COMPOSTING HIGH MOISTURE MATERIALS: BIO-DRYING LIVESTOCK MANURE IN A SEQUENTIALLY FED REACTOR

J.H. Lee, H.L. Choi

Department of Animal Science and Technology
College of Agriculture and Life Sciences
Seoul National University
Suwon, Korea 441-744

INTRODUCTION

Composting has gained rapid acceptance as a method of recycling relatively dry organic materials such as leaves and brush and, when alternative disposal costs are high, even moist materials such as grass clippings and dewatered sewage sludges. However, as moisture contents rise above 60%, the need for a dry bulking amendment increases the costs of composting, both by direct purchases of amendment and though increased reactor capacity and materials handling requirements. High moisture materials also present increased risks of anaerobic odor formation through reduced oxygen transport (Miller, 1991). These costs and operational challenges often constrain the opportunities to compost high moisture materials such as agricultural manures.

During the last several decades economies of scale in livestock production have been increasing livestock densities and creating manure management challenges throughout the world. This issue is particularly pressing in Korea, where livestock farms typically manage little or no cropland, and the nutrients and biochemical oxygen demand in manure pose a serious threat to water quality. Composting has recently become popular as a means of recycling manure into products for sale off the farm, but bulking amendments (usually sawdust) are expensive and availability is limited. This paper describes a pilot scale system designed to minimize bulking agent requirements by using the energy liberated by decomposition. In this context the composting reactor is used as a biological dryer, allowing the repeated use of bulking amendment with several batches of manure.

LITERATURE REVIEW

Drying has been long recognized as part of the composting process(Finstein et al,1986; Haug,1993),but it is usually viewed as a secondary effect where the primary focus is waste stabilization. Among those who have developed systems to use the energy of aerobic oxidation specifically for high rate drying of wet organic wastes are Badder et al.(1975) and Jewell et al.(1984). Recycling pelletized product through their bioreactor and achieving autoheated temperatures of over 74℃, Badder et al. dried swine and dairy wastes to less than 5% moisture, with minimum detention times of 5 and 12 hours respectively. Jewell et al. examined a range of operational parameters for drying dairy manure, finding maximum degradation rates at 60℃ and 40% moisture, and maximum moisture removal rates at 46℃ and 14 liters air per gram water added. Jewell et al. called their process "Biodrying", which is the term we utilize this paper.

MATERIALS AND METHODS

An enclosed bioreactor with two horizontal, cylindrical chambers was designed, manufactured, and operated to evaluate its drying performance in two tests. The design concept of recycling an end-product as a bulking amendment for treatment of poultry manure was introduced into the pilot biodryer, of which main benefit is to require far less saw dust. Two cylindrical chambers, each of the diameter of 400mm and the length of 1,600mm each were horizontally placed one above the other, connected with a recycle auger. Each chamber included a ribbon-type screw rotating at 5 rpm, which provides materials transport, mixing, and size reduction. The biodryer was enclosed with a steel sheet housing and the gap in between was filled with saw dust for insulation. The biodryer was operated 12 hours on/12 hours off. Warm air was introduced to the lower chamber with rate of 7 kℓ/min for 30 minutes on/15minutes off alternatively during operation hours to remove moisture by evaporation and convection.

Treatments of poultry manure with (Test2) and without (Test1) sawdust as shown in Table1, were implemented to evaluate the drying effectiveness (reduction rate of moisture content of the biomaterials) of a biological dryer allowing the repeated use of a bulking amendment with several batches of manure. During each test additional manure was added on days 2 and 4. In addition to the moisture content, the variation of temperature and germination rate were observed with lapse of composting days to explore the impact of the treatment of manure on these factors, and to test the stability of the end-product when it is applied to land as a fertilizer.

RESULTS

1. Temperature variation of biomaterials

Typical temperature variation between inside(compost) and outside (ambient) was demonstrated in both tests, but the difference of temperatures for Test2 was much higher throughout the period of experiment, as shown in Table 2. Addition of saw dust as a bulking agent with raw poultry manure would help not only to reduce moisture content but also to increase the porosity of the mixture, which eventually leads to higher temperature by extensive activity of microbes through better aeration. Maintaining the thermophilic state of the mixture would be an imperative condition for reduction of moisture efficiently.

2. Moisture content variation of biomaterials

Table 3 clearly shows the benefit of bulking amendment addition by doubling or tripling the reduction rate of moisture content of the mixture (Test2) compared to Test1. This fact suggests the repeated use of bulking amendment with several batches of manure does not lower the moisture reduction rate as long as the mixture maintains thermophilic temperature over an extensive period of time, hopefully longer than two weeks.

3. Seedling germination test of end-product

Seedling germination test with winter rape (brassica napus L.) was performed to examine the stability of materials with (Test2)/without treatment (Test1). Table 4 illustrates the significance of an intensive composting process for a stable end-product which does not harm crops when it is returned to soil.

ANALYSIS AND DISCUSSION

In this section we analyze the data from Test2 to estimate volatile solids degradation, energy generation, and moisture removal. These three factors interact to determine the efficiency of the biodrying system, with maximizing moisture removal the ultimate goal. Moisture removal in a biodrying process is dependent on the energy generated through biodegradation. In this analysis we use the chemical oxygen demand to volatile solids (COD/VS) ratio to estimate oxygen consumption per gram of manure degraded. Oxygen consumption is normally quite proportional to energy generation, with the energy liberated during the utilization of 1 mol of oxygen approximately equal to 104.2 Kcal(13.6 KJ/g O_2)(Haug, 1993), or 14 KJ/g O_2(Finstein et al, 1986). The COD/VS ratio for poultry manure was calculated as 1.27(UADA,1992), multiplied by 14 KJ/g O_2 gives an estimate of 17.8 KJ/g O_2 VS degraded. These values are slightly lower than the calculated heat of combustion for sawdust of 20.1 kJ/g dry matter loss reported by Keener et al. (1992). Assuming that all degradation is of manure rather than sawdust gives a maximum error of less than 10% and a somewhat conservative estimate of heat evolution.

In large pilot scale composting systems it can be difficult to directly measure the mass of substrate degraded. For a complete mix reactor the ash and volatile solids percent of a sample and the original mass data can be used to calculate the volatile solids mass using the following equation:

$$VS_{mt}=\frac{VS_{mo}(Ash_{\%o}\times VS_{\%t})}{(Ash_{\%t}\times VS_{\%o})} \qquad (1)$$

Where, VS_{mt} : the mass of volatile solids at time t
VS_{mo} : the initial mass of volatile solids
$Ash_{\%o}$: the initial percent of ash
$VS_{\%t}$: the percent volatile solids at time t
$Ash_{\%t}$: the percent ash at time t, and
$VS_{\%o}$: the initial percent volatile solids

In these initial experiments ash and volatile solids(VS) data were not collected, but by assuming ash concentration remained proportional to the conserved minerals Ca and P between additions of manure, equation (1) can used to calculate the mass of volatile solids degraded and the resultant energy released during Test2. Table 5 indicates and the concentration effect for each mineral fraction measured, calculated as the ratio of the mineral (P, K, or Ca) concentration at time t. The concentration effect, estimated ash, VS, and resultant energy release calculations were made daily during each two-day period between manure additions, and then reinitialized by summing the ash and VS in the added manure to the calculation ash and VS remaining in the reactor. The results of these calculations as presented in Table 6.

The concentration effect indicated in Table 5 should increase between additions of manure, as volatile solids are converted to CO_2 and water and the ash and conserved mineral fractions of total solids increase. This was not consistently observed, with particularly anomalous results for potassium(K) between days 2.1 and 4, so the data presented in Tables 6 and 7 result from the mean concentration rate of phosphorous(P) and Calcium(Ca). There was also considerable variability in the concentration effect (due to sampling or analytical variability), and thus the calculated VS degradation observed for each of these conserved element. Nonetheless, over the complete trial for each set of mineral data we calculate significant volatile solids degradation. The Average VS removal rate calculated in this way was 55.9% with a standard deviation of 19.6%. Using the mean concentration rates of P and Ca (Table 5), the VS removal rate was 65.7%.

While this degradation rate is significant, especially considering the mean solids retention time in the reactor was only 4.6 days, it may be possible to increase it further with continuous aeration. Jewell et al.(1984) report approximately 40% VS removal in dairy manure at a solids retention time of only two days. Their biodryer was configured similarly but operated under continuous aeration with mixing only 4 minutes per hours. Experiments with mixing frequency and aeration rates are planned to further optimize the process with this reactor configuration.

We used a similar approach to calculate water removal from the system, using the VS reductions calculated above to reduce total mass in the system, and multiplying the percent moisture by that mass to estimate the changes in water mass with times. Assuming the input materials were at 20℃ we calculated the energy required for vaporization of the water lost from the system, and compared that with the energy produced by VS degradation (Table 7).

The estimated water removal as a fraction of total water added to the system was 42%, based on the mean concentration ratios of P and Ca, and based on each individual conserved mineral (ranged from 38.8% to 52.2%, with a mean of 45.2%). This rate of drying, while significant, can also be further improved by increasing the efficiency of the reactor. In addition to evaporation of water, energy from biological decomposition also must be used for heating the air (and water vapor) flowing through the system, as well as provide for conductive losses. In a model of full scale composting system with wet materials, the energy utilization for evaporation has been estimated at 75% of the total heat loss (Haug,1993). Our estimates of the fraction of biologically generated energy used for evaporation range from approximately 27% to 46%. This relatively low efficiency is probably due to the small size and inadequate insulation of the reactor, resulting in large conductive heat losses. Currently experiments are proceeding with a larger insulated reactor, and we expect the efficiency of the biodrying system to be considerably improved.

CONCLUSIONS

The major results obtained are summarized as follows :

1) Test2 (poultry : saw dust = 1:1 on volume basis) performed about 15% reduction of moisture content per batch , which suggests significant implication that the possibility of using recycled mixture material as a water amendment for another batch so that at least 50% of saw dust can be saved comparing to a completely batch system.

2) Temperature discrepancy between inside and outside reactor for the Test2 was observed about 25~30℃ at one day after new batch run while Test1 maintained only 10 ~15℃ difference. The treatment of poultry manure with saw dust played an important role for keeping aerobic condition of the mixture, which leads to higher temperature to more moisture removal.

SUMMARY

An enclosed system(biodryer) with two horizontal cylindrical chambers was designed, manufactured, and operated to evaluate its biodrying performance in two tests. The design concept of 'recycling an end-product as a bulking amendment' for treatment of poultry manure was introduced in the pilot biodryer, of which main benefit is to lessen the consumption of saw dust. Two cylindrical chambers, each of diameter of 400 mm and length of 1,600 mm were horizontally placed in one above the other, connected with a recycle auger. Each chamber includes a ribbon-type screw rotating at 5 rpm, which provides materials transport, mixing, and size reduction. The biodryer was enclosed with a steel sheet housing and the gap in-between was filled with saw dust for insulation. The biodryer was operated 12 hours on and 12 hours off. Warm air was introduced to the lower chamber with 7kℓ/min for 30 min on/15 min off alternatively during operation hours to remove moisture by evaporation and convection.

Treatments of poultry manure with(Test2) and without(Test1) sawdust were implemented to evaluate the drying effectiveness (reduction rate of water content of the materials) of a biological dryer allowing the repeated use of bulking amendment with several batches of manure. In addition to the moisture content, the variation of spatial temperature, C/N ratio, microbial density, and germination rate were observed with the lapse of composting days to explore the impact of the treatment of manure on these factors and test the stability of the end-product as a fertilizer.

The major results obtained are summarized as follows:

1) Test2 (poultry:saw dust=1:1 on volume basis) performed about 42% reduction of moisture content per batch, which suggests the possibility of using recycled mixture material as a moisture amendment for multiple batch, so that at least 50% of saw dust can be saved comparing to a non-recycled batch system.

2) Temperature difference between inside and outside the reactor for Test2 was observed about 25℃~30℃ one day after a new batch started while test1 maintained only 10℃~15℃. The treatment of poultry manure with saw dust played an important role for keeping aerobic condition of the mixture, which leads to higher temperature and to more moisture removal.

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Table 1. Experiments Design

Tests Items	Test 1	Test 2
initial moisture content of biomaterials	74.3 %	71.8 %
Sawdust (Bulking Amendment)	**No used**	**used**
Mixing ratio (Sawdust : Poultry manure)	-	1 :1 (volume basis)
initial mass of poultry manur (Kg)	70	65
running time	6 days	6 days

Table 2. the Changes of temperature with time

Test	day	0	1	2	2.1	3	4	4.1	5	6
Temp.	Test 1	27.6 (2.4)*	32.3 (10.9)	36.0 (12.5)	35.5 (1.9)	44.5 (19.7)	36.4 (12.6)	35.4 (4.1)	40.1 (11.8)	37.1 (12.4)
	Test 2	31.4 (3.8)	55.6 (31.7)	54.9 (29.9)	35.9 (5.7)	60.1 (29.6)	52.9 (27.6)	34.1 (5.3)	42.6 (17.5)	41.1 (15.5)

* ( ): temperature difference of (inside - outside)

Table 3. the Changes of moisture content with time

Test	day	0	1	2	2.1	3	4	4.1	5	6
M.C.(%)	Test 1	74.3	71.4	69.6	74.1	72.3	70.25	73.9	71.7	68.5
	Test 2	71.8	67.7	60.3	72.9	65.2	58.3	70.5	63.4	57.0

Table 4. Seedling Germination (%)

Test	day	0	1	2	2.1	3	4	4.1	5	6
Germination Test	Test 1	8	4	0	0	0	4	4	8	8
	Test 2	41.7	45.8	50.8	87.5	87.5	87.5	79.1	96.0	96.0

Table 5. Concentration effect calculated for conserved mineral fractions in Test 2

Time (days)	Potassium (%)	Potassium (conc/con*i*	Calcium (%)	Calcium (conc/con*i*	Mean of P & Ca (conc/con*i*	Phosphorus (%)	Phosphorus (conc/con*i*)
0	2.5	1.000	0.50	1.000	1.000	1.12	1.000
1	3.0	1.200	0.50	1.000	1.161	1.48	1.321
2	4.3	1.720	0.60	1.200	1.247	1.45	1.295
2.1	3.5	1.000	0.44	1.000	1.000	1.48	1.000
3	2.9	0.829	0.50	1.136	1.102	1.58	1.068
4	3.1	0.886	0.69	1.568	1.355	1.69	1.142
4.1	3.1	1.000	0.44	1.000	1.000	1.62	1.000
5	4.2	1.355	0.50	1.136	1.099	1.72	1.062
6	4.3	1.387	0.80	1.818	1.471	1.82	1.123
				totals :	22.02		

Table 6. Calculated VS degradation in Test 2

Time (days)	Mean of P & Ca	Ash (%/100)	VS (%/100)	VS (Kg db)	ΔVS (Kg db)	Δ Energy (KJ)
0	1.00	0.18	0.82	37.75	0.00	0.00
1	1.16	0.21	0.79	23.06	3.21	55.51
2	1.25	0.23	0.77	21.03	1.35	23.99
2.1	1.00	0.23	0.77	31.06	0.00	0.00
3	1.10	0.26	0.74	27.78	2.64	47.01
4	1.36	0.32	0.68	20.78	4.48	86.11
4.1	1.00	0.30	0.70	31.36	0.00	0.00
5	1.10	0.32	0.68	27.35	2.83	50.37
6	1.47	0.43	0.57	17.12	7.23	128.53
				total :	22.02	391.52

Table 7. Estimated water removal and energy balances for Test2.

Time (days)	H_2O (%)	H_2O (Kg)	ΔH_2O (Kg)
0	71.80	60.06	0.00
1	67.70	61.94	7.12
2	60.30	53.95	7.99
2.1	72.90	89.85	0.00
3	65.20	79.25	10.60
4	58.30	66.78	12.47
4.1	70.50	102.68	0.00
5	63.40	92.84	9.84
6	57.00	81.47	11.37
			total : 59.39