Monitoring and evaluating composting process performance

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Composting has come into widespread use as a wastewater sludge treatment process during the last several years. A recent nationwide survey showed 78 operating sludge composting facilities, 62 in various stages of realization, and 5 that had been shut down.[1] The major cause of shut-down was nuisance odor; this is also a problem at operating facilities.[2]

The increased use of composting as a sludge treatment technology, unlike other biological technologies, has occurred without benefit of a specific, objective measure of process performance in terms of waste decomposition rate. As detailed elsewhere[3-5] and outlined below, decomposition rate is an overriding determinant of composting process performance.

The absence of a decomposition rate measure in composting contributes to suboptimal process design and control, erratic operational performance, odor problems, and proliferation of proprietary processes and associated claims that are usually untested and sometimes extravagant. This study explores possible means of assessing decomposition rate in field practice.

RATE AND EXTENT OF REACTION

Composting can be represented in general terms by

$$\text{fresh organic waste} + O_2 \xrightarrow[\text{metabolism}]{\text{microbial}} \text{stabilized organic residue} + CO_2 + H_2O + \text{heat} \quad (1)$$

As with any reaction, the basic issues concern the rate of reaction (kinetics) and the extent to which it approaches completion (thermodynamics). Rate of reaction is synonymous with rate of waste decomposition, and therefore is central to process performance. Extent of reaction is synonymous with extent of decomposition (degree of stabilization), and therefore is a determinant of product quality.

Various aspects of product quality are under active investigation for using the process residue as compost (organic ammendment for soil).[6-9] In contrast, the concept of evaluating the performance of a composting process in specific, objective terms is novel. Although the two factors, process performance and product quality, are not entirely separable, this study emphasizes process performance in terms of decomposition rate.

BENEFITS OF FAST DECOMPOSITION

There are several reasons for maximizing the rate of decomposition in wastewater sludge composting.

- The problem of odor associated with processing is addressed at its source, in that putrescible, odor-causing material is rapidly decomposed through aerobic metabolism.[10-12]
- The problem of odor associated with the process residue (which might be used as a compost) is similarly addressed because of the greater progress made toward stabilization in a given time period.[13]

The practice of sludge composting is increasing rapidly, but the lack of specific objective criteria of process performance has led to unnecessary expense and problems.

- The rate of water vaporization is directly related to the rate of waste decomposition;[3,4,14] water removal is an objective in sludge treatment because dry residue is more easily managed.
- Recycled process residue (compost) might be used instead of woodchips as the bulking agent;[15] this requires a dry residue, hence a high rate of decomposition.
- Given a high rate of decomposition there is less material to be handled, less inventory, and less need for facility space and mechanical appurtenances.[4]
- Less inventory, particularly of woodchips, decreases the opportunity for growth of *Aspergillus fumigatus*;[16] this cellulolytic, potentially pathogenic fungus produces airborne spores at composting facilities.[17]

Thus, decomposition rate strongly influences cost-effectiveness of facility construction and routine operation. Because of its association with control of odor and potential public health hazards it is also a factor in public acceptance.

TESTS INVOLVING ORGANIC CONTENT

Organic content is measured through various destructive tests performed on samples of material or extracts therefrom. Some tests are nonspecific and measure a collective property, such as volatile solids. Others are for a specific compound or class of closely related compounds, such as starch. The result of a single test represents an instantaneous condition, whereas a time-course series might measure a rate.

Volatile solids. Volatile solids (VS), the percent of dry solids lost by ignition at 550°C, are widely used as a rough measure of organic matter.[18] Aerobic biological activity decreases the volatile solids content by converting organic carbon to CO_2; therefore, VS measurement over time during processing might serve as a rate parameter. However, the test lacks both specificity and sensitivity, which limits its usefulness.

The test fails to discriminate among readily metabolized, putrescible material, less readily metabolized material, and organic material that is not metabolized during any reasonable composting period. Process performance is primarily concerned with the first of these, secondarily with the second, and not at all with the third. Also, Equation 1 shows that both fresh organic waste and stabilized organic residue are included in the VS test, which decreases sensitivity.

Similarly, sensitivity is poor because a high percentage of the dry weight is volatile matter. This means that the decomposition of a relatively large amount of VS may result in only a small change in percent VS. For example, if the initial VS is 80%, then destruction of half the volatile matter would only reduce VS to 67%. In the composting of mixtures of wastewater sludge and municipal solid waste, the rate of decrease in VS was approximately 0.6% per day over a 1-month period.[19,20]

A further problem is associated with the VS test on sludge composted with woodchips or other organic bulking agents that originate outside of the waste stream. The test does not discriminate between the woodchips (or fragments) and the sludge. Also, usually only a small sample can be ashed; this is a significant technical problem with heterogeneous materials.

Total organic carbon. The total organic carbon (TOC) test is based on complete combustion like the VS test; CO_2 production is determined rather than ash weight. TOC is slightly more specific for organic matter. Otherwise, it suffers from essentially the same disadvantages as the VS test. Also, the analytical procedure is more involved.

The VS test was more consistent and reproducible than the TOC test in municipal solid waste composting.[21] The ratio of VS to TOC was approximately 2.1:1. Data are available on the relationships among TOC, peptides, amino acids, polysaccharides, and lower fatty acids in water extract of composting wastes.[22]

Carbon-to-nitrogen ratio. The ratio between carbon and nitrogen (C:N) is a significant product quality parameter when the process residue is used as compost, because material with a wide C:N can immobilize soil nitrogen and "rob" the growing plant. The ratio narrows as composting progresses because of the conversion of organic carbon to CO_2. The composting material itself is usually analyzed to determine C:N, but in a comparative test aqueous extracts provided a more reliable indication of product quality.[23] Extracts from mature composts characteristically had a C:N of 5:6, regardless of whether the waste was wastewater sludge, municipal solid waste, animal manure, or leaves. The corresponding unextracted composts had C:N values from 5 to 20. Regardless, the C:N ratio narrows too gradually to serve as a sensitive indicator of composting rate, though a narrow ratio is characteristic of a high-quality compost.

Chemical oxygen demand. Aerobic biological decomposition decreases the capacity of the organic material to reduce chemical oxidants, such as potassium dichromate; hence a chemical oxygen demand (COD) test might serve to assess decomposition rate. The product is expected to have both a lower COD per unit weight and per unit carbon than the reactant (Equation 1). Like VS and TOC, COD is a non-specific, collective, property and measures organic matter in general and includes both reactants and products. However, the COD test does not completely oxidize all of the organic matter. The relationship between COD and putrescibility is not constant or known.

The COD of municipal solid waste decreased from 900 to 350 mg/g during a 6-month composting period.[24] The material was considered ready for use after 2 months (COD approximately 700 mg/g). In the composting of a mixture of wastewater sludge and municipal solid waste, progress was followed in terms of extractable COD.[20] The decrease in this parameter was relatively even from 7000 to 2500 mg/L over a 34-day period (rate approximately 130 mg/L • d). Reports on the relationship between total and extractable COD are lacking.

Biochemical oxygen demand. Tests for biochemical oxygen demand (BOD) are based on aerobic microbial decomposition, and so are oriented toward putrescible material. The standard 5-day BOD (BOD_5) test,[18] like that for COD, was developed for polluted water rather than solid material. Adaptation to solid material poses difficulties in the preparation of accurate dilutions, inoculum standardization, and slow rate of oxygen demand exertion.[25,26] Other difficulties are that no single incubation temperature can adequately represent the composting system, and results are not available until after 5 days of incubation.

Materials balance. Parameters such as total solids content, volatile solids content and water content may be used to estimate materials balance. A materials balance has great practical significance because it integrates many aspects of facility design, construction, and routine operation. These studies are not generally applicable in field practice because they require complete[27,28] or partial[4] measurement of entering and exiting materials.

Starch. Starch is putrescible, easily extracted with hot water, readily analyzed by quantitative or qualitative (spot plate) procedures,[29,30] and therefore might seem attractive as an indicator of process performance. However, the concentration of starch in a wastewater sludge was too low (approximately 0.2%) to be useful.[21] The starch concentration in a municipal solid waste was ten times greater, and in combined composting with sludge decreased 90% to 94% during 10 days of composting. Starch disappearance has questionable usefulness as an indicator of process performance; it must be virtually absent for good product quality.

Cellulose. Cellulose comprises a major portion of solid waste and wastewater solids[31] but is not highly putrescible; for example, it degrades more slowly than starch. Two cellulose assay procedures were proposed for composting use,[32] but time-course disappearance studies seem to be lacking. A potential complication is that an aerobic heterotrophic bacterium (*Acetobacter xylinum*) can synthesize cellulose, and the possibility of its growth and synthesis of cellulose during mesophilic stages of composting cannot be excluded. Although a test for cellulose might be useful in assessing product quality, it does not seem promising for process performance evaluation.

Other tests. Oil and grease, as extracted in 1,1,2-trichloro-1,2,2-trifluoroethane, may include hydrocarbons, fatty acids, soaps, fats, lipids, oils, and waxes.[18] Such materials tend to be putrescible. A confounding factor might be *in situ* microbial synthesis, especially of lipids.

Proteins in wastewater sludges contribute to putrescibility. This class of compounds is not useful as an indicator, however, because it is universally synthesized. This may account for an increase in the concentration of extractable protein from Day 8 to Day 14 during the co-composting of municipal solid waste and wastewater sludge.[20] Thereafter the concentration of protein decreased.

Analyses of water extracts showed various changes as composting progressed.[22] The peptide concentration generally decreased slightly with time, though it increased substantially in one case. Polysaccharides, amino acids, and lower fatty acids decreased consistently; the latter two classes had the most potential for evaluating process performance. However, the focus of that study was product quality. Other specialized techniques do not lend themselves to routine process performance evaluation.[33]

TESTS INVOLVING MANIFESTATIONS OF DECOMPOSITION

Unlike tests of organic content, which necessitate sampling and destructive analytical procedures, the composting mass itself might be monitored nondestructively for certain manifestations of decomposition. However, the size of field-scale systems poses difficulties. Alternatively, a manifestation might be measured in a series of samples from the composting mass. This approach is also not without difficulties.

Heat generation. Microbial decomposition of organic matter generates heat metabolically (Equation 1); measurement of the rate of heat generation would therefore indicate the decomposition rate. The measurement would be expressed in units of energy/mass · time, such as $J/g \cdot s$.

There are two ways to measure heat generation rate. The first is based on outlet air enthalpy (heat content) plus conductive heat loss, minus inlet air enthalpy. The enthalpy of air depends on its temperature and relative humidity, and to a minor extent any departure from ambient levels of oxygen and carbon dioxide. This approach to heat measurement was successfully used to continuously monitor a laboratory-scale composting physical model for an experimental mass of approximately 2 kg dry weight of wastewater sludge.[12] It is difficult to apply to field-scale systems because air flow, outlet temperature and relative humidity, and the mass of the material being composted need to be measured.[28,34]

The second approach to heat measurement is the differential calorimetry technique, which measures heat removal solely by conduction. Conduction from high-rate field scale systems is relatively slight,[34] which would eliminate this approach on fundamental grounds. A sample could be examined calorimetrically because only conduction is operative in the instrument, but the practicality is doubtful.

Temperature elevation. Temperature is a system quality that cannot, by itself, indicate the quantity of heat generated.

Water production. The water produced metabolically in composting (Equation 1) cannot ordinarily be distinguished from background water. Moreover, the composting system tends to dry because water production is small compared to evaporative loss.

Oxygen consumption and carbon dioxide production. Aerobic respiration, the dominant form of metabolism in composting, consumes O_2 and produces CO_2 (Equation 1). As such, the rate of O_2 uptake and CO_2 output (for example, mg O_2 or $CO_2/g \cdot s$) indicates decomposition rate. It is difficult to measure these rates in the field, however, because the calculation is based on measurement of outlet air volume and O_2 or CO_2 concentration and weight of the composting material.[28] Measurement of O_2 uptake or CO_2 output is less difficult in a suitably designed laboratory-scale experimental apparatus.[35-38] Instantaneous measurement from a sample could be obtained through respirometry; although this might indicate stability in the sense of product quality,[8] it would be a cumbersome means of monitoring process performance.

APPROACHES UNIQUE TO COMPOSTING

The aforementioned tests except for temperature elevation could be applied, in principle, to any type of biological waste treatment system. There are, however, two approaches that are unique to composting; these are based on ventilation demand and the drying tendency.

Information on the rate-limiting factors operative in the composting system, how these factors might be relieved to approach a maximal rate of decomposition, and how the system behaves when so managed are addressed fully elsewhere.[3-5,10-15,34] They are summarized here, in part by presenting the results of a field demonstration. The possibility of using ventilation demand and drying tendency to indicate process performance can be understood in this context.

Primary rate-limiting factor: temperature. Consider an organic mass which is ventilated specifically to ensure a minimal O_2 residual in the outlet air (for example, 5 to 15%), an approach commonly taken to composting.[39-41] This leads unintentionally to excessively high temperature and slow decomposition.[42]

This outcome results from the interplay of two relationships.[5] First, more air is needed to remove heat than to supply O_2 for aerobic decomposition. Given inlet conditions of 20°C and 50% relative humidity (RH) and outlet conditions of 60°C and 100% RH, the ratio between the amount of air needed to remove heat to that needed to supply O_2 is 8.98. Second, a negative interaction between microbial heat generation and temperature occurs at temperatures above 55 to 60°C and progressively suppresses heat generation.[3-5,10] Unless it is controlled, temperature typically peaks at 75–80°C, at which point decomposition is slow. Consequently, attention to the role of ventilation in supplying O_2 separate from heat removal leads to a condition of self-inhibition, and counters the waste management goal of speeding decomposition.

In contrast, deliberate use of ventilation to approach maximal decomposition rate via temperature control also automatically ensures thorough oxygenation. Implementation is by means of temperature feedback control of a blower. This provides time-variable ventilation on demand and matches ventilative heat removal to heat generation, in reference to biologically favorable temperature. The operational goal is to prevent temperature in excess of 60°C. This approach to composting process control induces the following chain of events: decomposition consumes O_2 and generates heat; heat elevates the temperature; temperature exerts a demand for ventilation; ventilation removes heat and supplies O_2 in excess. A temperature supportive of rapid decomposition is maintained in this manner while oxygenating the mass.

Secondary rate-limiting factor: drying tendency. If the temperature is not allowed to become rate-limiting, a drying tendency is established. This is because the main mechanism of ventilative heat removal (approximately 90%) is water vaporization, and metabolic production of water makes up only a small part of the evaporative loss (approximately 10%). Thus, the faster the decomposition, the stronger the drying tendency. This allows dryness to become the rate-limiting factor, in combination with substrate depletion.[3,4] Whether dryness should be permitted to become limiting or the material remoistened to sustain microbial activity is a separate operational issue.

FIELD DEMONSTRATION

These relationships can be illustrated by a representative field demonstration.[13] Approximately 27 t (wet) of a mixture of primary wastewater sludge belt-filter press cake (moisture content and VS content both approximately 75%) and woodchip bulking agent were formed into a pile over a base of woodchips (Figure

1). The approximate mix ratio was 1 t sludge:2m^3 woodchips. Overall, before woodchip cover was added (25 to 30 cm thick) the pile was 15 m long by 4.3 m wide by 2.0 m high. Each flexhose end was connected to a 0.33-hp, 22.9-cm radial blade blower. All six blowers were operated simultaneously in the forced-pressure mode.[43] A control thermistor, that continuously reports to a temperature controller was placed at Position 6, and a gas sampling probe at Position 11 (O_2 analysis every 4 hours). Thermocouple probes for temperature monitoring were at all of the positions. Samples (mixture of sludge and woodchips) for moisture content determination were taken from between Positions 6 and 11.

Blower operation was controlled by a timer and a temperature controller-thermistor combination. The timer provided baseline operation, which was scheduled for 1.5 min on-time per 15 min (8% on-time). The controller was assigned a setpoint of 45°C, and its thermistor was located in the pile at Position 6; this subsystem provides for on-demand temperature feedback control. The combination of setpoint and thermistor location was selected to prevent temperature from exceeding 60°C. Blower operation was monitored continuously by an event recorder.

The trial was started on May 27, 1980 and ended on June 9, 1980. During this period the ambient air temperature ranged from 10 to 31°C, and rainfall was 3.3 cm in 6 events.

The period of temperature feedback control commenced at Hour 10 and terminated at Hour 170 (Figure 2A). The blower was operated on the fixed schedule (baseline) from time-zero to Hour 10 and from Hour 170 to Hour 300. During the period of feedback control the median temperature was 48°C (range 19–70°C) for 728 observations, and 10% of these observations exceeded 60°C (main grid probes only). Figure 2B is based on the data from only the innermost vertical series of probes. The temperature gradient in the direction of airflow indicates intensive heat generation.[3,5,13] The minimum detected O_2 concentration was 6% by volume, but most measurements ranged from 16% to 20%. The initial moisture content was 56%; this decreased to 24% during 8 days of composting (Figure 2C).

VENTILATION DEMAND AS A DECOMPOSITION INDICATOR

The relevant sequence is as follows: decomposition generates heat; the heat elevates temperature; the elevated temperature exerts a demand for ventilation through temperature feedback control; the demand is manifested in blower operation (percent on-time). The intensity of on-demand blower operation is a function of heat generation; therefore, it represents the intensity of decomposition. The demand parameter is illustrated in Figure 2A.

It is difficult to quantify the relationship between blower demand and heat generation because the water-holding capacity of air greatly increases with temperature and thereby increases the amount of heat removed for a given duration of blower on-time. For example, for inlet air at 25°C and 60% RH, and outlet air at 50°C and 100% RH, the amount of heat removed is 221 kJ/kg dry air. With outlet air at 70°C and 100% RH, the removal is 3.4 times greater, 750 kJ/kg dry air. Moreover, short-circuiting and other vagaries of airflow can confound the relationship.[44]

Nevertheless, quantification of heat (or decomposition) is not required in an absolute sense for operational purposes. Advantages of using ventilation demand as an indicator of decomposition are that it relates to a fundamental manifestation of decomposition (heat generation), relates to the entire mass without sampling, and can provide instantaneous data automatically. Of course, ventilation demand is an option only if temperature feedback is the basis of process control.

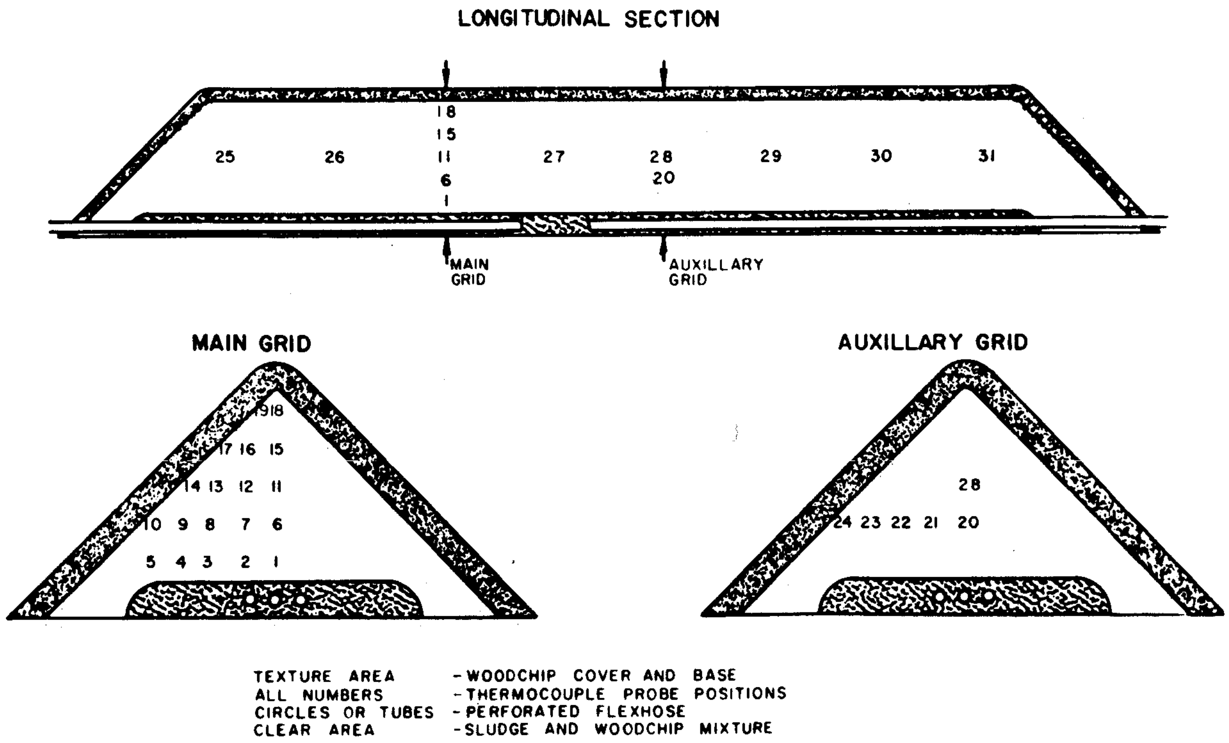

Figure 1—Sectional representation of the illustrative pile (Pile 8 in reference 13).

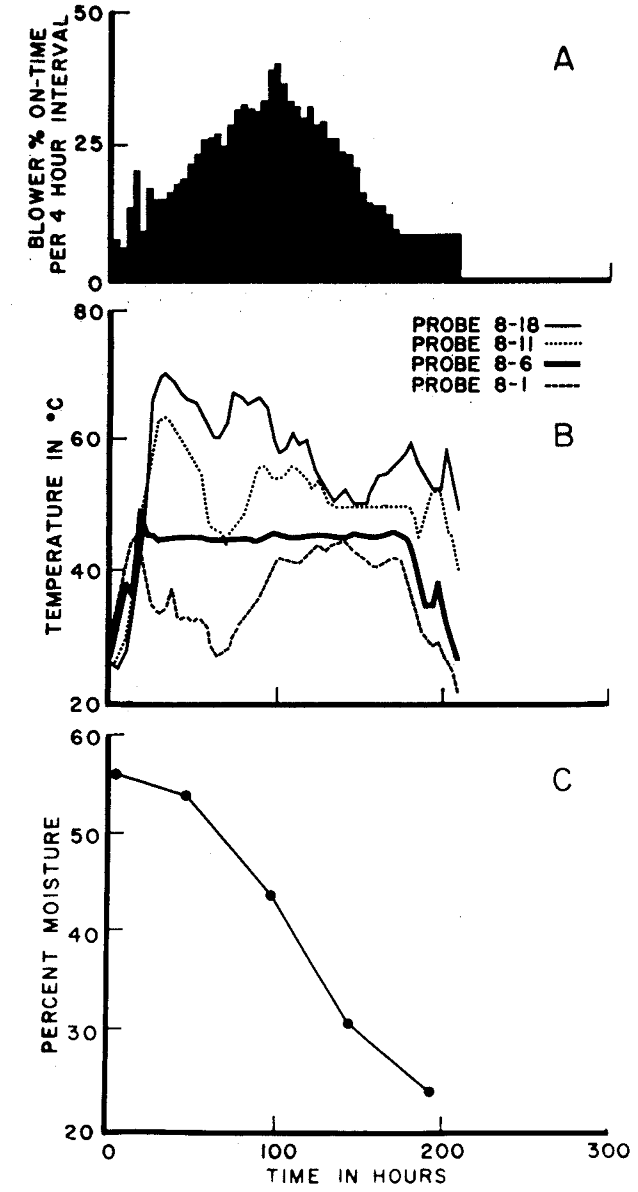

Figure 2—Data summary for the illustrative pile. a) blower on-time per 4 hour interval; b) temperature at the innermost vertical series of probes; c) moisture content in the central interior pile region.

DRYING AS A DECOMPOSITION INDICATOR

Unlike ventilation demand, which is pertinent only if temperature feedback control is used, drying is more generally applicable as an indicator of decomposition. The relevant sequence of events is: decomposition generates heat; the heat drives vaporization; the vaporization removes water and dries the material. Thus, the course of drying indicates the course of decomposition. Factors related to this possibility are discussed below.

Moisture content. The course of drying is monitored by determining moisture content. This is an objective test (as contrasted to subjective evaluation such as for odor, appearance, feel). The test is simple and can be done in 1 hour,[18,45] which makes the data available for real-time operation decision-making.

Potentially confounding factors. Drying underestimates decomposition to the extent that mechanisms of heat removal other than vaporization are operative, and to the extent that wat inputs make up for vaporization. Drying overestimates decomposition to the extent that vaporization is driven by unsaturatio of the inlet air.

Conduction. Loss of heat through conduction detracts fro vaporization, which causes drying to underestimate decomposition. With rapid composting accomplished through temperature feedback control, conductive loss was estimated to accoun for only 2% of the total heat removed.[34] Conductive loss migh be slightly greater from a pile ventilated only to maintain an oxygenated condition, caused by a steeper temperature gradien at conductive surfaces. The effect of reactor structure walls (i used) would be variable, depending on the surface area-to-volume ratio and whether the walls acted as insulator or conducto It is likely, however, that conduction would still play a smal role.

Specific heat. Heat to raise the temperature of the composting mass (heat storage) is not, *per se*, available for vaporization. Assuming ambient inlet air at 20°C and exit air at 50°C, it was calculated that 2% of the heat goes into storage.[3] The value is 4% with exit air at 80°C.

Sensible heat. A certain amount of heat goes into raising the temperature of dry air (sensible heat). Based on the same inlet conditions as above, this is 4% (80°C outlet air) to 14% (50°C outlet) of total heat removal.

Water input. Water is produced metabolically during composting. This makes up part of the water lost through vaporization and causes drying to underestimate decomposition by approximately 8%.[3] It is not possible to generalize about inputs of rainfall, but penetration into an active mass is generally slight. It is not necessary to shelter the composting mass against rainfall because water tends to be vaporized.[4]

Radiant heat. Analysis of radiant outflow and inflow (sunlight) indicates that this mechanism of heat exchange may be neglected for practical purposes.[34]

Unsaturation of inlet air. Any unsaturation of the ambient air induces vaporization unrelated to heat generation, which causes drying to overestimate decomposition. This problem was examined through hypothetical calculation and field experimentation.[3,14] It was concluded that approximately 96% of the vaporization is driven by metabolic heat generation, and 4% by unsaturation of the inlet air.

Sensitivity. Sensitivity is first examined in terms of the mass of water removed and then in terms of moisture content, as described elsewhere.[3] Specific heat, metabolic water, and dry air convention enter into this analysis. Additionally, it is assumed that the microbial oxidation of 1 g of organic matter to CO_2 and H_2O releases 25 122 J. Therefore, measurement of the mass of water removed indicates organic matter decomposition 7.8 to 8.6 times more sensitively at 50° and 80°C, respectively, than measurement of the mass of volatile solids decomposed. However, mass measurements are derived from materials balance studies, and as such as not ordinarily available in field practice.

For practical purposes the problem reduces to the ratio of Δ % moisture content to Δ % volatile solids content. This ratio is not constant over the course of composting; it widens with time because of different relative changes in the masses of water and volatile solids. The ratio exceeds unity at the start of composting under realistic conditions, but further generalization is not possible. In the case of an initial moisture content of 75% (wet weight basis) and a volatile solids content of 75% (dry weight basis), as the moisture content drops below 30% the cumulative ratio is 3.5. When moisture content decreases from 31% to 30%, the instantaneous ratio is 9.8. The moisture content test is therefore more sensitive, by a variable amount, than volatile solids as an indicator of decomposition.

DISCUSSION

The absence of a generally accepted, specific, and objective criterion of composting process performance impedes progress by confounding efforts to identify sources of operational difficulty. Similarly, efforts to improve efficiency and reliability at the design and operational levels lack focus. In terms of process selection, meaningful comparison among different designs is also stymied.

Comparison among systems. A rigorous comparison among different proprietary and non-proprietary systems would probably require a separate thermodynamic analysis of each under operating conditions. This might then be translated into projected construction and operating costs per unit of sludge decomposed. Such analyses would represent large-scale research projects and are not currently available.

Information on the principles of process design and operation that lead to odor control and cost effectiveness are currently available, and would be useful to decision-makers. Both odor control and cost effectiveness necessarily result from rapid decomposition. These principles and their implementation are explored partially in this paper, and fully elsewhere.[3-5,11-15,47] The factors to be considered include blower capacity, blower control (temperature feedback), uniformity of air distribution, height of the composting mass, minimization of the bulking agent, and appropriate use of mechanical agitation (not as means of process control). Any data on blower demand and drying tendency, if properly evaluated, would aid decision-making.

Any proposed reactor structure, enclosure, or mechanical appurtenance should be of demonstrated use; for example, enclosure and excessive height, separately or in combination, can degrade process performance.[4,5,11,13]

Monitoring an on-line plant. If process control is based on temperature feedback, as it must be if maximization of decomposition rate is a goal, ventilation demand would be a useful means of monitoring process progress. This is because exertion of demand is a fundamental manifestation of decomposition, refers to the entire system collectively without complication of sampling error, and can provide data instantaneously. Basing process control on temperature feedback is gaining rapid acceptance.[1,13,20,28,33,37,46]

Failure of demand to build normally would be an early warning of an operational problem.[44] The decline from peak level subsequent to the normal demand increase could be taken as a signal that the time for the next unit operation is approaching. What that operation might be depends on the site-specific characteristics of the sludge and the particular treatment goals of the facility. Thus, declining demand might signal the approaching termination of the biological phase of sludge treatment or the time to rewet the material to sustain microbial action and initiate a curing stage. Alternative operational possibilities are discussed elsewhere.[5,11,13]

The decrease in moisture content also relates to decomposition collectively in that the water removal mechanism (vaporization) is driven by heat generated at the expense of the waste. The change in moisture content can indicate decomposition rate regardless of the approach to process control. Note that it is the course of drying during the composting, not the final moisture content that indicates process performance.

Use of moisture content as an indicator of performance is conservative in that it underestimates the course of decomposition. The factors causing underestimation and their approximate mean values are: conduction, 2%; specific heat of the material, 3%; sensible heat, 9%; metabolic water production, 8%. A factor that causes overestimation is unsaturation of the ambient inlet air; the value of this factor is 5%. The net bias is thus approximately 17% in the conservative direction (underestimates decomposition).

In assessing the progress of stabilization, volatile solids or some other measure of organic content might be of more direct interest. Nonetheless, it is advantageous to use drying tendency as a surrogate measure for reasons of convenience and sensitivity. Time-course correlative studies relating moisture content, volatile solids, and other parameters would be useful. Yet, the current state of knowledge supports use of moisture content decrease to indicate process progress.

In routine use, neither blower demand nor drying tendency would measure decomposition accurately and consistently in an absolute sense. Basically, this is because the correction factors needed to convert the data to the amount of decomposed organic matter are not constant throughout the composting cycle. This does not negate the value of blower demand and drying tendency in field practice, because highly accurate measurement is not needed. These parameters are convenient in routine operation and seem to be superior to any present alternative for monitoring process performance.

SUMMARY AND CONCLUSIONS

- The use of composting as a sludge treatment process has developed rapidly, but without the benefit of a specific, objective criterion of process performance. This has led to unnecessary expense and widespread problems, particularly with odor generation.
- To date, traditional and other tests involving organic content measurements have proven inadequate, mainly because of poor specificity and sensitivity, while some methods involving manifestations of decomposition are not applicable to field-scale systems.
- Two approaches unique to composting seem very promising: ventilation demand and course of drying.
- The demand for ventilation stems from heat generation, which is directly related to decomposition. Although limited to systems using temperature feedback control (which is necessary for high-rate composting), it is the preferred method for routine monitoring because of its ease and instantaneous results.
- The course of drying depends on water vaporization, which results mainly from generation. It is useful in any system as long as conduction is not a major heat removal mechanism (usual case).

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