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# Stability Measurement of Biosolids Compost by Aerobic Respirometry

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Oxygen uptake of biosolids compost was measured during both laboratory and full-scale studies. Aerobic respirometry of solid samples of compost provided a precise measure of microbial activity. There was a noticeable decreasing trend in oxygen consumption over 25 days of composting, thereby indicating increasing stability. Moisture content also was found to affect the compost stability. During 48-hour respirometer tests, the compost sample did not dry to the point where respiration was inhibited. Measurement of volatile solids reduction alone during biosolids composting with large quantities of sawdust revealed little about stability.

## *Introduction*

Over the past 40 years, researchers have investigated many physical, chemical and biological parameters to monitor composting process performance and final end-product stability. Early on, experimental studies were conducted with municipal solid waste (MSW) to observe the effects of moisture content, pH and oxygen concentration on composting temperature and the quality (including stability) of the end-product. Tests on the composted materials were initially performed to evaluate trends or patterns and not to define actual characteristics of the end-product. Thus, parameters that showed increasing or decreasing patterns over specific composting periods (i.e., 30 to 120 days) were considered good stability measures.

Early measurements of compost respiration were published in the 1950s by Wiley (1955, 1956, 1957) who proposed using carbon dioxide production as a test parameter for high-rate composting. Wiley showed some correlation (e.g., $r = 0.791\text{-}0.817$) between carbon dioxide production and compost temperature. McCauley and Shell (1956) used oxygen uptake as an index for microbial activity and compared these findings to maximum oxygen diffusion rates. Those early studies used respiration rate as an operational parameter, but not as a stability index. That is, the test was not designed to provide a measure of the putrescibility, or biodegradability, of the residual material. One of the first individuals to correlate respiration rate with compost stability was Schulze (1961) who showed that finished MSW compost having different moisture levels had large differences in oxygen uptake. Schulze reported average oxygen uptake rates of 0.015, 0.385 and 0.756 mg $O_2$/g VS/hr at 19.6, 51.3 and 60.4 percent moisture, respectively. Recently, improvements in equipment and understanding of fundamentals have led several investigators to use different approaches for respiratory measures and procedures (Pressel and Bidlingmaier, 1981; Usui *et al.*, 1983; Willson and Dalmat, 1986; Haug and Ellsworth, 1991; Frost *et al.*, 1992) and tests have been conducted on solid samples and slurries. The Composting Council of Alexandria, Virginia, a lead group in composting advocacy, is currently preparing guidance documents for measuring physical, chemical and biological parameters of compost products and oxygen consumption in a solid matrix form recently has received considerable attention.

Because of this interest in oxygen consumption and because no universally-acceptable stability index exists today, the authors conducted a study to evaluate the feasibility of using aerobic respirometry as a method for measuring the stability of solid compost matrices. The objective was to show a relationship between oxygen uptake and the duration of composting in an in-vessel system and to show how oxygen uptake is affected by moisture content of the compost matrix.

## *Materials and Methods*

### *Respirometer System*

The aerobic respirometer used in the current is shown schematically in Figure 1 and consisted of sealed glass vessels to contain the compost samples, oxygen flow measuring cells and a computer for data acquisition (AER-200 system, Challenge Environmental Systems, Inc., Fayetteville, Arkansas). As oxygen is consumed by microorganisms in the glass vessels, the partial pressure decreases and oxygen is pulled into the vessel through a cell that creates small bubbles (0.05 mg $O_2$/bubble) in a confined liquid. As each bubble passes through a sensor, it is counted and accumulated to provide a constant record of oxygen uptake. For the tests conducted for the current study, twenty grams (wet weight) of compost were placed into each glass test vessel which contained an elevated floor made of fritted glass. A 60cc syringe filled with sodium hydroxide pellets and inserted into a port at the bottom of the glass cell served as a carbon dioxide trap. A peristaltic pump was used to circulate the gaseous contents through each vessel and the carbon dioxide trap. The data logger on the respirometer was set to record cumulative oxygen uptake every 30 minutes. All respirometer tests were conducted at 35°C. Two to three replicates were performed for each compost sample and the tests were conducted for 48 hours.

The experimental setup allowed oxygen to be dispersed throughout the compost sample thereby minimizing the diffusion and mass transfer limits identified by Shell (1955) as being an important factor in measuring compost stability. Minimization of

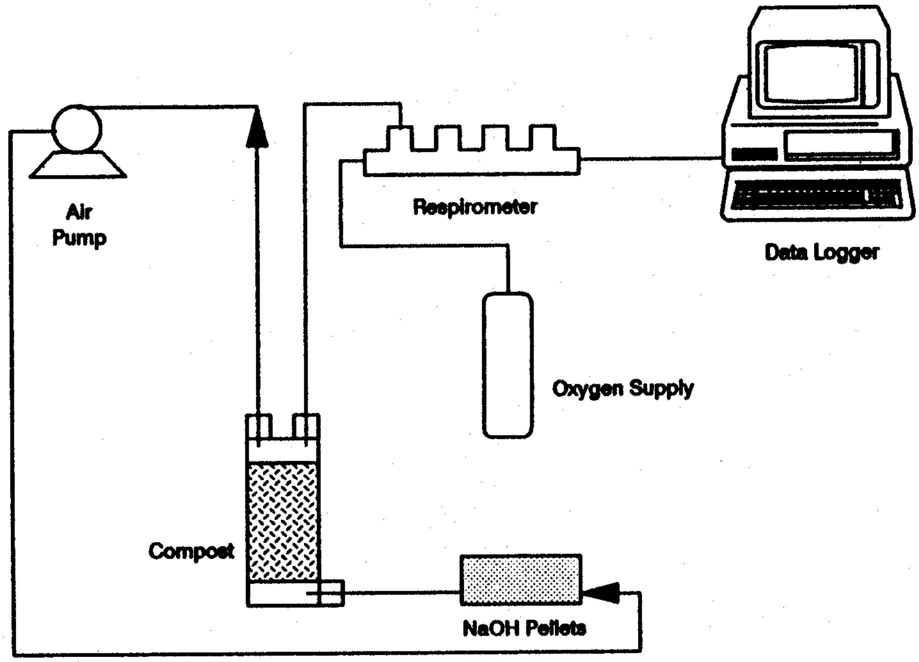

Figure 1. Schematic diagram of respirometer and sample container with sodium hydroxide, carbon dioxide trap

diffusion limits is important because oxygen transfer through the biomass layers and into the bacterial cell wall is typically considered to be the rate limiting step in fixed-film biological reactions such as exist in compost matrices. Thus, oxygen should be plentiful in the porous matrix to maximize oxygen flux. An advantage of this approach is that the carbon dioxide in the porous compost matrix is removed continuously, thereby avoiding buildup that can affect the pH.

### *Compost Source*

Samples of compost were obtained from the University Area Joint Authority (UAJA) composting facility located near State College, Pennsylvania (See Figure 2). UAJA composts primary and waste activated biosolids using an in-vessel, agitated-bed system developed by International Process Systems, Inc. of Hampton, New Hampshire. The UAJA facility consists of 12 bays, each 220 feet in length and each capable of handling approximately 4.5 wet tons of biosolids per day. The biosolids are cocomposted with sawdust, typically at mixtures of 62 percent waste sludge, 26 percent sawdust and 12 percent recycled compost by wet weight. Aeration is provided by blowers while the compost is mixed. The air is then cycled on and off intermittently throughout the bay length on a schedule that is based on temperature and time. Samples of compost were collected at 0, 24, 48, 96, 168 and 216 feet along the bay several hours after mixing. Two grab samples were removed from the top 12 inches of the compost pile at each location using a stainless steel scoop and placed into plastic bags. The individual samples collected at each location were composited and prepared for analyses within one hour of sampling. Subsamples were removed from the composited samples for respirometer and other analyses.

Figure 2. UAJA biosolids compositing facility, State College, Pennsylvania

TABLE 1.
General compost characteristics[1]

| Location Within Bay (feet) | No. of Samples | Total Solids[2] % Solids (95% C.I.) | Total Solids CV (%) | Volatility[2] % volatile (95% C.I.) | Volatility CV (%) | pH[3] |
|---|---|---|---|---|---|---|
| 0 | 7 | 41.4 (40.1-42.6) | 9 | 91.5 (91.0-91.9) | 2 | 6.4 |
| 24 | 1 | 41.3 (39.3-43.2) | 4 | 91.3 (90.6-91.9) | 1 | 7.0 |
| 48 | 2 | 45.8 (44.8-46.8) | 3 | 90.4 (89.2-91.6) | 2 | 7.4 |
| 96 | 3 | 59.8 (57.5-62.1) | 7 | 90.1 (89.4-90.7) | 1 | 7.8 |
| 168 | 2 | 69.0 (68.0-70.0) | 2 | 89.5 (88.2-90.8) | 2 | 7.8 |
| 216 | 1 | 70.4 (70.2-70.6) | 0.1 | 90.6 (89.5-91.7) | 1 | 7.8 |

[1] Samples obtained between February and May 1994.
[2] Results are averages from five replicates from each sample.
[3] pH values based on one composite sample.

TABLE 2.
Comparison of total dry solids and volatility both before and after respirometer tests

|  | Total Solids |  |  | Volatility |  |  |
|---|---|---|---|---|---|---|
|  | Mean (% Solids) | CV (%) | 95% C.I. (% Solids) | Mean (% Volatile) | CV (%) | 95% C.I. (% Solids) |
| <u>0 feet</u> |  |  |  |  |  |  |
| Before | 41.4 | 9 | 40.1-42.6 | 91.5 | 2 | 91.0-91.9 |
| After | 41.6 | 5 | 40.8-42.4 | 90.5 | 2 | 89.7-91.3 |
| <u>24 feet</u> |  |  |  |  |  |  |
| Before | 41.3 | 4 | 39.4-43.2 | 91.3 | 1 | 90.6-91.9 |
| After | 48.2 | 3 | 46.4-49.9 | 93.1 | 1 | 91.8-94.4 |
| <u>48 feet</u> |  |  |  |  |  |  |
| Before | 45.8 | 3 | 44.8-46.8 | 90.4 | 2 | 89.2-91.6 |
| After | 48.8 | 6 | 46.8-50.7 | 90.0 | 2 | 88.8-91.2 |
| <u>96 feet</u> |  |  |  |  |  |  |
| Before | 59.8 | 7 | 57.5-62.1 | 90.1 | 1 | 89.4-90.7 |
| After | 60.7 | 5 | 58.4-63.0 | 90.7 | 1 | 90.0-91.4 |
| <u>168 feet</u> |  |  |  |  |  |  |
| Before | 69.0 | 2 | 68.0-70.0 | 89.5 | 2 | 88.2-90.8 |
| After | 74.3 | 8 | 70.3-78.3 | 89.6 | 2 | 88.3-90.8 |
| <u>216 feet</u> |  |  |  |  |  |  |
| Before | 70.4 | 0.1 | 70.2-70.6 | 90.6 | 1 | 89.5-91.7 |
| After | 75.6 | 1 | 74.5-76.8 | 90.9 | 1 | 90.1-91.7 |

## *Physical and Chemical Analyses*

Percent dry and volatile solids and pH of the compost were examined along the length of the bay. Percent solids were measured by drying 2 to 5 g samples of the compost at 103°C for 24 hours (Standard Methods, 1992). Volatility was obtained by ashing the dried samples at 550°C for one hour. Dry and volatile solids were measured before and after oxygen uptake tests. The pH of the compost samples was determined from an extract using a 1:10 v/v solution of compost and distilled water, respectively.

## *Results and Discussion*

Physical and chemical analyses performed on the compost samples are presented in Tables 1 and 2 as the mean, the coefficient of variation (C.V. = standard deviation expressed as a percent of the mean) and 95 percent C.I. for total solids and volatility.

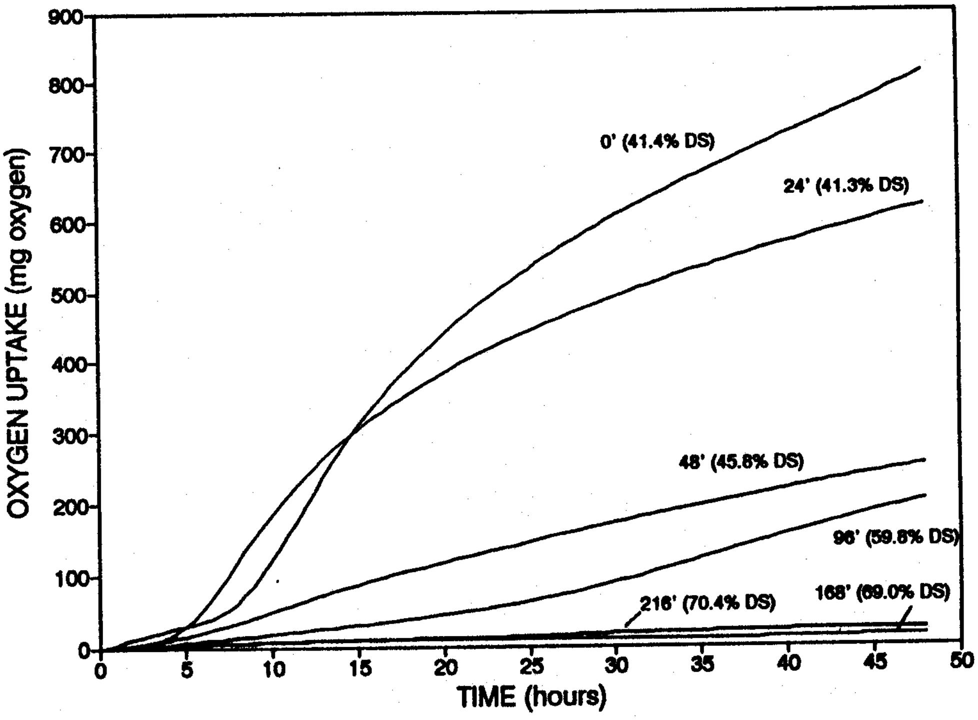

Figure 3. Cumulative oxygen uptake for test bay (average of two to three samples)

The 95 percent C.I. indicates the range within which the mean of replicated analyses is expected to fall 95 percent of the time. Data sets having 95 percent C.I. values that do not overlap are considered to be significantly different. The data in Table 1 show that percent dry solids in the full-scale bays increased from an average of 41.4 percent at 0 feet to 70.4 percent at 216 feet over the 25 days of composting. A relatively large increase of about 14 percent in dry solids content was recorded between 48 and 96 feet. The 95 percent C.I. did not overlap for total solids between the 0 and 216 foot locations, thereby indicating a significant difference in moisture content over the length of the bay. The 95 percent C.I. for volatility overlapped at all locations indicating that the volatility was essentially the same throughout the bay. This constant volatility was expected because of the large quantity of sawdust in the compost mix. The pH of the compost samples increased gradually from about 6.4 to 7.8 which is typical of composting reactions as carbon dioxide is stripped over the length of the bay.

Cumulative oxygen uptake curves are shown in Figure 3 for samples taken at intervals throughout the length of a test bay. The graph indicates that the 48-hour total oxygen consumption was greatest for compost samples taken at 0 feet with oxygen uptake decreasing with distance (and time) along the bay. Each sample was placed in the respirometer at the percent dry solids content shown with each curve. Compost samples taken from the 0 and 24-foot locations showed similar patterns of microbial activity. The lag in oxygen uptake was expected for samples near the beginning of the bay (0 feet) and represents the time required for the microorganism population to adapt to the compost environment.

Figure 4 presents the oxygen uptake rate associated with the respective cumulative oxygen uptake curves shown in Figure 3. The peak oxygen uptake rate ranged from a high of 5.3 mg $O_2$/hr/g DS (dry solids) at 0 feet to a low of 0.03 mg $O_2$/hr/g DS at 216 feet. In most cases, the oxygen uptake rate peaked early in the 48-hour respirometer test. The respiration rates for compost samples taken at 48 feet and

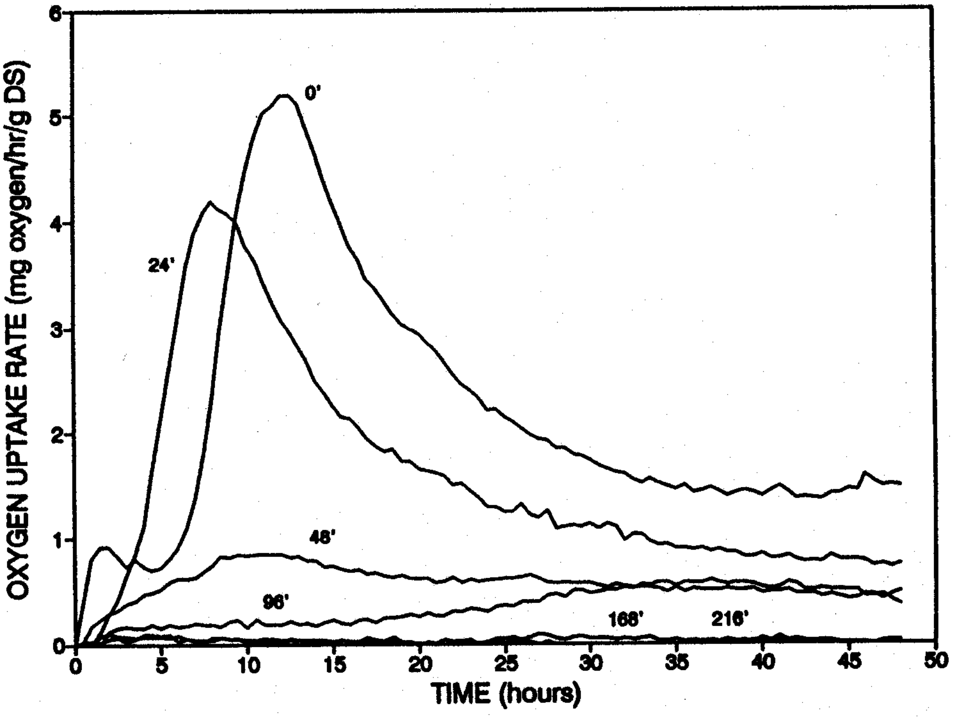

Figure 4. Oxygen uptake rate for test bay (average of two to three samples)

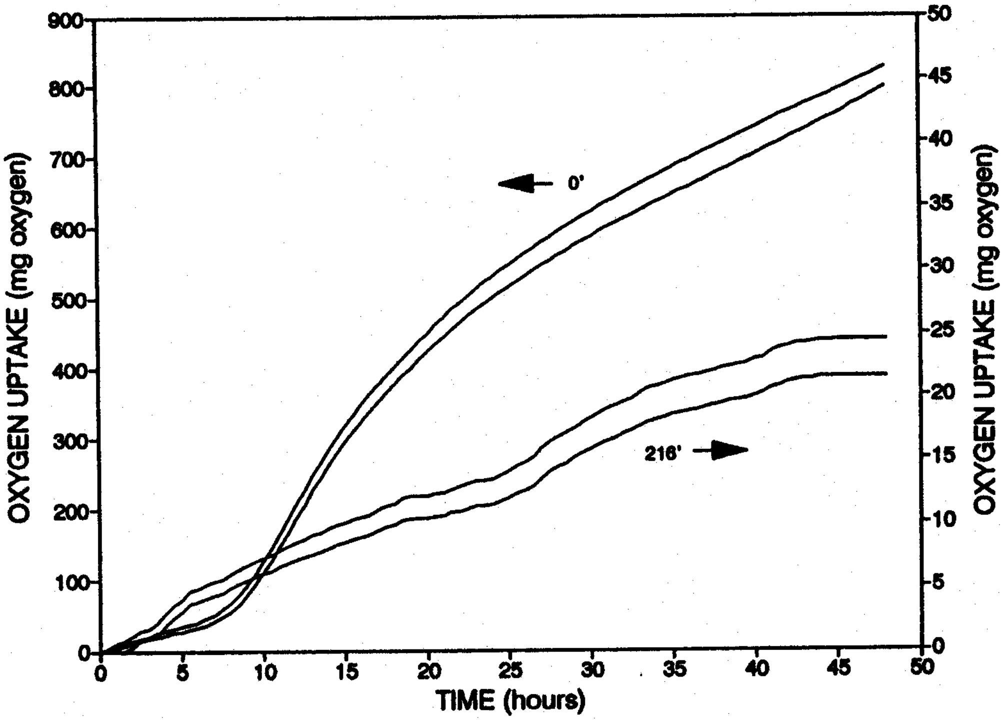

Figure 5. Replicates of oxygen uptake for test bay at 0 and 216 feet

greater were generally flat, possibly indicating a change in dominant microorganisms, a decreasing moisture content, or residual organic matter that was more resistant to biological degradation (e.g., cellulose, hemicellulose and lignin).

Our findings were similar to those reported by Iannotti *et al.* (1993) where the rate of mean percent oxygen saturation was lowest after 31 days of composting and by Schulze (1961) who found that moisture content can affect respiration rate. The solids content both before and after the respirometer tests are shown in Table 2. These data show that a minor amount of drying occurred in the respirometer vessel during the 48-hour test. In some cases, the differences were statistically significant. The most likely cause of the drying was adsorption of moisture by the sodium hydroxide used to remove carbon dioxide from the recirculating gas stream.

Replicates of oxygen uptake tests for samples of compost taken at the 0 and 216-foot locations within the test bay are shown in Figure 5. The close repeatability of these tests indicates precision in the instrumentation and in the protocol for measuring oxygen uptake. The coefficients of variation over the 48-hour test period were five and 12 percent at 0 and 216 feet, respectively. Once again, these tests indicate large differences in microbial activity from front to back of the compost bay, therefore indicating a difference in compost stability.

In another study conducted by the authors at the UAJA plant during the summer of 1994, water was added daily to a full-scale test bay over a 25-day test period. The wetted bay showed higher compost temperatures throughout the test bay (Bay #3) than a control bay which received no moisture (Bay #4) (Figure 6) indicating that the compost reacted for a greater time when the moisture content was maintained above 40 percent. Oxygen uptake tests were performed on six samples collected from these two bays over a two month period of operation at the 216 foot point in the bay. These tests showed a lower oxygen uptake in the wetted bay than in the control bay indicating greater stability of the compost to which water was added (Figure 7). There-

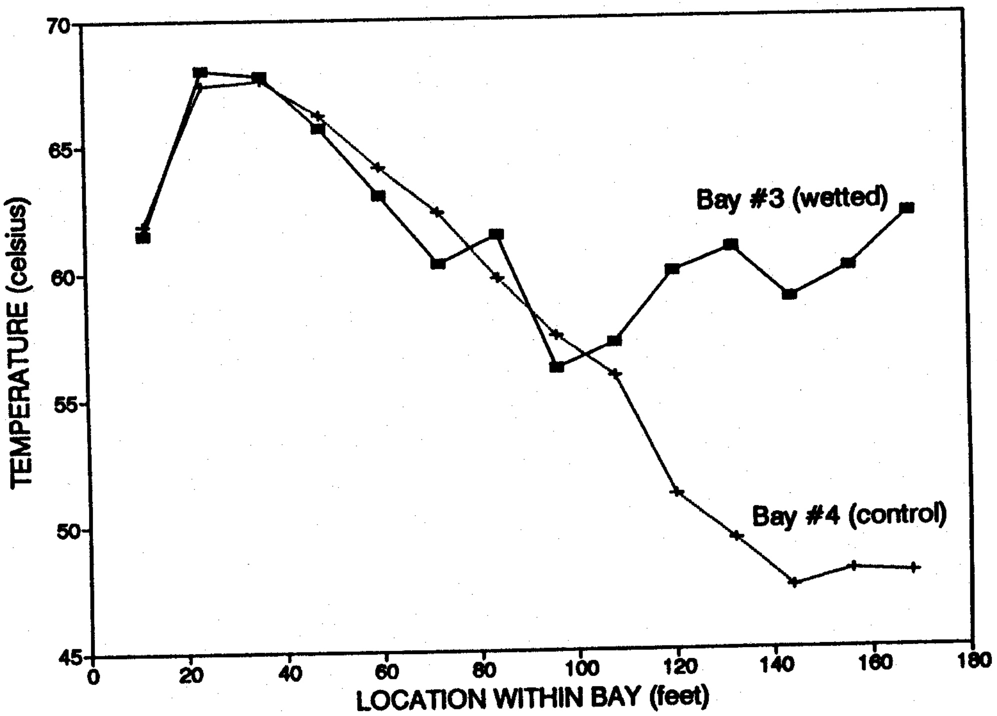

Figure 6. Core temperature for test bays (based on 40 measurements per location)

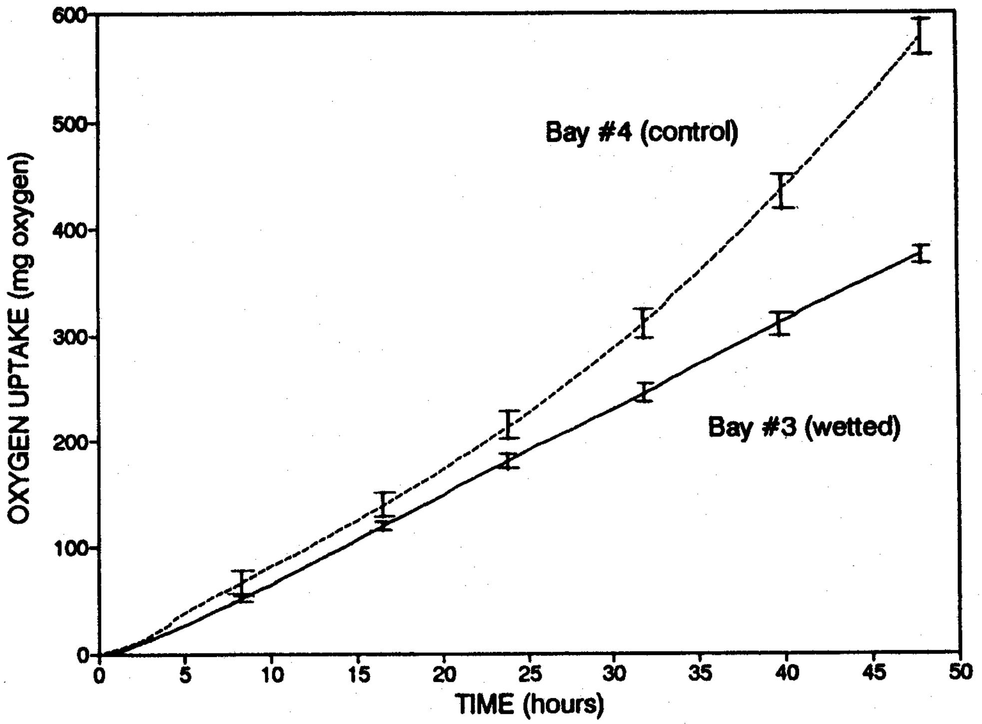

Figure 7. Cumulative oxygen uptake for test bays (error bars represent one standard deviation)

fore, moisture control improved compost stability by both sustaining temperature and reducing the oxygen uptake over the length of the bay. These tests showed good agreement among samples collected at different times — that is, coefficients of variation for bays #3 and 4 were one and five percent, respectively — thereby indicating both consistency in the compost operation and in the oxygen uptake measurement procedure.

## *Conclusions*

The intent of this work was to develop and demonstrate an improved procedure for measuring biosolids compost stability using aerobic respirometry. Better characterization of compost reactions is essential if compost products are to be compared among different facilities. Biological respiration is a fundamental biological parameter (similar to biochemical oxygen demand, BOD, in wastewater treatment) and shows trends similar to those of other indices (e.g., pH, C:N, VS, humic acids), but most other parameters are not fundamentally dependent on organic matter stability. Oxygen uptake provides an improved measure of compost stability because it represents a fundamental biological characteristic of the compost process and directly reflects the activity of the aerobic microbial reaction. Our test results indicated that respirometers provide a precise and representative measure of aerobic microbial activity during composting. Therefore, if the composting environment contains adequate moisture, oxygen, nutrients and microorganisms, oxygen uptake reflect the stability of the residual organic matter.

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