COMPOSTING PULP AND PAPER INDUSTRY SOLID WASTES : PROCESS DESIGN AND PRODUCT EVALUATION

By

K. C. Das and E.W. Tollner
Department of Biological and Agricultural Engineering
University of Georgia, Athens GA

T.G. Tornabene
School of Applied Biology
Georgia Institute of Technology, Atlanta GA

INTRODUCTION

Over 70% of the recyclable organic solid wastes produced by the U.S. pulp and paper industry are presently landfilled. A single mill in Georgia produces about 100,000 dry tons of solid wastes a year. At moisture contents of 50-90%, disposal of these materials costs the company about a million dollars each year. Interest in reducing cost and exploring more sustainable solutions through reuse, has lead to the identification of four compostable waste streams, namely, sludge, bark (wood yard debris), grit and ash. Research literature suggests that composting can be a suitable treatment that eliminates the usual problems of solid waste by (1)improving handling characteristics of sludges and ash, (2)reducing weight, moisture content and volume, and (3)removing nuisance due to odors. The resulting product has increased storability and improved physical characteristics and a balanced nutrient base suitable for high rate application in agriculture, forestry, landscaping and related industries.

Sludges from pulp and paper mills are mainly cellulose fiber generated at the end of the pulping process prior to entering the paper machines. They are composed essentially of fibrous fines and some inorganics such as kaolin clay, calcium carbonate, titanium dioxide and other chemicals used in the specific manufacturing process. The fibrous fines are 59-72 % (dry basis) cellulose, 6-16 % lignin and 7-10 % hemicellulose (Sosulski and Swerhone, 1993). Ash contents in the sludges range from 10 to 70 %. The high cellulose, lignin and ash contents make the material rather slowly degradable by microorganism. Hence, providing an environment that enhances growth of cellulolytic organisms such as *Trichoderma* spp. (Lynch and Wood, 1985) will be key to accelerating stabilization.

Carter (1983) reported the successful full scale composting of primary and secondary sludges bulked with bark. Comparing the product with other commercial composts and peat, Fitzpartick (1989) reported that Dwarf oleander growth was significantly better in this compost than in peat and at least one other commercial compost blend. Cellulose degradation from an initial 40% (dry basis) to a final 19% was observed during composting primary sludge, bark and nitrogen fertilizers as amendment (Valente et al., 1987). The process of accelerated windrow with forced aeration took a minimum of 60 days and in some cases 90 days. Higher degradation rates were found when the material was inoculated with bovine manure which could have introduced a population of cellulose degrading microorganisms, thus accelerating the process. A 3:1 v/v mixture of refiner mechanical pulp (RMP) and chemimechanical pulp (CMP) was composted by Campbell et al. (1991). The material composted just as well with urea amendment as without. The mixture heated to 60°C within 2 days and stayed above 45°C for over 14 days. Moisture reduced from 55% to 33% over a 6 week period. No significant loss in dry matter was noticed in that study. In another study, Campbell et al., (1995) reported composting a blend of bleached kraft/NSSC primary sludges, ash and paunch (cattle stomach contents as nitrogen source) from a slaughterhouse. They report significant reduction in dry matter, up to 50 % of the initial. The nutrient balance stabilized from an initial C:N of 270 to a final of 14-67. Increased fraction of ash in the blend produced a more agronomically valuable compost.

In this project, our objective was to quantify the operational steps in the composting of typical pulp and paper mill solid wastes, namely, sludge, bark (wood yard debris) and ash. Rapid composting of these high carbon solids requires a blend with optimal moisture, porosity and nutrients (C/N ratio). The evaluation of mixes and

nitrogen supplement both as mineral fertilizers and organic forms (chicken litter) were the overall objectives of this project. The specific objectives were :

1. Determine the best blend of primary sludge, grit, bark, ash and a nitrogen source that maximizes degradation and stabilization during composting,
2. Compare ammonium nitrate and poultry litter as the two nitrogen amendments,
3. Determine the minimum amount of amendment required for composting,
4. Characterize the stability and nutrient values of the final compost product,

MATERIALS AND METHODS

Primary sludge, bark (wood yard debris), grit and wood ash were collected from the Weyerhaeuser pulp mill located in Oglethorpe, Georgia, USA. Poultry litter was obtained from the Poultry research center of the University of Georgia in Athens, Georgia. Ammonium nitrate was purchased as bags of fertilizers from a local farm supply store.

Initial physical and chemical properties testing were measured on six samples from each feedstock obtained at different sampling times ranging over six months. Moisture content was evaluated by drying about 200g of sample in an oven at 105°C for 24 hours. After complete drying, the sample was finely ground and incinerated at 550°C for 6 hours to estimate the volatile solids and ash content. A portion of the ground sample, about 50g was used for chemical and nutrient analysis. Total carbon and total nitrogen contents were evaluated using a Leco CNS analyzer. Mineral contents were measured by first preparing the sample by incinerating in a muffle furnace for four hours at 500°C (to remove organics) and dissolving the residual ash in aqua regia. The extract was analyzed using an inductively coupled plasma atomic emission spectrometer. A known standard material (apple leaves) was simultaneously analyzed to ensure measurement accuracy. If measurement error based on the apple leaves were greater than 15% the readings were discarded.

Germination index (phytotoxicity) was evaluated using the cress seed germination test described in the Washington State Interim Guidelines (1994). A 0.45μ filtered water extract of the compost was produced and water cress seeds were added to 2mL of the extract placed in a petri dish and allowed to incubate at 30°C for four days. At the end of four days, the percentage of seeds germinated and root length of the germinated seeds were measured and expressed as percentages of a control (distilled water) germination plate. The germination index was calculated as the product of the percentage germination and the root length. The pH of the material was measured after dissolving 25 mL of the compost sample in 50 mL of distilled water and placing in a shaker for 15 minutes. The extract was filtered through a coarse filter and pH was measured on the filtrate.

Pilot composting was done in stainless steel vessels with a diameter of 38.1cm, depth of 49.5cm and a volume of 56.8L. The vessels were insulated with 7.6cm of foam insulation to minimizes conductive heat loss thereby simulating an environment within a large compost pile. Temperature of the material in the vessel was monitored using T-type thermocouples at two locations, 25.0 and 37.0cms from the surface. Vessels were aerated using a temperature feedback control with an adjustable set point that was set at a predefined temperature, e.g. 55°C. When the compost temperature exceeded the set point, air was continuously introduced to the vessel at a rate of 40.8 m^3/day. When the temperature of the compost was below the set point, air was introduced intermittently based on a timer providing aeration for 30 seconds in every 20 minutes. The resulting effective aeration of 1.02 m^3/day was designed to provide sufficient oxygen (>6% residual oxygen) to maintain aerobic microbial growth. Solenoid valves activated the airflows into the vessels and every event of valve opening and closing was recorded to a datalogger. Hence, the total airflow into each vessel was accurately calculated. An automatic sequencer extracted headspace gas from each vessel successively at a rate of 1 L/min for a period of 210 seconds every hour. After clearing sampling lines for 180 seconds, the gas stream was passed through gas analyzers to measure residual oxygen and carbon dioxide concentrations. Gas analyzers were calibrated using standard gas once a day. Compost temperature, gas analyzer data, airflows and measured ambient air temperature and humidity were written to a data logger once every hour.

At the start of each composting trial, weighed quantities of materials at known moisture content were placed in the test vessels. At each "turn" (approximately one a week), test vessels were weighed and contents emptied. The contents of each vessel were homogenized in a large plastic drum and water was added to the material to adjust the

moisture content when required. Several sub-samples were taken and combined to form one representative composite of approximately 250g for moisture, volatiles and nutrient analysis. A similar sample was used for pH and germination index (phytotoxicity) measurement. Two sets of experiments were performed, namely, preliminary trials and replicated trials. In the preliminary trials, different blends of the four feed stocks were evaluated with the two nitrogen amendments at different rates. One mix was selected at the end of the preliminary trials and this was evaluated with different rates of nitrogen amendments in replicated trials.

RESULTS AND DISCUSSION

The variability in properties among feed stocks and over time was significant. Average moisture content (Table 1) of the four paper mill feedstocks ranged from 50-70% with standard deviations as high as 8.0%. The volatile solids percentage indicating biodegradable matter were low in ash and high in grit and bark. The wastes being largely from woody sources are high in cellulosic carbon and low in nitrogen as indicated by the high C/N ratio (Table 1).

The objective of creating a blend was to include as much primary sludge as possible without losing optimal bulk density and moisture contents. Bark was included largely to provide bulking and grit was included to provide the volatiles that accelerate degradation. The initial base mix (WM_0) of Sludge 45%, grit 28% and bark 27% (by dry weight) resulted in a C/N ratio of 245.4 and a moisture content of 59.1%. The high C/N and low C/N treatments were developed by adding more (1.35 kg/kg of WM_0) and less (0.40 kg/kg of WM_0) of chicken litter (see Table 2). From a total dry matter loss the two treatments show no difference (Table 2). The volatile solids loss over the period of composting were different, however, the amount of mill solid waste base mix (WM_o) was 71% of the mix (i.e. only 29% chicken litter) in the first treatment and only 42% (i.e. 58% chicken litter) in the second which could account for the higher (5.7 %) volatile solids loss in the second mix.

Other base mixes (WM_1 and WM_2) were developed by adding ash to the other three streams as shown in Table 2. WM_1 and WM_2 behavior were very similar in the poultry litter amended treatments. The total dry matter loss (8.6 and 9.1%) and the total volatile solids loss (7.0 and 6.9%) were similar for each of the treatments. Several ammonium nitrate dosages were evaluated ranging from 20.1 to 86.4 g/kg (dry basis) corresponding to a nutrient balance of 12.5 to 47.9 C/N ratio. Surprisingly, both dry matter loss and volatile solids loss reduced with increasing nitrogen levels. This suggests that a lower dosage would be appropriate and the high corresponding C/N ratio is caused by the portion of the total carbon being unavailable to microbial metabolism.

The important results from the replicated trials are tabulated in table 3. Increasing the amount of poultry litter added to the wood mix (WM_3) from 0.18 kg/kg to 0.44 kg/kg resulted in an increase in dry matter loss from 14.8 to 20.1 % of initial mix. An increase in the stability of the final product compost was also seen with increasing poultry litter content. A value of stability index of 0.5 mg/g/hr or less indicates stability. Except the first and sixth treatment, all others treatments produced composts that had stable values. Increasing rates of ammonium nitrate addition did not show any clear increase in degradation. Similar to the preliminary trials, although the total dry matter loss ranged between 12.2 to 16.7%, there was not consistent increase or decrease in degradation with increasing nitrogen levels. Figure 1 shows the temperature profile of two levels (8.7 and 15.9 g/kg) of ammonium nitrate dosage along with the temperature profile in a chicken litter amended treatment. The increase in ammonium nitrate shows a delay in temperature increase, possibly due to a mild ammonia toxicity. The chicken litter amended materials were very active within 24 hours and completed most of the biological activity within the first ten days.

The compost was cured for over 60 days after removal from the bioreactors and then tested for physical and chemical properties. The final properties are shown in Table 2. It is clearly evident that the compost with poultry litter as the amendment has a higher level and diversity of micronutrients. This makes the compost more attractive to horticulturists than the ammonium nitrate amended material. This material also had a lower final C/N ratio of 37.4 (initial C/N of 80.9) compared to the ammonium nitrate amended which had a C/N of 97.9 (compared to initial of 136). The low C/N ratio is an important property of final compost as this indicates how much of a nitrogen tie up would result if the compost was applied to the soil. The level of phosphorus (an essential macronutrient) in the ammonium nitrate amended compost was very low (0.04%) compared to 0.29% in the chicken litter amended mix. The ratio between N, P and K is critical in judging the compost to be of balanced nutrient value. In this regard the chicken litter amended compost was far superior to the other.

CONCLUSIONS

The compostability of a mix of primary sludge, bark, grit and ash was evaluated. It was found that the mix could be composted to a stable and agronomically useful product. The following are some key findings :

1. The best mix from a degradation stand point was 57% (dry weight basis) sludge, 25% grit, 6% bark and 12% ash. The mix (WM_0)had an initial moisture content of 54% and a C/N ratio of 412.7,
2. Addition of nitrogen amendments decreased C/N ratio and increased total degradation. It was sufficient to use no greater than 0.18 kg(chicken litter)/kg(WM_0) on a dry basis resulting in an initial C/N of 80.9,
3. Adding ammonium nitrate at 5.42g/kg(WM_0) resulting in a C/N ratio of 136 was sufficient to provide about 15% dry matter degradation and a final compost with a stability of 0.078 mg(oxygen)/g(VS)/hr.
4. From a product quality standpoint, chicken litter amended compost was superior. It provided higher and a wider variety of nutrients.
5. From a degradation standpoint the ammonium nitrate amended mixes result in greater amount of pulp mill solids being processed within a given time period.
6. At the end of 30 days of composting the stability ranged between 0.14 to 0.88 mg(oxygen)/g(VS)/hr. After sufficient curing the composts are extremely stable at 0.078-0.096 mg(oxygen)/g(VS)/hr.

The authors wish to acknowledge the contributions of Ms. Sheila Powell and Mr. Mark Jones in the conduct of these experiments. Funding for this project was provided by Weyerhaeuser Inc., and other grants through the University of Georgia Experiment Stations, Athens GA.

TABLE 1. Initial properties of the feedstock materials used in composting trials[1].

	Sludge[2]	Bark[2]	Grit[2]	Ash[2]	Poultry Litter[3]
Moisture content, % wb	50.4 (4.6)	70.0 (0.9)	56.2 (5.8)	52.6 (8.0)	19.2 (4.3)
Volatile solids, % db	57.0 (3.5)	90.8 (2.8)	90.8 (8.3)	34.2 (12.8)	87.6 (3.4)
Carbon content, % db	35.0 (5.4)	45.3 (1.6)	48.9 (3.3)	20.8 (4.0)	43.4 (0.9)
Nitrogen content, % db	0.05 (0.03)	0.39 (0.07)	0.15 (0.06)	0.01 (0.01)	2.6 (0.8)
C/N Ratio	700	116	326	2080	16.7
pH	8.0 (0.6)	5.9 (0.1)	5.5 (0.8)	10.0 (1.4)	8.1 (1.1)
Germination index, %	63.2	59.5	27.2	71.1	0

[1]Numbers are average of 6 measurements over 3 sampling times. Numbers in parenthesis are standard deviations.
[2]Sludge, bark, grit and ash were obtained from Weyerhaeuser's Flint River Facility, Oglethorpe, Ga.
[3]Poultry litter was obtained from the University of Georgia poultry research center, Athens, Ga.

TABLE 2. Preliminary composting trials mix ratios, degradation and product stability.

Materials in compost mix	Composition (weight, db)	Initial C:N -	Total Dry matter loss, % (of initial)	Total Volatile solids loss, % (of initial)
WM_0 = 45% Sludge, 28 % Grit, 27 % Bark (dry weight basis)				
WM_0+ Poultry Litter	1:0.40	48.2	13.7	1.2
WM_0+ Poultry Litter	1:1.35	26.7	14.8	5.7
WM_1 = 38% Sludge, 24 % Grit, 10 % Bark, 28 % Ash (dry weight basis)				
WM_1+ Poultry Litter	1:0.16	84.0	8.6	7.0
WM_2 = 45% Sludge, 29 % Grit, 11 % Bark, 15 % Ash (dry weight basis)				
WM_2+ Poultry Litter	1:0.19	76.6	9.1	6.9
WM_2 + Amm. Nitrate	20.1 g/kg (db)	47..9	16.9	13.4
WM_2 + Amm. Nitrate	42.1 g/kg (db)	24.7	15.9	8.0
WM_2+ Amm. Nitrate	47.1 g/kg (db)	22.2	15.7	7.9
WM_2+ Amm. Nitrate	86.4 g/kg (db)	12.5	14.4	3.3

1. Target moisture content in all preliminary trials was 60% (wb). Actual measured moisture contents during the 30 days of composting averaged 61.8% (Std Dev. 4.8%) with a range of 67.7 to 54.2 %
2. Ammonium nitrate (fertilizer grade, 34 %N) were applied at rates measured in g(of ammonium salt)/kg(dry matter of compost material).

TABLE 3. Summary of replicated composting trials.

Materials in compost mix	Mix Ratio (weight, db)	Initial C:N	Total Dry matter loss % (of initial)	Total Volatile solids loss, % (of initial)	Final Stability Index, mg(O2)/g(VS)/hr
WM_3 = 57% Sludge, 25 % Grit, 6 % Bark, 12 % Ash (dry weight basis)					
WM_3+Poultry Litter	1:0.18	80.9	14.8	9.0	0.880
WM_3+Poultry Litter	1:0.26	63.5	16.4	10.7	0.491
WM_3+Poultry Litter	1:0.44	45.8	20.1	-	0.140
WM_3+Amm. Nitrate	5.42 g/kg	136.0	15.2	-	0.202
WM_3+Amm. Nitrate	8.70 g/kg	96.8	12.6	15.3	0.494
WM_3+Amm. Nitrate	10.9 g/kg	81.1	16.3	12.5	0.792
WM_3+Amm. Nitrate	15.9 g/kg	59.2	12.2	5.9	0.347
WM_3+Amm. Nitrate	67.2 g/kg	15.7	16.7	-	0.179

1. Target moisture content in all preliminary trials was 60% (wb). Actual measured moisture contents averaged 61.8% (Std Dev. 4.8%) with a range of 67.7 to 54.2 %
2. Ammonium sulfate (laboratory grade, 21 %N) and ammonium nitrate (fertilizer grade, 34 %N) were applied at rates measured in g(of ammonium salt)/kg(dry matter of compost material).

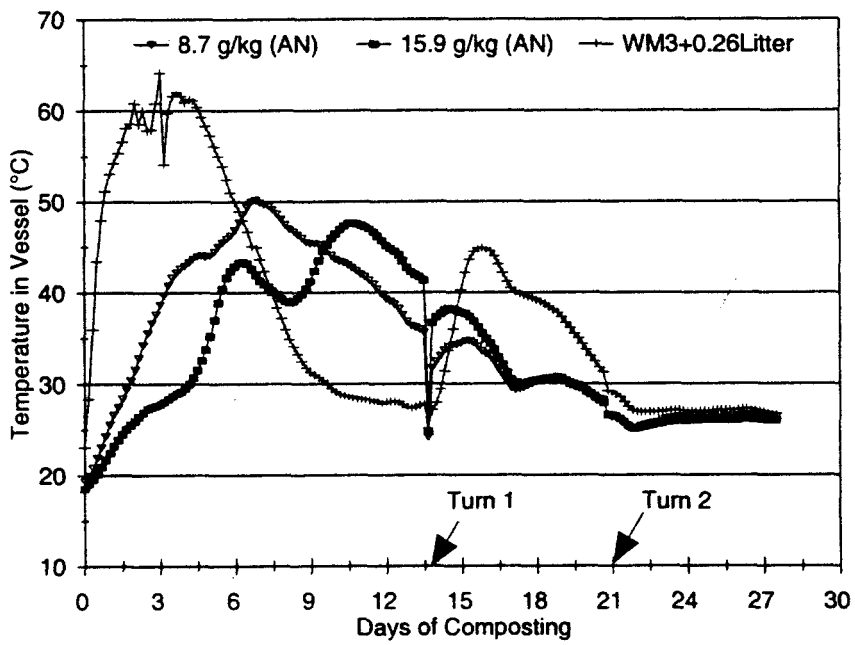

Figure 1. Temperature profile during a composting trial with low and high rates of ammonium nitrate (AN) amendment compared with chicken litter amendment. WM3 is a mix of the four feedstock as shown in Table 3. Temperature profiles are average of temperatures in three bioreactors under identical conditions.

TABLE 4. Final composted and cured sample chemical characteristics and stability.

	Ammonium Nitrate Amended mix Rate = 5.42 g/kg (Table 3)	Poultry Litter Amended mix Rate = 1:0.18 (Table 3)
C, %	13.7	14.2
TKN, %	0.14	0.38
C/N Ratio	97.9	37.4
P, %	0.04	0.29
K, %	0.09	0.27
Ca, %	2.74	2.41
Mg, %	0.08	0.15
S, %	0.06	0.12
Mn, %	0.03	0.04
Fe, %	0.15	0.12
Al, %	0.22	0.20
B, ppm	<0.6	5.65
Cu, ppm	6.32	159.20
Zn, ppm	46.3	122.4
Na, ppm	556	1059
Pb, ppm	4.28	4.66
Çd, ppm	0.53	0.45
Cr, ppm	4.02	3.59
Ni, ppm	3.34	3.14
Mo, ppm	<0.5	0.61
As, ppm	0.24	0.62
Se, ppm	<0.3	<0.3
Stability Index, mg-O_2/g-Volatiles/hr	0.078	0.096

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