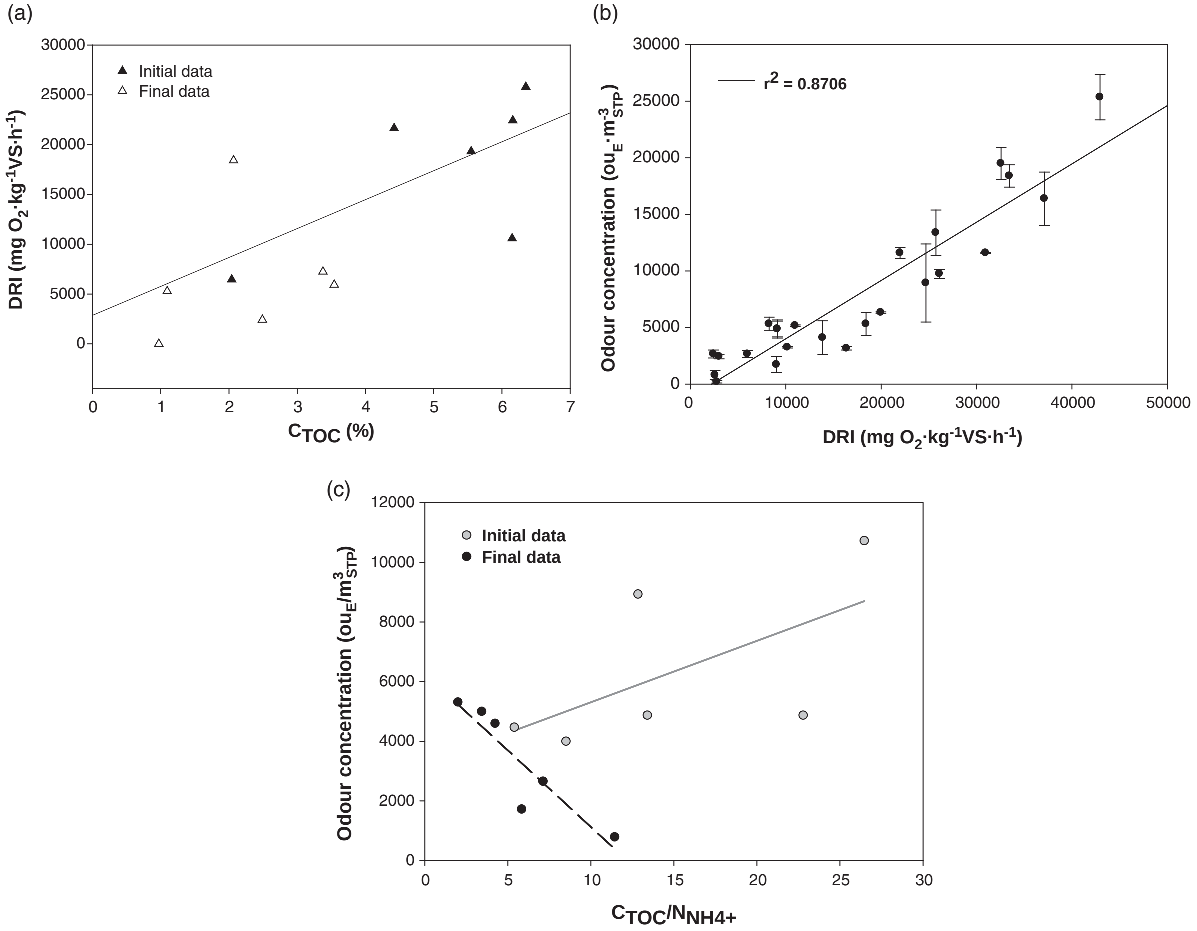

Figure 5. (a) Relationship between DRI and C_{TOC}. (b) Relationship between odour concentration and DRI values obtained in the six experiments. (c) Linear correlation between odour concentration and $C_{TOC/NH4+}$. Initial and final values obtained in the six experiments.

biofilters was considered a critical variable with regard to the final results in line with other authors.[29–31] However, moisture is usually the least controlled variable at industrial scale.

As shown in Table 3, very high odour removal efficiencies (99%) were obtained throughout experiments 1 and 2, where the moisture content of both biofilters was close to 80%. These efficiencies decreased to 95% in experiments 3 and 4, in which the moisture content was maintained at about 55%. In experiments 5 and 6, in which moisture was approximately 20%, the mean efficiency of both biofilters decreased to 85% for the compost biofilter and 70% for the prunings biofilter.

Table 3. Biofiltration process: biofilters efficiency according to the material moisture.

Experiment	Biofilter	Moisture (%)	Efficiency (%)	Residual odour concentration$_{max}$ (ou_E/m^3)
1	Compost	80	99	180
2	Pruning	80	99	23
3	Compost	55	95	900
4	Pruning	55	95	970
5	Compost	20	85	1700
6	Pruning	20	70	1560

The typical odour removal efficiency in biologically active filters is considered to be 90%. Moreover, biologically active filters are considered to perform adequately when residual odour is lower than 2500 ou_E m^{-3}.[32] In accordance with this standard, the biofilters used in this research study had an adequate removal efficiency when moisture content was higher than 55%. However, the odour concentrations did not exceed 2500 ou_E m^{-3} in the cases studied. It should be noted that these biofilters were not subjected to very high odour loads. In the worst case, if the reactor generated 20,000 ou_E m^{-3}_{STP} and the maximum flow rate of the reactor outlet was 1.39 10^{-4} m^3 s^{-1}, the odour emission rate would only be 2.78 ou_E s^{-1}. According to these results, in industrial-scale composting processes where the concentration of odour emissions might be lower than at pilot scale, moisture should be monitored to minimize odour emissions to the biofilter, improve its operation and extend its working life.

The high odour removal efficiency determined in both biofilters, regardless of moisture content, could be associated with a high EBRT (86 s). However, according to Kennes and Veiga,[33] typical EBRT values for treating different pollutants in conventional biofilters usually range from 20 to180 s. It is well known that the process of biofiltration is not cost effective for high EBRT values. In the case of potential odorous sulphide and nitrogenous compounds, these high EBRT values could moreover lead to a low removal efficiency and the accumulation of dangerous intermediate products.[34]

4. Conclusions

The simulation of a tunnel composting process with a dynamic respirometer for 15 days was carried out in a correct manner as demonstrated by the variables obtained during the follow-up process, particularly regarding the basification of the pH and the decrease in respirometric variables (SOUR and OD_{20}) and C_{TOC}.

The close relationship between odour concentration, temperature and microbiological activity quantified as DRI observed throughout the composting simulations in the dynamic respirometer has confirmed the importance of carrying out this initial stage of intensive fermentation in closed systems and the possibility of monitoring odour emissions by dynamic olfactometry. The importance of odour emission evaluation was also demonstrated in the adequate correlation ($r^2 = 0.8706$) obtained between odour concentration and the DRI.

Odour concentration can be considered a monitoring variable in the composting process due to the relationship found between this variable and other characteristic variables in the process such as pH, C_{TOC} and respirometric variables.

The use of biofilters made of plant prunings (*Populus*) and partially stabilized, microbiologically active compost with specific physicochemical features is one of the most efficient systems to remove odour, provided that the moisture content is appropriate. It is essential to monitor moisture content during composting processes, particularly at the industrial scale. Significant differences were not detected between both types of filling under adequate conditions of moisture.

Finally, dynamic olfactometry is a viable method to evaluate odour emissions and the odour removal efficiency of biofilters at pilot scale. The results of this method can be extrapolated at industrial scale to minimize the odorous impact of composting processes.

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