A novel respirometer for determination of compost stability

C. Tsiodra[1] ,G. Lambrou[1], G. Seintis[1] and A. G. Vlyssides[1]
[1]National Technical University of Athens, School of Chemical Engineering,
Laboratory of Organic Chemical Technology
Iroon Polytechniou 9, Zografou 15780, Athens,
Corresponding author email: avlys@tee.gr

Abstract

In this work a novel technique is described to estimate maximum Oxygen Uptake Rate (or maximum CO_2 evolution) results as well as the biological kinetic rate k (day-1) of O_2 uptake only in a few days (1-2 days). Additionally the time required in order the autotrophic and heterotrophic bioreactions is needed to be completed, could be calculated. Based on these results the status of a composting process could be estimated. The current process has been tested on different substrates. The characteristic oxygen absorption curves which were obtained are correlated with other parameters such as Water Holding Capacity (WCH), pH, EC, Humic and Fulvic contents as well as Cation Exchange Capacity (CEC). It is observed that there is a good correlation between the measured oxygen consumption in order to be used for the prediction of the compost evolution of any substrate. As the composting time is being the maximum oxygen uptake rate and the stabilization time are reduced.

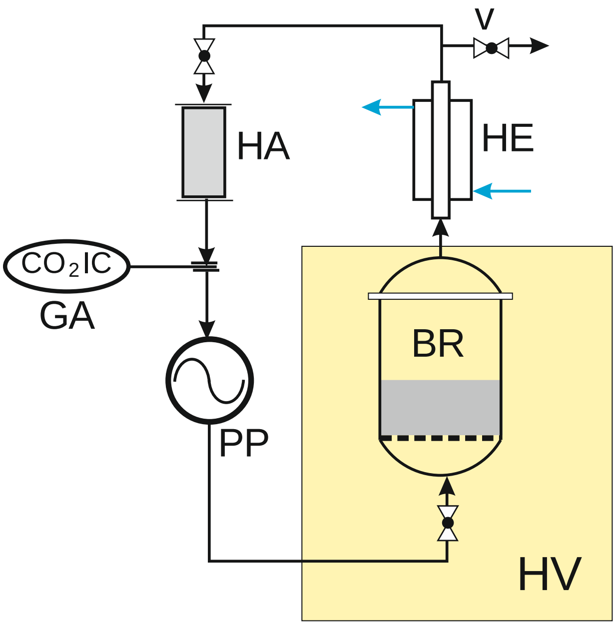
Keywords: compost stability, respirometer, olive mill wastes, oxygen uptake rate

Purpose

Composting is an aerobic biological process where decomposition of biodegradable organic matter takes place. It consists of three phases: (a) the thermophilic or biodegradable organic carbon stabilization phase, (b) the mesophilic or maturing phase, and finally (c) the psychrophilic or humification phase. During the first phase (phase of stabilization) dominating actinomycetes that deconstruct organic compounds increasing the temperature above 50^{o}C. During the maturation phase eukaryotic microorganisms take place in order to control the bioreactions. At the same time the nitrification reactions are completed. At the final stage of humification organic products of previous phases transformed into fulvic and humic compounds giving the final product the properties of water holding capacity, the ion exchange and biological activity. The most critical phase of composting is the thermophilic phase of stabilizing the satisfactory outcome of which prejudice the satisfactory development of the other two phases. Therefore, adequate control of this phase is the key to the success of the whole process of composting (Muktadirul Bari Chowdhury, et. al. 2013).
The biological stability suggests the extent to which readily biodegradable organic matter has decomposed. The key point of this knowledge is the degree of biological stability of a compost due to fact that it is recognized because it affects the potential for odor generation, biomass re-heating, residual bio gas production, re-growth of pathogens, phytotoxicity, plant disease suppression ability and process parameters such as airflow rate and retention time (Adani, et. al. 2006).
The organic substrate stabilization achieved with low moisture content up to 50%. Although there are many direct process control parameters for adequate monitoring of compost such as temperature, pH and moisture, more information considering the biological activity of the composting process can be obtained by monitoring the oxygen uptake rate (OUR) of the organic matter. The latter is assessed indirectly by measuring the CO_2 that is produced from the biological respiration of the organic material. However, it is necessary to highlight the fact that respiration can be considered one of the most important measure methods of the microbial activity. Respirometry (CO_2 evolution rate and/or O_2 uptake rate) has been widely used to evaluate microbial activity through a reliable, repeatable and scientifically assessment and therefore, stability of a compost sample (Gomez, et. al. 2012).
In this study, a novel respirometric technique was developed in a composting material from detoxified olive oil mill wastes. This novel setup consists of a lab-scale batch incubator with controlled temperature and moisture content, a peristaltic pump for the recirculation of air and a CO_2 probe. Organic materials from different composting phases were tested for their respirometric abilities. CO_2 evolution rates were measured during each cycle and obtained results were evaluated considering the composting progress. Usually maximum levels of OURs are reached approximately at 12-48 hours, depending on the temperature.

Methods

The device consists of a closed bio reactor of 2L volume where 150 gr of solid organic substrate are putting. The bio-reactor digester is placed in a temperature controlled area (HV) and the temperature was set at 45°C. Once sealed airtight entire system respirometer (lines and containers) to the absorption of oxygen from the biomass be intermittent processed, start the positive displacement PP pump (peristaltic pump) supply 7 L / h and which continuously recirculates the air contained in respirometer. The air is recirculated through the middle of the biomass into the digester and passing exhaust reflux water so that the moisture swept by the biomass to be returned to digester BR. The air then passes through the dehumidifier HA in order to dehumidify the recirculated air avoiding any affect on the CO_2 measurements in the gas analyzer GA below. The dehumidifier contains $CaCl_2$ as a means of dehumidification. The gas analyzer is based on the principles of thermal conductivity. As concern the maximum oxygen uptake rate measurements and the time of bio reactions overcome are calculated and loaded in a proper computer program. Given the assumption that for each mole of CO_2 produced are absorbed one mole of oxygen then the O_2 absorption chart is equivalent to CO_2 production. In this diagram, the slope of the curve represents the oxygen absorption rate (gr O_2/kg compost/d). An appropriate software calculates the largest slope and the value was used in this study as the maximum oxygen absorption rate. Stabilization of the gas concentrations completed approximately in 12 to 48 hours depending on the temperature. Figure 1 presents the respirometer which used in the lab in order to measure the O_2 adsorption.



BR = Bioreactor Digestion

PP = Peristaltic Pump

HE = Water Conseder

HA = Moisture Removal

GA = Gas Analyzer

V = Venting Gas Line

HV = Temperature Control Area

Figure 1. Respirometer

In order to determine the volumetric cumulative oxygen consumption for each sample over the whole test period, the following equation was used:

$$V_1 = (O_i - O_e) * \mathbf{F} * \Delta_t \qquad (1)$$

Where:
V1 = cummulative volumetric oxygen consumption (L)
Oi = oxygen concentration in incoming air (volume %)
Oe = oxygen concentration in exhaust air (volume%)
F= air flow rate (in L/h) and
Δt= period of time

The oxygen consumption is calculated using the following formula:

$$\mathbf{C= V_1*V_2 * 32/ 22,414 *1000} \qquad \mathbf{(2)}$$

C= oxygen consumption in grams
V_2= 1,5 ml (reactor volume)
22,4141 L= volume of 1 mole of oxygen under standard conditions of temperature and pressures
32 gr= weight of 1 mole of oxygen
The oxygen consumption expressed in mg O_2/Kgd.c./d)

Results

The indicative parameters which should be taken into consideration for the final stage of the process are: the Water Holding Capacity (WHC), pH, Electrical Conductivity (EC), Organic matter, the oxygen content, humic - fulvic compounds, Germination Index and Cationic Exchange Capacity (CEC). A comprehensive set of those specific parameter measurements take place. When these specific parameters, starting to stabilize or give a specific range of values means that the product is in phase of humification- composting. The table below presents the indicative parameters during the stage of humification.

TABLE 1. The indicative parameters at the stage of humification

PARAMETER	UNIT								
TIME	WEEKS	1	2	3	4	5	6	7	8
WHC	% db	162	151	140	120	124	149	125	118
pH		8,4	8,2	8,3	8,45	8,7	8,7	8,8	7,89
EC	mS/cm	1313	1403	1284	1323	1388	1061	1708	764
ORGANIC MATTER	% db	83,27	83,69	87,82	83,68	83,44	84,14	82,83	80
ORGANIC CARBON	% db	46,3	46,5	48,8	46,8	46,4	46,7	46	40
TOTAL ORGANIC NITROGEN	% db	1,24	1,54	1,35	3	2	2,5	2	3
CEC	meq/100g	29,9	30	28	32	39	45	55	59
GERMINATION INDEX	%	101,57	125	130	120	116	125	115	130
HUMIC ACIDS (HA)	gr/kg d.c	6	6	7	5,9	8	7	8	10,3
FULVIC ACIDS (FA)	gr/kg d.c	0,9	1	1	0,7	2,3	2	2,2	3,5
MAXIMUM OXYGEN RATE. O2 rmax	mg/kg OM -d	697	611	519	361	196	219	164	29
C/N	% db	37,33	30,19	36,14	15,6	23,2	18,68	23	26,67

The parameters which play important role in the composting process as they are depicted from the table are germination index, humic acid content as well as Cation Exchange Capacity. As concern CEC is increasing rapidly during the course of the process reaching 59meq / 100 g d.m. Finally, measurements of germination index substrate showing the final conversion of a phytonutrient fertilizer as the final product were 130% phytonutrient. Notably, significant increases were observed in the content of humic compounds unlike in fulvic substances content which decreased. Of course, the measurement of these took place when the product began to take its final form and composition touching the price of 10 gr/ kg.d.m. Another of product maturity coefficient is the ratio HA / FA which must be greater than 2.5 to be considered as a product not phytotoxic. In this product the coefficient reaches a value of 10.

Each diagram of the figure 1 depicts the rate of oxygen consumption of each sample in mg O_2/kg dry compost per day needed in order to produce CO_2. At the beginning of each cycle, there is a lag phase after which the rate of oxygen consumption increased (Lazaridi and Stentiford, 1998). However, it presents the typical CO_2 production diagram or absorption O_2 by respirometry and calculation of maximum tilt. For each sample the start at point was 80-90 mg O_2. This rate increased achieving the highest pick and after that reduced gradually as the composting process completed (at diagram h).

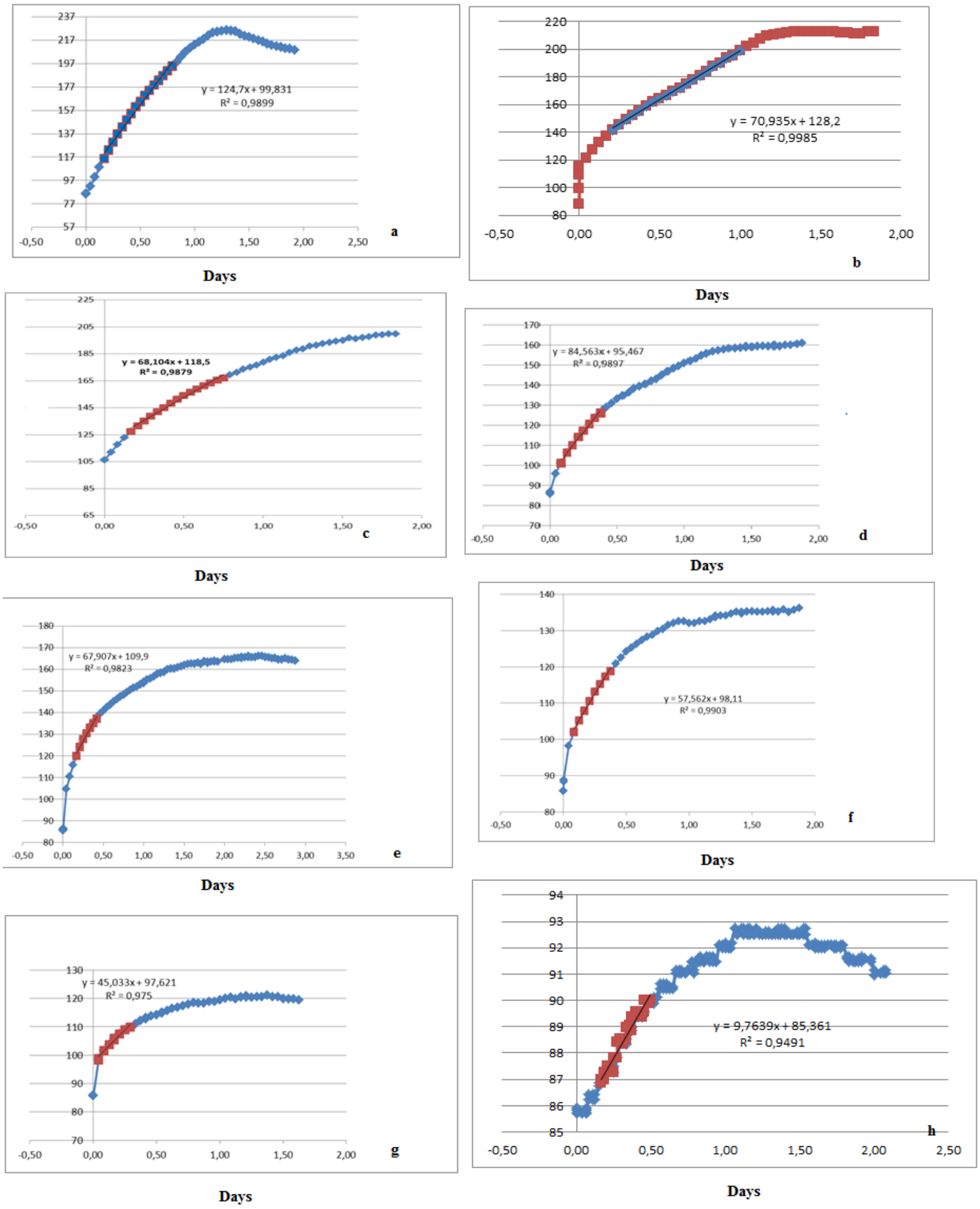


Figure1. Maximum Rate of Oxygen Consumption (mgO_2/kg. d. c/d)

The oxygen in the compost is directly related to the microorganisms grown there in. At the beginning of the process a large number of microorganisms start growing. The maturation of the product portending the completion of the procedure as well as the number of microorganisms decreases as prevailing aerobically. This is obvious through the figure 2, which depicts the correlation of the average total maximum oxygen consumption rate with time (in 8 weeks). At the beginning of the procedure the oxygen consumption takes the value 700 mg O_2/kg, d.c/d, which gradually decreased getting the value 30mg O_2/Kg. d. c. /d. At the end of 2 months finally gets value 30 mg O_2 / kg d.c./ d. with correlation coefficient 96%. The microbial structure system by bacteria, protozoa plays an important role in the raising of the oxygen consumption (Tiqiua, et. al ., 1996).

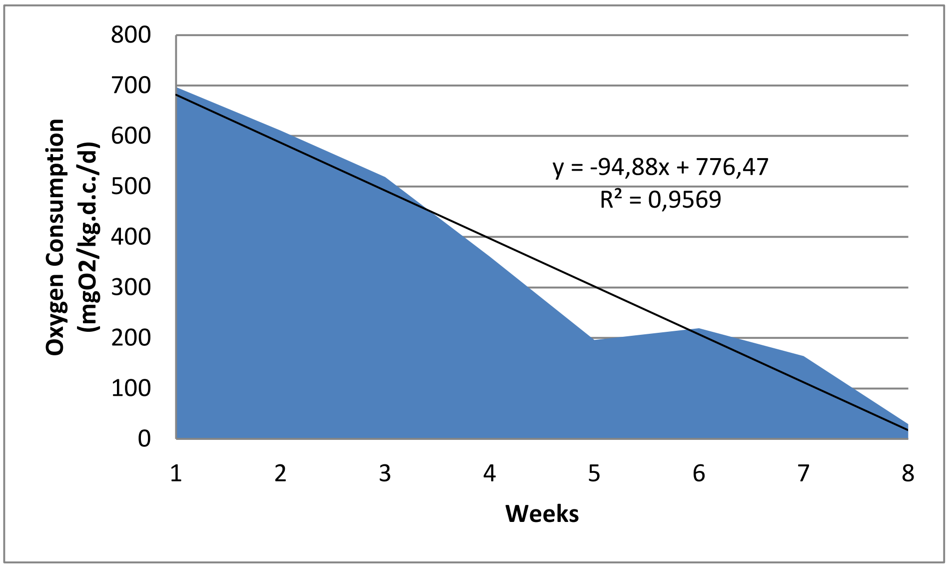


Figure 2. Oxygen Consumption (mgO_2/kg. d. c/d)

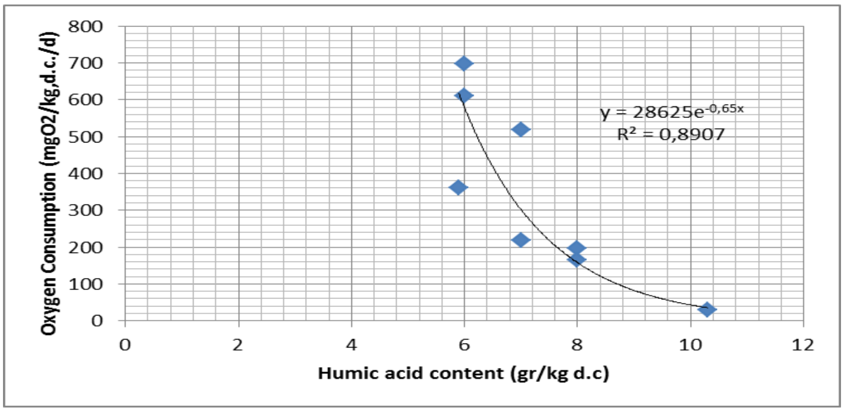


Figure 3. Oxygen Consumption (mgO2/kg. d. c/d) vs Humic acid content

One of the major parameters always studied in the composting process, and especially at the end of the process is the concentration of humic and fulvic acid contents. According to the figure 3 as the concentration of humic compounds increases the oxygen consumption decreased exponentially. The correlation coefficient is sufficiently high achieving 90%. This increase is very significant and can be justified observing the values of parameters in table 1. Humic acids have a strong advantage which is the oxygen existent in their structural component of the nucleus. Additionally the high concentration of humic compounds in a product can justify the high pH as well as the dark to black in color (Stevnson , 1982).

Conclusion

As it was mentioned above the terms "compost stability" and "compost maturity" are two different meanings which the most of the times are confused. The term maturity is often assessed through sensory activity or the potential for plant growth. Maturity is best assessed with plant growth and a combination of several other assays. On the other hand stability can be determined by the rates of O_2 uptake, CO_2 produced or the heat released as a result of microbial activity. The chemical and physical stability of the compost determines the shelf-life and applicability of compost for various uses. A stable compost is one that shows an advanced degree of organic matter decomposition with resistance to further decomposition. A stable compost shows steady values of a number of indices like respiration rates, microbial count and biomass, organic matter, content, C/N ratio, and storage temperature (Wichuk and McCartney, 2010).
Under an effort to measure the most significant biological parameter development factors based the whole process, a device created, which gives the ability to measure the maximum oxygen adsorption rate in 2 days. Due to the fact that the oxygen is directly connected with all the other parameters as it was mentioned above, a correlation between the rmax and other parameters were presented. There is a strong correlation between oxygen consumption and humic acid content, which depicts the final stage of the composting process. Though that correlation, is given the chance for a

rough estimation of the parameters of a sample calculated the oxygen consumption. The maximum rate of oxygen consumption enables prediction and monitoring of composting evolution.This is so important due to fact that there is the ability to save time in analyzing the samples in industrial application.

References

1. Adani, F., Ubbiali, C., Generini, P., The determination of biological Stability of composts using the Dynamic Respiration Index: The results of experience after two years, Waste Management, Vol (26), p. p. 41-48, (2006)
2. Gómez,R.G., Lima, F.G. and Ferrer, A.S., The use of respiration indices in the composting process: a review, Waste Management & Research, 24,p.p. 37-47,(2006).
3. Muktadirul Bari Chowdhury, Ａ. K. Md., Akratos, C. S., Vayenas, D.V., Pavlou, S. 108:119. Olive mill waste composting: A review, International Biodeterioration & Biodegradation, Vol. (83), (2013)
4. Lazaridi, K.E. and Stentiford, ED.I, A simple restpirometric technique or assessing compost stability, Water Resources, Vol.32, No12, p.p.3717-3723, (1998)
5. Stevenson, F.J., Humus chemistry.Genesis, composition, reactions. John Wiley and Sons (1982).
6. Tiquia, S. M. . Tam, N. F. Y. , Hodgkiss, I. J., (1996), Microbial activities during composting of spent pig-manure sawdust litter at different moisture contentsicrobial, Bioresource Technology 55, 201-206.
7. Wichuk, K. M., and D. McCartney, Compost stability and maturity evaluation—a literature review, Can. J. Civil. Eng., 37, p. p. 1505 ‑ 1523, (2010).