Composting paper mill deinking sludge with forced aeration

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Brouillette, M., Trépanier, L., Gallichand, J. and Beauchamp, C. 1996. **Composting paper mill deinking sludge with forced aeration**. Can. Agric. Eng. **38**:115-122. Static pile forced aeration was used as an alternative to mechanical pile turning to compost paper mill deinking sludge. The experimental set-up consisted of two pile heights (2 and 3 m) and three aeration pipe spacings (no aeration, 1-m and 2-m aeration pipe spacing) resulting in different aeration levels. Aeration was provided for 10 consecutive months. Results showed that 3-m piles required longer aeration times to maintain temperatures in the required range. All aerated treatments maintained temperatures between 50 to 65°C compared to 30 to 40°C for non-aerated treatments. Temperatures in aerated treatments were maintained between 50 to 65°C even when the temperature of the air injected into the material was as low as -20°C. Water content remained within the optimum range (60 to 71%) for efficient composting for all treatments. Fibre levels gradually decreased during the experiment with cellulose being the most degraded. The compost fibre contents was only affected by depth within the piles. The degree of composting, as evaluated by the light absorbency test, was higher for aerated treatments, especially for the 1-m pipe spacing treatment. Depth within the piles also affected light absorbency measurements. More nitrogen was converted into the organic form in the aerated treatments, especially for the 1-m pipe spacing treatment. Composting deinking sludge with forced aeration is feasible in Eastern Canada even under winter conditions. Keywords: aerobic composting, automatic control, temperature, deinking residues, sludge.

Un système d'aération forcée a été utilisé pour le compostage des résidus provenant du désencrage du papier. Le dispositif expérimental était constitué de 6 traitements différents formés de 2 épaisseurs de résidus (2 et 3 m) et de 3 espacements des tuyaux d'aération (sans aération, tuyaux d'aération espacés de 1 et de 2 m) correspondant à 3 niveaux d'aération. Les résultats ont démontrés qu'après 10 mois de compostage les traitements de 3 m d'épaisseur nécessitaient une plus grande aération afin de maintenir la température au niveau désiré. La température du compost s'est maintenu entre 50 et 65°C dans les traitement aérés, même en conditions hivernales où l'air injecté avait une température d'environ -20°C. Dans les traitements non aérés la température du compost variait de 30 à 40°C. La teneur en eau des résidus est demeurée dans la zone optimale pour le compostage (60 à 71%) dans tous les traitements. Les fibres en général, et la cellulose en particulier, se sont graduellement dégradées tout au long de l'expérience. Le contenu en fibre des échantillons prélevés à la fin de l'expérience a varié en fonction de la profondeur. Les analyses colorimétriques ont démontrées que le degré de compostage atteint était plus élevé dans les traitements aérés. Les résultats des analyses colorimétriques ont aussi été influencés par la position verticale des échantillons. L'azote a davantage été converti sous forme organique dans les traitement aérés, particulièrement pour les traitements où l'espacement des tuyaux d'aération était de 1 m. Finalement, les résultats obtenus démontrent que le compostage des résidus de désencrage par aération forcée est réalisable en conditions hivernales de l' Est du Canada.

INTRODUCTION

Growing environmental concerns and the need for efficient resource management have led to an increased use of recycled paper. In Canada, the proportion of recycled fibres used by the pulp and paper industry increased from 4.6% in 1965 to 11.4% in 1990. Since 1990, the demand for recycled fibres in newsprint production has steadily increased. Inks must be removed from used paper before it can be efficiently recycled. The deinking process produces a waste by-product, called deinking sludge, that contains mainly paper fibres, clay particles, and inks. Johnson (1992) has estimated that by the end of the decade, the world production of deinking sludge will be more than 8 million tons per year.

Different strategies are used to dispose of deinking sludge. Landfilling is the most popular option, although costs are increasing. Burning is used to generate energy for many factories, but may lead to air pollution. Direct application of fresh sludge on agricultural land is another option; however, extensive land areas would be needed to receive the large amounts of sludge produced (Carroll and Gajda 1990). Composting is one of the most promising avenues to recycle deinking sludge. Composting reduces the volume and stabilizes the sludge so it may be economically used for agriculture, landscaping, and horticulture.

The biological process of composting, by which an organic substrate is decomposed, can be divided into two stages. The first stage is characterized by a high exothermic microbial activity and results in temperatures around 50°C. In the second stage, the microbial activity is reduced, resulting in lower temperatures and enabling the degradation of refractory organic material by mesophilic microorganisms. Certain conditions must be met for efficient composting to occur. Water content must ideally be maintained between 40 and 65% on a wet basis, but may be as high as 85% if sufficient porosity is maintained (Haug 1993). In the high activity phase, temperatures should stay in the range of 48 to 65°C (Golueke 1984). Moreover, the C/N (carbon/nitrogen) ratio of the sludge should be between 30 and 50 at the beginning of the process (Thambirajah and Kuthubutheen 1989; Thorstrup 1985).

Since microorganisms need oxygen for organic matter oxidation, composting requires sufficient air supply (Lau et al. 1992). A number of systems can be used to ensure proper aeration. They range from simple mechanical turnings to complex aeration systems. Optimal aeration conditions are difficult to achieve with mechanical turnings at large composting plants because in the first stage of composting, optimal management could necessitate more than one mechanical turning per day (Mustin 1987). Static pile forced aeration system is an interesting alternative due to its relatively low cost and simple operation and maintenance.

The objectives of this research were to verify the technical feasibility of a static pile aeration system to compost deinking sludge and to evaluate its effect on the quality of the resulting compost.

MATERIALS AND METHODS

Experimental set up

The static pile forced aeration procedure uses a ventilation unit to force air into a perforated pipe system located under the composting material This induces air convection movement into the material and delivers oxygen to the microorganisms. These systems provide computer controlled ventilation and have been used to compost other types of residues (Kutter et al. 1985; Riffaldi et al. 1986; Van-Oostrom et al. 1991).

The experimental site was located at a composting plant near Québec City, Québec. Experiments were carried out from November 1992 to September 1993. Residues used for the experiment were a mix of 95% fresh deinking sludge and 5% composted sludge for inoculation. The deinking sludge came from the Daishowa newspaper recycling plant located in Québec City. Deinking sludge was characterized prior to the experiment to identify compounds that might cause contamination problems in agriculture. More than 150 organic and inorganic components were analysed, including heavy metals, PCB, and hydrocarbons. Results did not show any contamination problem. The fresh deinking sludge had a C/N ratio of 330. The C/N ratio was lowered to about 30 by mixing 8.3 kg of mineral fertilizer (26-13-13) per cubic meter of sludge.

The experiment was carried out using two pile heights (2 and 3 m). For each height, aeration treatments of 1-m pipe spacing (T3, T4), 2-m pipe spacing (T1, T2) and no aeration (T5, T6) were used (Fig. 1). One 2.2 kW blower was used for each pile height and operated under positive pressure. Aeration was provided through 100 mm diameter perforated plastic pipes located at the bottom of the piles. For each aerated treatment, temperatures were monitored at three locations with thermocouples installed at elevations of 0.5, 1.0, and 1.5 m above the bottom of the pile for the 2-m pile, and at 0.5, 1.5, and 2.5 m for the 3-m pile. Temperatures were measured at only one location in the non-aerated treatments at elevations of 0.5 and 1.5 m for the 2-m pile and at 0.5, 1.5, and 2.5 m for the 3-m pile (Fig. 2). Temperatures were recorded by a Campbell CR10 datalogger using two multiplexing devices.

Aeration strategy

Aeration was controlled by the temperature in the piles of sludge. Because the amount of air required for heat removal exceeded that needed for oxygen supply (Psarianos et al. 1983), the ventilation strategy consisted in preventing excessively high temperatures that could lead to the inhibition of the composting process (Lau et al. 1992). It was impossible to control independently the temperatures of the four aerated treatments. Temperatures were controlled by the datalogger in the 1-m pipe spacing treatments of each pile height, knowing that the temperature control in the 2-m pipe spacing treatments would not be optimal. Aeration was provided under three automatic modes. The system operated under mode 1 from November 1992 to February 1993, when outside temperatures were most of the time below freezing. Ventilation was stopped during the night to avoid freezing of the composting material. This was particularly important at the beginning of the composting process because temperatures in the piles were low. During daytime, between 10:00 A.M. and 3:00 P.M., aeration was provided when the average temperature in the 1-m pipe spacing treatments exceeded 55°C. Aeration was stopped when the average temperature dropped below 53°C. Moreover, a 10 minute ventilation period was imposed at the beginning and end of the daytime period. Because temperatures of the composting material

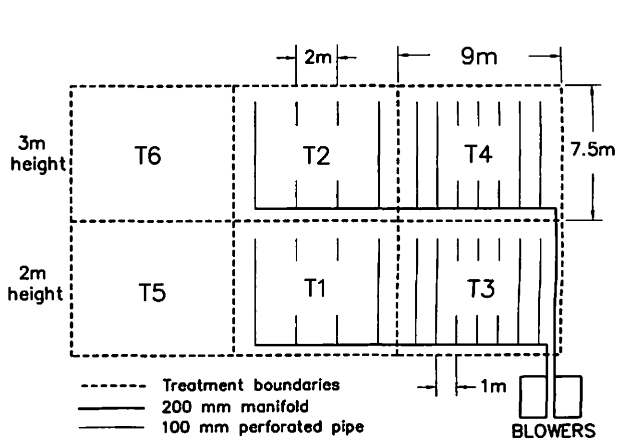

Fig. 1. Plan view of the experimental setup and abbreviations for the six aeration treatments.

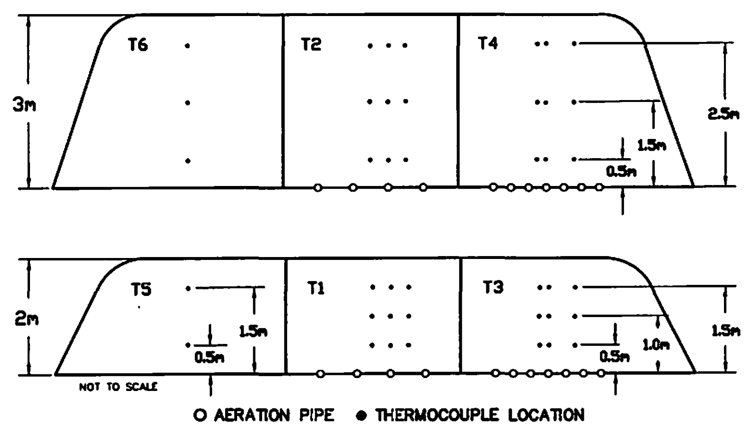

Fig. 2. Elevation view of the experimental setup.

remained around 55°C, even when outside temperature was -20°C, the system was set to mode 2 in February 1993. In this mode, ventilation control was completely automatic with start and stop set-points at 55 and 53°C, respectively. By the end of May, ventilation times had decreased for the 2-m piles and mode 3 was set to provide a minimum level of aeration to avoid anaerobic conditions. In this mode, four five minute aeration periods per day were added to mode 2. This mode remained in operation until the end of the experiment while the 3-m piles remained under mode 2.

Sampling and analyses

The maturity of a compost is important if it is to be used successfully in agriculture (Inbar et al. 1990). As no single method is currently available to estimate compost maturity, a combination of chemical, physical, and biological parameters is recommended (Riffaldi et al. 1986). Commonly used parameters are the C/N ratio, the fibre content (Inbar et al. 1990; Jimenez and Garcia 1991), and the color measured by light absorbency (Morel 1982).

Periodic measurements To eliminate side effects, temperature readings and samples were taken at least 2 m away from the edge of each treatment. Temperature readings were collected every five minutes at locations shown in Fig. 2. Average hourly readings for each depth were recorded along with starting time and duration of each ventilation period. Once a month, compost samples were taken in each treatment at two random locations and at five equally spaced vertical positions. Samples were analysed for water and fibre content. The evolution of fibres (cellulose, hemicellulose, and lignin) and insoluble ashes were measured five times during the experiment by the methods of Goering and Van Soest (1970) and Van Soest and Wine (1967). Results of fibres analysis were expressed on the insoluble ashes basis (grams of fibres per gram of insoluble ashes).

Final measurements The final sampling was made with two objectives: 1) to compare the level of composting reached in each treatment by composite and grid samples, and 2) to evaluate spatial variations in composting by grid samples.

Composite samples were taken from two exposed cross-sections made in each treatment. Between 10 and 14 continuous samples (from top to bottom of the piles) were mixed thoroughly to form a composite sample. Sub-samples from each composite sample were used for measurement of carbon and different forms of nitrogen. Total nitrogen and carbon were determined by oxygen combustion with a Lecon CNS-1000. Concentrations of NH_4-N and the combined form of NO_3-N and NO_2-N were determined by distillation. Electrical conductivity and pH were measured on composite samples using a compost-water solution of 1:20. Results of electrical conductivity were multiplied by 4 and expressed on a 1:5 ratio to be compared with values from the literature.

The objective of the grid sampling was to quantify differences in composting due to the aeration treatments, and to allow the identification of preferential composting zones in the aerated treatments. Preferential composting can be caused by variations in aeration level due to the relative position of a given volume of material with respect to the aeration pipes. Samples were taken in each treatment at four equally spaced depths. For convenience, depths were labelled from 1 (top of the pile) to 4 (bottom of the pile). For aerated treatments, four series of samples were taken above the aeration pipes and three at mid-spacing between the pipes. For each non-aerated treatment, seven equally spaced series were sampled with four depths per series. All samples were analysed for water content and light absorbency (Morel 1982). Light absorbency, an estimation of humic and fulvic acid concentrations, is measured by comparing the light intensity coming in and out of a solution of compost extract. Light absorbency is unitless. The higher the light absorbency, the darker the sample, and the higher the degree of composting. For fibre content (cellulose, hemicellulose, and lignin) and insoluble ashes, 16 samples per treatment were analysed (two series of samples above the aeration pipes and two series between).

Bulk density, porosity, and free airspace (ratio of gas volume to the total volume) were also evaluated at the end of the project. Four series of samples were taken at 7 depths in treatment T2. Wet bulk density was calculated by dividing the wet weight of the sample by the volume of the cylinder used to get the samples. Porosity and free airspace were calculated (Haug 1993) with a sludge density of 1250 kg/m^3.

RESULTS AND DISCUSSION

Temperatures and ventilation times

All aerated treatments maintained temperatures from 50 to 65°C compared to 30 to 40°C for non-aerated treatments. Compost temperatures were maintained at that level even in winter when the monthly temperature of the air injected into the compost was as low as -20.9°C (Table I). Figure 3 shows typical temperature variations for a non-aerated and an aerated treatment. Higher temperatures in aerated treatments were the result of higher exothermic activity of microorganisms. The oxidation of organic matter is an exothermic reaction and temperature alone is not the best indicator of microbial activity. Heat production would be a better indicator of the composting activity. Non-aerated treatments maintained relatively high temperatures due to the heat accumulation in the compost pile, but the heat produced in the aerated piles was always evacuated by forced convection.

Table I: Monthly avarage, maximum, and minimum air temperatures

	Temperature (°C)		
	Average	Maximum	Minimum
November	-0.9	2.5	-4.2
December	-6.5	-2.5	-10.2
January	-12.5	-7.5	-17.5
February	-15.6	-10.2	-20.9
March	-5.8	-0.1	-11.4
April	4.5	9.0	-0.1
June	11.5	16.9	6.0
July	16.5	22.4	10.6
August	19.8	25.1	14.4
September	19.2	24.6	13.8

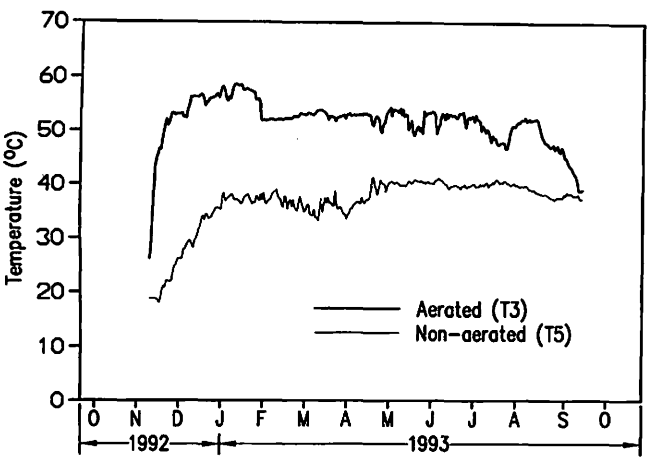

Fig. 3. Variations of temperature for an aerated and a non-aerated treatment.

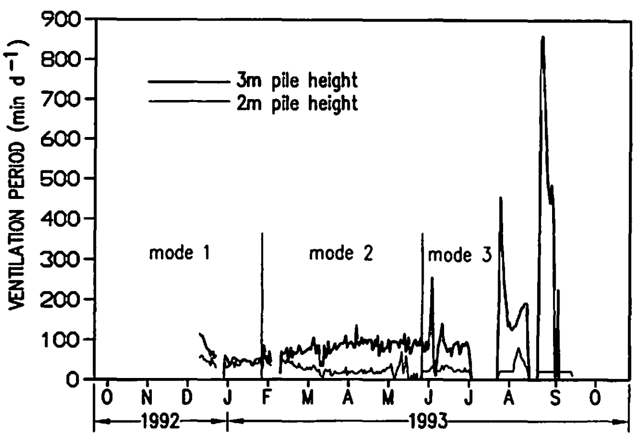

Fig. 4. Variations of ventilation periods.

Temperatures remained in the thermophilic range for the four aerated treatments until the end of the experiment. The mesophilic or maturation stage, in which temperature decreases, was never reached. Organic matter such as lignin, hemicellulose, and cellulose is difficult to degrade (Thorstrup 1985), which may explain the long thermophilic period. During the ventilation period, the air flow in the 2-m height pile was evaluated to 7 and 12 m^3/min for the 2-m and 1-m pipe spacing, respectively, and to 5 and 9 m^3/min in the 3-m height pile for the 2-m and 1-m pipe spacing. Ventilation periods are shown in Fig. 4 for each control mode. Under mode 1, ventilation periods were similar at about 50 min/d. Under mode 2, ventilation periods were higher for the 3-m pile than for the 2-m pile. Ventilation periods were around 100 min/d for the 3-m pile and around 30 min/d for the 2-m pile. The lower ventilation rate for the 2-m pile indicated a lower heat production, which was probably due to the smaller compost volume. After July 1, several fluctuations in ventilation periods were experienced due to different technical problems. Blowers accidentally stopped for the first time when aeration pipes became filled with water draining from the compost. When the blowers restarted, temperatures were high and more air was needed to evacuate the accumulated heat. On August 13, a power failure caused the blowers to stop. The same increase in ventilation was observed when they restarted 8 days later.

Evolution of composting material

Water content did not vary significantly during the experiment. It remained between 60 and 71% for all treatments, which is near the optimal range for efficient composting. In this range of water content, microorganisms can easily move from fibre to fibre in the aqueous environment with enough free airspace to provide sufficient oxygen mass transport. The composting process resulted in mass reduction of the material. Because the mass of the insoluble ash remained constant during composting, fibre content was expressed on an insoluble ash basis. Results showed that there were no significant differences in insoluble ash content between treatments. For all treatments, fibre content decreased progressively (Fig. 5) with cellulose degradation being the most prominent. For all treatments, 43% of cellulose, 15% of lignin, and 39% of hemicellulose were degraded during the experiment. The average insoluble ash content for the six treatments increased from 14.3 to 19.6%, which resulted in an average mass reduction of 27% during the 10 months the experiment lasted.

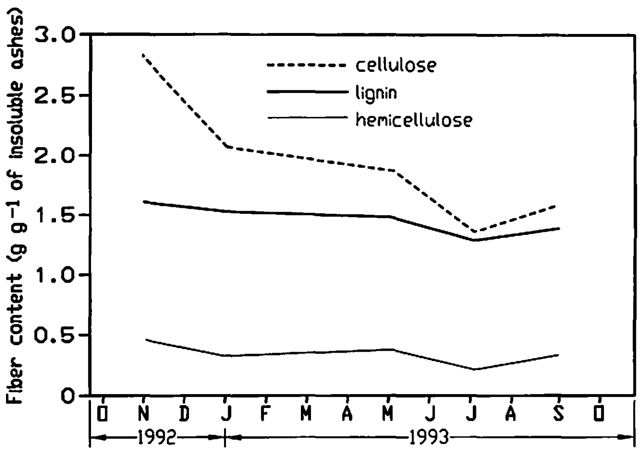

Fig. 5. Evolution of fiber content vs time (average from the six treatments).

Effect of treatments on the degree of composting

Carbon and nitrogen Table II shows concentrations of total carbon and different forms of nitrogen for each treatment at the end of the experiment. Mineral fertilizers added at the beginning of the experiment remained mostly inorganic (NH_4-N, NO_3-N, and NO_2-N) in non-aerated treatments, while part of it was immobilized by the biomass and transformed into organic nitrogen in aerated treatments. Since nitrogen remained in the inorganic form in non-aerated treatments, losses by volatilization may explain lower total nitrogen concentrations in these treatments. The concentration of NH_4-N decreased as the aeration level increased and the total of NO_3-N and NO_2-N concentrations were slightly higher in aerated treatments indicating better aerobic condi-

Table II: Results of analyses on compost material at the end of the experiment

	1-m pipe spacing		2-m pipe spacing		Non-aerated	
	2-m height	3-m height	2-m height	3-m height	2-m height	3-m height
N_{total} (mg/kg)[a]	9 030	9 290	9 140	8 860	7 490	6 240
NH_4-N (mg/kg)[a]	522	852	1 960	2 030	4 410	5 290
NO_3-NO_2 (mg/kg)[a]	220	31	254	95	32	35
N_{org} (mg/kg)[a]	8 290	8 400	6 930	6 740	3 050	920
C_{total} (mg/kg)[a]	374 000	381 000	382 000	390 000	376 000	380 000
C/N_{total}	42	41	42	44	50	61
C/N_{org}	45	45	55	58	123	413
Insoluble ashes (%)	20.33	19.47	19.26	18.83	20.68	19.73
Cellulose. (g/g)[b]	1.49	1.65	1.63	1.72	1.41	1.33
Lignin (g/g)[b]	1.38	1.40	1.43	1.41	1.33	1.37
Hemicellulose (g/g)[b]	0.47	0.44	0.46	0.46	0.48	0.53
Light absorbency	0.206	0.202	0.142	0.125	0.083	0.069
Elec. cond. (mS/cm)	2.0	4.0	2.8	3.6	4.4	4.8
pH	7.3	7.1	7.2	7.4	7.4	7.4

[a] Dry basis
[b] grams of fiber per gram of insoluble ashes

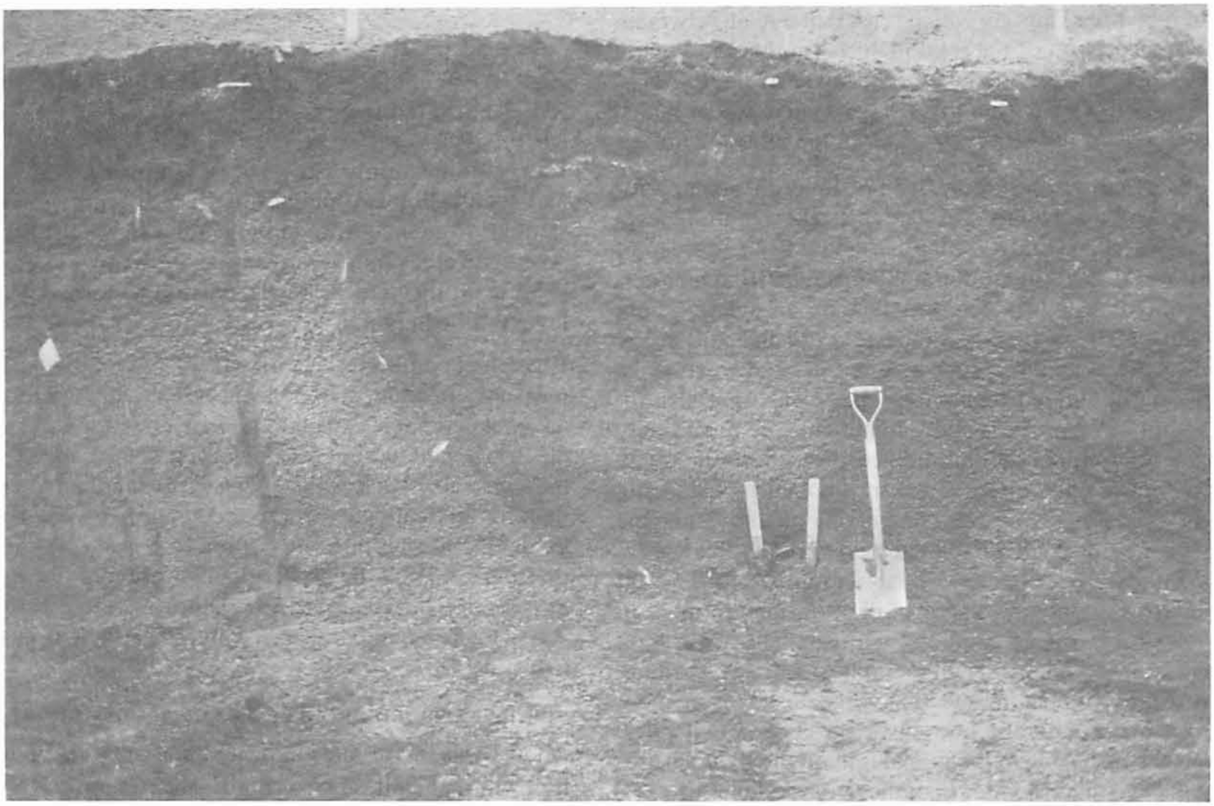

Fig. 6. Cross section of deinking sludge at the end of the composting period. Treatment without aeration is presented on the left side and with aeration on the right side.

tions. Composting experiments conducted by Riffaldi et al. (1986) and Morel et al. (1986) also showed a rise in nitrate concentrations with aeration. This suggests a more efficient composting in aerated treatments. The C/N ratio is commonly used to assess the maturity of a compost, where N indicates all forms of nitrogen. A C/N ratio below 20 is generally a sign of stability. However, this ratio can vary according to the type of substrate used. In the present experiment, the final C/N ratio was lower in aerated treatments, implying a greater stability of organic matter.

Table III: Light absorbency (dimensionless)

		1-m pipe spacing		2-m pipe spacing		Non-aerated	
		2-m pile height	3-m pile height	2-m pile height	3-m pile height	2-m pile height	3-m pile height
depth	1	0.113	0.144	0.109	0.083	0.188	0.181
	2	0.154	0.211	0.119	0.119	0.077	0.031
	3	0.224	0.225	0.125	0.181	0.032	0.032
	4	0.332	0.230	0.216	0.117	0.036	0.032

Another way to assess compost maturity is to compare the C/N ratio in which only the organic nitrogen is considered (C/N_{org}). Using organic nitrogen instead of total nitrogen excludes mineral nitrogen added at the beginning of the experiment and gives a better idea of the biomass evolution. Table II indicates that the C/N_{org} ratio is directly related to the aeration level. For the 3-m high treatment, C/N_{org} values of 413, 58, and 45 were obtained for the non-aerated, 2-m, and 1-m pipe spacing, respectively. In the non-aerated treatments, a difference was observed between the 2-m and the 3-m height pile average C/N_{org} ratio, which were 123 and 413, respectively. The difference can be explained by the presence of a 400 mm thick layer of well composted material on top of both piles (Fig. 6), which represent a relatively more important proportion of the total material in the 2-m than in the 3-m height pile, and resulted in a lower average C/N_{org} ratio in the 2-m pile. Within this zone, oxygen was provided to microorganisms by air diffusion from the atmosphere.

Light absorbency Average values of light absorbency for each treatment (Table II) indicate that the aeration level affected light absorbency, which is related to the degree of composting. After 10 months, deinking sludge from non-aerated treatments was less composted, with an average light absorbency of 0.076. Average values of 0.134 and 0.204 were found in the 2-m and 1-m pipe spacing aerated treatments, respectively. In aerated treatments, the lower light absorbencies found in 2-m pipe spacing treatments are most likely caused by non-optimal aeration since the aeration strategy was based on temperature control in the 1-m pipe spacing treatment. The lower rate of composting in the 2-m pipe spacing treatments could be related to lower microbial activity caused by an excessive heat accumulation. Light absorbencies were always lower in the 3-m than in the 2-m height piles for the same aeration treatment. The lower light absorbency observed in the higher piles indicates a more difficult air movement in the material caused by a more compacted material at the bottom of the 3-m height piles. However, the influence of the pile height on the light absorbency level was much smaller than the aeration level.

The effect of forced aeration on the color of composted material can be seen in Fig. 6, which shows the boundary between the 3-m pile height non-aerated treatment (at left in Fig. 6) and the 3-m pile height with 2 m pipe spacing aerated treatment (at right in Fig. 6). The last aeration pipe of the aeration treatments is located between the two poles left of the shovel. The boundary between the two treatment can be clearly seen in Fig. 6 and is outlined by white flags. It indicates the position of the left most airflow line originating from the aeration pipe.

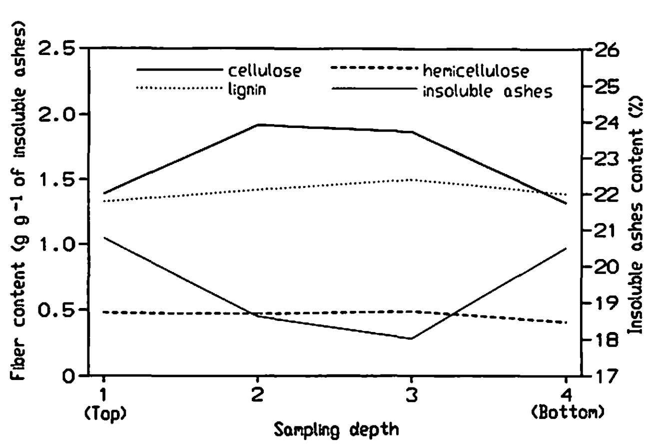

Fig. 7. Effect of depth on fibre and insoluble ash for aerated treatments.

Fibre and insoluble ash Analyses of fibre (cellulose, lignin, and hemicellulose) and insoluble ash were performed on samples from the grid sampling at the end of the experiment. Average values for each treatment are shown in Table II. No significant differences were found with respect to aeration level or pile height.

Electrical conductivity and pH Electrical conductivity is a measure of soluble salt concentration, which is used to plan adequate compost utilisation. Once converted to a 1:5 ratio, electrical conductivity values were between 2.0 and 4.8 mS/cm (Table II). Results of electrical conductivity indicated that, for all treatments, composted material could be used for gardening, for potting with filling material, or for incorporation into soil (Northeast Regional Agricultural Engineering Service 1992). Measured pH values were between 7.1 and 7.4, which is comparable to values mentioned in literature (Mustin 1987).

Spatial variation in the degree of composting

An analysis of variance indicated that only the vertical position within the piles had a significant effect ($\alpha = 0.01$) on the degree of composting. The effect of the vertical position of the samples in the aerated treatments is presented in Fig. 7 for insoluble ash. These results show that samples at the top and bottom of the piles had a higher ash percentage and a lower cellulose mass. This can be explained by a more important organic matter degradation occurring at these locations caused by greater oxygen availability near the aeration pipes and near the pile surface. The effect of depth on lignin and hemicellulose degradation was negligible.

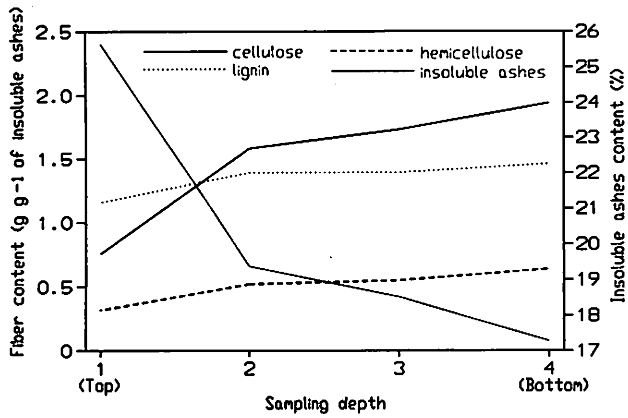

Fig. 8. Effect of depth on fibre and insoluble ash for non-aerated treatments.

Averages of light absorbency measurements were compared to determine whether sample depth and position (above or between aeration pipes) had an effect on the degree of composting. Table III shows that depth had an important effect on measured light absorbencies. For aerated treatments with a 1-m pipe spacing, the degree of composting increased gradually with depth. Samples closer to the surface were less composted than those at the bottom of the pile. These results contradict those from the fibre analyses (Fig. 7) which show that composting was similar on the surface and bottom of the piles. According to Swift and Heal (1985), the progressive decomposition of organic matter is characterized by different decomposing organisms that invariably change during the process. In this experiment, different mushrooms and plants were observed on top of the piles. Their presence on the surface may explain differences in nutrient use, as measured by fibre content, and humic production as estimated by light absorbency. The effect of sample depth was also observed in piles with 2-m pipe spacing. However, in the 3-m pile height, the most composted samples were at depth 3, whereas samples at the bottom of the pile (depth 4) were, on average, less composted because less aeration between aeration pipes. These less composted zones resulted from unequal air distribution due to the wider pipe spacing.

Table IV: Wet bulk density, porosity, and free airspace in the treatment with 2-m pipe spacing and 3-m pile height

Depth from surface (mm)	Wet bulk density (kg/m^3)	Porosity (%)	Free airspace (%)
200	429	90.0	66
500	521	86.4	58
800	593	84.1	53
1100	711	80.8	43
1400	705	81.1	44
1700	780	79.7	38
2000	897	77.7	29

For non-aerated treatments, the effect of depth on fibre and insoluble ash content is shown in Fig. 8. Closer to the top of the piles, where oxygen diffusion from the atmosphere occurred, ash percentages were higher and masses of all fibres were lower indicating better composting. In the surface layer, treatments with no aeration have higher percentages of insoluble ashes (25%) and lower masses of fibres (0.75 g of cellulose per gram of insoluble ash) than in the aerated treatments (21% and 1.4 g of cellulose per gram of insoluble ashes, respectively). Organic matter degradation on the surface was therefore greater in non-aerated treatments than in aerated treatments. The concentration of nitrogen added as fertilizer at the beginning of the experiment remained relatively unchanged for non-aerated treatments. The greater degradation observed on the surface of the non-aerated treatments may explain why the overall average content of fibres and insoluble ashes was almost similar to those of the aerated treatments.

Results from light absorbency measurements from non-aerated treatments indicated that samples closer to the top were darker than the others. In the surface layer, oxygen was brought to microorganisms by diffusion from the atmosphere allowing better composting. These results are consistent with those from the fibre analyses. Average values measured on the surface layer of non-aerated treatments were higher than those from the aerated treatments. These observations confirm that surface composting was better in the non-aerated treatments than in aerated ones.

Bulk density, porosity, and free airspace Results of wet bulk density, porosity, and free airspace measurements are presented in Table IV. The 3-m pile height was 2.3 m high after 10 months due to compacting and mass reduction. Progressive compacting influenced the wet bulk density which increased linearly with depth. Free airspace results were between 29% (bottom) and 66% (top) which is adequate for proper aeration according to Haug (1993) who mentioned that free airspace should be at least 30% for proper oxygenation. According to these results, deinking sludge composting pile should not be higher than 3 m to maintain acceptable free airspace at the bottom. To compost higher piles, a bulking agent would be necessary to provide structural support and maintain sufficient air spaces within the composting matrix.

CONCLUSIONS

The following conclusions can be drawn from the study.

1. Composting of deinking sludge with forced aeration is feasible in North-Eastern Canada even with oustside temperatures as low as -20°C. For aerated treatments, the temperature of the composting material remained between 50 and 65°C. Higher piles had a larger mass and produced more heat while composting resulting in longer ventilation times to maintain temperatures within the desired range (53 to 55oC). Temperatures and heat production were lower in non-aerated treatments, indicating lower microbial activity.
2. All measurements of fibre content decreased with time while cellulose was the most degraded fibre. There was an average 27% mass reduction of the piles.

3. Aeration improved microorganism activity as supported by light absorbency and C/N_{org} ratio data. Treatments with 1-m pipe spacing were most composted, whereas no effect of pile height on composting was observed in any of the treatments.
4. Organic nitrogen was higher in aerated treatments. This reflects a higher microorganisms activity and increased deinking sludge degradation.
5. Fibre and light absorbency analyses indicated that the degree of composting varied with sample depth in the piles. For aerated treatments, light absorbencies and fibre contents analyses showed higher degradation near the aeration pipes. However, composting of the surface layer was also more efficient in non-aerated treatments than in aerated ones.
6. The free airspace value at the bottom of the 3-m height pile was comparable to the lower acceptable limit for efficient composting. This result indicates that deinking sludge piles should not be higher than 3 m if a bulking agent is not used.

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