COMPOSTING STRATEGIES FOR HIGH MOISTURE MANURES

Tom L. Richard, Ph.D.
Department of Agricultural and Biosystems Engineering
Iowa State University

One of the significant challenges to composting high moisture materials like manure is supplying adequate bulking material to provide porosity for oxygen transport through the pile. This added material, such as cornstalks, sawdust, or straw, often cost significant money or time to acquire, and can increase the volume requiring processing by several times, thus increasing materials handling and application costs. Recently several strategies have been developed which take advantage of the biological drying that naturally occurs during thermophilic composting to reduce bulking amendment requirements dramatically. This paper reviews the theory behind these "biodrying" strategies, describes several successful examples, and discusses some of key parameters to consider before attempting to compost high moisture manure.

Composting as traditionally practiced achieves a moderate level of drying, with manure usually blended with bulking materials to an initial moisture content of 65% (wet basis), and the subsequent heating, evaporation, and air movement reducing the moisture content to 45% or less over a period of weeks or months. This process is quite simple in its essence: manure (and amendments) contain energy, aerobic decomposing microorganisms are only about 60% efficient at converting that energy to cell synthesis or metabolic work, and the remaining 40% is transformed to "waste" heat. Air moving through the compost pile (either by forced ventilation or passive convection and diffusion) gets hot and evaporates water from the surfaces of particles.

There are two aspects to reconfiguring the traditional composting process for high-moisture manures. First, the linkage between microbial heat generation and evaporation must be explicitly recognized and optimized. A detailed discussion of this optimization problem has been presented elsewhere (Richard and Choi, 1996), but will be briefly reviewed here. Second, and perhaps more revolutionary, is a change in the materials handling system. Almost all composting is operated as a batch process, where materials are mixed together initially and then proceed through the process as a "batch". The suggested alternative, which can be considered as a sequencing batch or semi-continuous process, starts out as a batch but then get repeated sequential additions of more high-moisture manure.

Theoretical Analysis and Optimization

Biodrying of a composting material results from the interaction of physical and biological processes. The physical processes include airflow rate, vapor transfer rates from the substrate to the airstream, inlet and outlet conditions of temperature and relative humidity, and the reactor configuration as it affects the balance between conductive and convective energy losses. The biological process of principal importance is the degradation rate, which releases energy and is itself a function of temperature as well as moisture and oxygen concentration. For the purposes of this analysis we assume moisture and oxygen concentration are not limiting, since by definition we are starting with a high moisture mixture and utilizing high airflow rates to remove heat. Effective heat removal typically requires approximately an order of magnitude more airflow than is needed to satisfy aerobic reaction stoichiometry (Finstein et al., 1986).

The removal of water from a composting reactor can be accurately predicted through psychrometric analysis if the inlet and outlet temperatures and relative humidities as well as the airflow rate are known. The details of the psychrometric equations and their use have been presented elsewhere (Albright, 1990).

Although modeling the physical aspects of moisture removal is relatively straightforward, the biological aspects are considerably more complex. Several researchers have developed models, which describe the effects of temperature on degradation kinetics, with widely varying results (Richard and Choi, 1996). In this example, theoretical biodrying rates will be illustrated using the model of Andrews and Kambhu (1973), who used an equation similar to the classical Arrhenius form used in chemical and biochemical engineering. Using their parameters, the model has a temperature optimum at 57°C, decreasing to near zero at 68°C, which roughly corresponds to the results of several experimental studies.

Given the relationships between temperature, moisture removal and decomposition rate, the optimization problem requires us to look for the temperature at or above the peak in the temperature kinetic function where the change in moisture removal rate with temperature is zero.

This can be expressed:

$$\frac{d\left(d\theta/dt\right)}{dT}=0$$

where

$d\theta/dt$ = the rate of moisture (θ) removal with time (t)

For constant air inflow conditions, and assuming no change in substrate temperature within the pile, this reduces to a steady state problem. The problem can be solved by setting heat generation (determined by the kinetic and stoichiometric relationships) equal to heat removal (determined by the psychrometric relationships) to determine the optimum temperature for moisture removal.

Figure 1 plots the calculated rate of moisture removal at five different maximum decomposition rates (k_{max}), which span the range of most manure composting mixtures. At the highest decomposition rate, the model predicts moisture removal rates of over 1 kg H_2O per kg volatile solids (VS) per day. For comparison with units more typically presented in experimental results, if we assume VS = total solids (TS), a moisture removal rate of 1 kg H_2O per kg VS per day is equivalent to a reduction from 70% moisture to 57% moisture in 24 hours, while a moisture removal rate of 1.5 kg H_2O per kg VS per day is equivalent to a reduction from 70% moisture to 45% moisture in 24 hours.

Practical Examples

During the past few years, several investigators have developed innovative composting systems which include some or all, of the biodrying characteristics described above. Perhaps the first was that of Jewell et al. (1984), who used an auger system for drying dairy manure at Cornell University. While still operated as a batch process, they used mixing, temperature, and airflow management to accelerate drying. Jewell et al. (1984) found maximum degradation rates at 60°C and 40% moisture, and maximum moisture removal rates at 46°C with 14 liters air per gram water added. Jewell et al. (1984) were the first to call their process "biodrying ."

The strategy of a sequencing batch or semi-continuous materials handling process was implemented by Choi et al. (1995; Richard and Choi, 1996). The complete mix aerobic reactor was operated in a sequential batch mode, with poultry manure loadings every other day over a six-day composting period. Although a sawdust bulking amendment was added to the manure at reactor startup, no additional amendment was added during the six-day cycle. Instead, the biodrying process reduced moisture levels so that additional manure could be added while still maintaining adequate porosity for aerobic decomposition. Cumulative moisture removal was calculated at 45%, and cumulative volatile solids (VS) reduction was calculated at 56% during the six day cycle (Choi et al., 1995). These moisture removal rates can be converted to a mass basis if we assume the total solids (TS) content does not significantly change during a single day. With that assumption the observed one day decrease in moisture content from 70% to 62% is equivalent to a moisture removal rate of 0.78 kg H2O/kg TS - day, and the observed one day decrease from 62% to 54% is equivalent to a moisture removal rate of 0.46 kg H2O/kg TS - day.

These experimental results compare quite closely with those of our theoretical studies. The pilot scale reactor achieved moisture removal rates ranging from 0.46 to 0.78 kg H_2O /kg TS - day (Richard and Choi, 1996). Over the six day reactor cycle, calculated VS reductions were approximately 56 percent (Choi, et al., 1995), equivalent to an average degradation rate of about 0.09 kg VS/kg initial VS per day. These moisture removal results are only slightly below the model's predicted values at a comparable k_{max} of 0.1day $^{-1}$. The relatively high conductive losses from the pilot scale reactor probably account for the slightly lower moisture removal rate from our experimental results.

In the past year, two additional groups have implemented their own strategies for biodrying high moisture manures. Paul and Barton (1997) used mixing, forced aeration, and sequential manure additions to compost liquid hog manure (2% dry matter) with broiler litter and wood shavings. With less than 2500 kg of litter and shavings they were able to evaporate over 4300 kg of H_2O during a three month period under winter conditions. Patni and Kinsman (1997) used irrigation to sequentially add swine manure slurry (2% dry matter) to a 2770 kg straw/slurry passively aerated windrow, evaporating 5182 kg of H_2O during a two month late-fall composting cycle.

Summary and Conclusions

Biodrying of high moisture organic residuals is a natural corollary to the composting process. Systems designed for the sequential addition of wet organic materials can significantly reduce bulking amendment requirements while simultaneously achieving high decomposition rates. This mode of operation can alternatively be viewed as a sequential batch reactor, recycling the bulking amendment for multiple batches of compost, with a very high proportion of recycled compost in each mix. This high rate of recycle can reduce or eliminate the lag time associated with composting system startup, further increasing decomposition and moisture removal rates.

References

Andrews, J.F., and K Kambhu. 1973. *Thermophilic Aerobic Digestion of Organic Solid Wastes.* EPA-670/2-73-061, PB 222 396. NTIS, Springfield, VA. 76 pp.

Albright, L.D. 1990. *Environment Control for Animals and Plants.* ASAE Textbook No. 4. ASAE, St. Joseph, MI. 453 pp.

Choi, H.L., H.T. Kim, J.H. Lee, and T.L. Richard. 1995. Composting High Moisture Materials: Bio-drying Poultry Manure in a Sequentially Fed Reactor. Presented at the 3rd Korea-Japan Binational Seminar on Biological Science. Nagoya University, Japan. December 18-21, 1995.

Finstein, M.S., F.C. Miller and P.F. Strom. 1986. Waste treatment composting as a controlled system. pp. 363-398. In: *Biotechnology: a comprehensive treatis in 8 vol.* , H.-J. Rehm and G. Reed (eds.), *Vol. 8. Microbial degradations,* W. Schönborn (vol. ed.). VCH Verlagsgesellschaft (German Chemical Society), Weinheim, FRG.

Jewell, W.J., N.C. Dondero, P.J. Van Soest, R.J. Cummings, W.W. Vergara, and R. Linkenheil. 1984. *High Temperature Stabilization and Moisture Removal from Animal Wastes for By-Product Recovery.* Final report prepared for the Cooperative State Research Service, USDA, Washington, DC. Project number SEA/CR 616-15-168. 169 pages.

Patni, N.K. and R.G. Kinsman. 1997. Composting of dilute manure slurries to reduce bulk by water evaporation. ASAE Paper No. 974115. Presented at the ASAE 1997 International Meeting in Minneapolis, MN. ASAE, St. Joseph, MI.

Paul, J.W. and P.K. Barton. 1997. Enhancing moisture removal during composting of liquid hog manure with shavings or poultry litter. Technical Report #135. Pacific Agri-Food Research Centre - Agassiz, B.C., Canada.

Richard, T.L., and H.-L. Choi. 1996. Optimizing the composting process for moisture removal: theoretical analysis and experimental results. ASAE Paper No. 964014. Presented at the ASAE 1996 International Meeting in Phoenix, AZ. ASAE, St. Joseph, MI.

Figure 1. Effect of maximum degradation rate on moisture removal rate, using the model of Andrews and Kambhu (1973).