

Composting of Pulp and Paper Mill Power Boiler Fly Ash with Wastewater Treatment Sludge

by

Graydon Alexander Ross Hackett

B.A.Sc., Bio-Resource Engineering, University of British Columbia, 1996

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF APPLIED SCIENCE

in

THE FACULTY OF GRADUATE STUDIES

Department of Chemical and Bio-Resource Engineering

We accept this thesis as conforming
to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

June 1998

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Department of CHEMICAL AND BIO-RESOURCE ENGINEERING

The University of British Columbia
Vancouver, Canada

Date June 1/98

Abstract

Environmental concerns and economic realities are influencing the options available for sludge disposal from high rate wastewater treatment facilities in the pulp and paper industry. Landfilling and incineration of sludge products are no longer viable options. Composting of sludge and other waste products such as fly ash represents a way to reduce the amount of solid waste which must be disposed of. Composting produces a stabilized product that can be used as a beneficial soil amendment.

Elk Falls Pulp and Paper in Campbell River, B.C., sponsored an investigation into composting wastewater treatment sludge with power boiler fly ash to produce a beneficial soil amendment. Compost was produced in windrows 50 m long, 4 m high and 6 m wide. The windrows were sampled regularly and temperature, pH, C:N ratio and moisture content were measured to monitor biological activity. Samples of the initial and final compost products were analyzed for both agronomic properties and contaminants of concern, while the process was evaluated logistically.

Compost was produced in both a turned and static pile. Temperatures above 55°C for 3 weeks precluded weed growth. Moisture content was maintained above 50% to ensure microbial activity. The final compost contained high nutrient concentrations (P, K, Ca, Mg, Mn, B, Na, Al, N, S), a pH of 8.5 and an average C:N ratio of 43:1. All metal, PCB, chlorophenol and PAH concentrations were below regulated levels in British Columbia in the Contaminated Sites Regulation. The compost contained a final dioxin concentration of 41.3 pg/g TEQ. The lengthy period required to stabilize the compost (34 weeks) may have been due to N-limitation. Small-scale composter studies provided some evidence that the 1:1 sludge:ash mixture used in the large

scale experiments may be N-limited. The addition of chicken manure to the mixture of raw materials improved biological activity within the compost.

Leachate produced from compost of industrial wastes could potentially be hazardous and contaminate water resources. Leachate from the large scale compost piles was produced in the lab using a rigorous agitated leachate extraction test. Leachate samples were analyzed for copper, zinc, sodium, lead, nitrate, sulfate, total phosphorus, pyrene, naphthalene, phenanthrene and ionic material (electrical conductivity). The leachate met all the requirements for aquatic environments according to the B.C. Contaminated Sites Regulation. It is important to note that direct comparison of the leachate was made to the criteria which are specified for bodies of water after they have received all discharges.

Finally, land application trials of the compost were completed at a sod farm in the Comox Valley. These experiments were completed to provide information on the fate of dioxin/furans once mixed with soil and to test the fertilizer qualities of the compost. Application of compost (8 yards/acre; 15m³/ha) at the sod farm improved soil characteristics as measured by a number of parameters. The dioxin concentration in the final soil/compost mixture was 3 pg/g TEQ, as compared to the agricultural soil limit of 10 pg/g TEQ.

Composting produced an acceptable soil conditioner, with limited leachate concerns and such material may be attractive for large volume users of inexpensive soil material (sod farms, golf courses, land reclamation sites).

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Acknowledgement

A number of people greatly assisted me with this work. I gratefully acknowledge their generous donations of both time and expertise.

I would like to express my thanks for the financial support received from Fletcher Challenge Canada Limited, NSERC and COFI.

I wish to thank Dr. Anthony Lau and Bud Fraser for their support and assistance throughout the project. The effort of the support staff of the Department of Chemical Engineering, the U.B.C. Pulp and Paper Centre and the U.B.C. Environmental laboratory is greatly appreciated and acknowledged with thanks.

Dwayne Ducette and Zahid Mahmood are recognized for their contribution and assistance to the leachate work.

Thanks are extended to Chuck Easton and Mike Staiger who made my time at Elk Falls a valuable and rewarding experience. All other mill personnel who assisted with my project in various ways are also very appreciated. Nick Samsom is thanked for his assistance with the land application trials.

Special thanks are extended to Dr. Sheldon Duff for providing me with the opportunity to participate in this very rewarding experience.

Finally, I am grateful to my family and friends for their caring support and encouragement throughout this project.

Chapter 1. Introduction

Around the world, industrial and municipal engineers are under increased pressure to find alternatives to landfilling solid wastes. These wastes include sludges from high rate biological wastewater treatment systems and ashes generated from onsite power boilers. Specifically, the pulp and paper industry faces a growing solid waste disposal problem as environmental regulations become more stringent and landfill space grows more scarce (Dowe, 1993).

The pulp and paper industry in the United States produces an estimated 12.2 million tonnes/year of combined primary and secondary sludge (Anon, 1992; Dowe, 1993; Linderoth, 1989). Handling and disposal of such quantities of sludge can represent upwards of 40% of the cost of operating a wastewater treatment system (Anon, 1992). Dewatering followed by incineration or landfilling remain the preferred options for disposal. An estimated 3.4 million tonnes/year of ashes are also produced. (Vance, 1996). Nationwide, greater than 80% of boiler ashes are disposed of in landfills or lagoons with about 5% land applied.

In 1990, disposal by landfilling was estimated to cost \$CAN100/t exclusive of tipping fees (McCubbin et al., 1992) and the U.S. Environmental Protection Agency (USEPA) has estimated that over 5000 of the 6500 municipal landfill sites will close within the next 20 years; half of those in the next 5 years (Pickell and Wunderlich, 1995). These environmental and economic realities provide an incentive to develop new solid waste management technologies. Most attractive are those that have the potential to produce an economic gain while benefiting society and the environment.

Composting has the potential for generating a product from pulp mill solid wastes that can be used beneficially as a soil amendment (Campbell et al., 1991). Composting is the solid-phase decomposition of organic material by microorganisms under partially controlled conditions. The microorganisms feed on organic matter while producing heat, carbon dioxide and water vapour. The process reduces the volume and mass of raw materials while transforming them into a valuable soil conditioner. Composting of pulp mill sludge could potentially reduce sludge mass and odour, degrade toxic compounds inhibitory to plant growth, decrease nitrogen immobilization, and degrade chlorinated organic compounds while producing a marketable material suitable for horticultural and agricultural uses (Campbell et al., 1991; 1995; 1996).

Over the past decade there has been growth in the use of wood ash as a bulking agent and amendment for biosolids composting. Wood ash helps to achieve targeted solids contents, adds porosity and increases various beneficial macro and micro nutrient concentrations in the finished product. The use of ash also significantly reduces odours produced during the composting process (Carpenter and Beecher, 1997).

Several past pilot and full scale mill studies have demonstrated the feasibility and the advantages of composting pulp and paper mill sludge (Campbell et al, 1997; 1996; 1991; Carter, 1983; Julyan, 1995; Linderoth, 1989; Valente et al., 1987; Wysong, 1976). These studies have helped to establish comprehensive information about the composting process, determine chemical and physical characteristics of the compost and assess the suitability of compost for subsequent use as a plant growth medium. Other pilot studies have investigated the use of ashes as a soil amendment (Carpenter and Beecher, 1997; Etiegni et al, 1991; Julyan, 1995; Krejzl and Scanlon, 1996; Someshwar, 1996; Vance, 1996; Williams et al, 1996; Unger and Fernandez, 1989). Ashes applied

to land have resulted in increased growth and yield of agricultural crops, increased pH, and increased potassium and phosphorus availability. The long term effects of land application of sludge compost and ash have not been investigated. Nor have studies focused on the combined composting of pulp and paper mill sludges with the ashes produced at a mill site.

In this thesis, the feasibility of composting wastewater treatment sludge with power boiler fly ash from the Elk Falls Pulp and Paper mill is investigated. Composted material was tested at a local sod farm to determine its suitability as a soil amendment.

Chapter 2. Background

The Fletcher Challenge Canada Ltd. pulp and paper mill in Campbell River, B.C. produces approximately 325 tonnes of sludge from the wastewater treatment facility and 75 tonnes of ash from the power boilers every day. Both materials must be disposed of in an economically viable, and environmentally friendly manner.

Currently, the sludge is burned in the power boilers, slightly reducing the steam production capacity of the boilers due to the high sludge moisture content. More importantly, 20 truckloads per day of ash produced from the incineration of hog fuel and sludge in the boilers are landfilled. The future ability of the mill to obtain landfill permits is in question and Fletcher Challenge Canada Ltd. was interested in experimenting with composting of the sludge using wood ash as a bulking agent and source of macro and micro nutrients. The goal of this investigation was to produce a beneficial soil supplement while reducing the disposal rate of material to the landfill. The potential benefits of this project include: (1) decreasing the expense of constructing new landfill sites, (2) producing a nutrient rich compost product to improve soil properties, and (3) instilling public confidence in the industry by finding an environmentally beneficial use of 'waste' products.

2.1 Composting

Composting is the biological decomposition and stabilization of organic substrates producing a final product that is stable, free of pathogens and plant seeds, and which can be beneficially applied to land (Haug, 1993). It is a completely natural process of decay involving bacteria, fungi, worms and other small organisms. These microorganisms feed on organic material producing heat, carbon dioxide and water. Composting can result in weight losses in excess of 40% of the original material and therefore reduce the amount of organic matter bound for landfills. It can reduce hauling costs,

garbage odours, and benefit society by producing a higher-value material suitable for horticulture and agriculture (Campbell et al., 1991).

2.1.1 Process Microbiology

Composting results from the activity of various diverse microorganisms. No one organism or species dominates the compost pile because the materials and conditions continually change. The diversity of the microbial population ensures that the compost process does not cease when conditions change. The availability of microorganisms is rarely a problem for composting. Microbial competition and the physical and chemical environment ultimately determine which, and how many organisms persist. The most effective and successful microorganisms are normally present and inocula have not proven necessary (Gouin et al., 1992).

Bacteria, fungi and actinomycetes are the major groups of microorganisms that participate in composting. Each of these three groups has specific environmental conditions which favour their growth. Bacteria are small, simple organisms which are generally responsible for the rapid exothermic decomposition of low molecular weight compounds such as lipids, proteins and fats (Tchobanoglous and Burton, 1991). Bacteria tend to dominate the composting process as long as moisture content and pH remain in the range of 45-55% and 5-8, respectively (Gouin et al., 1992). Bacteria can survive in both anaerobic and aerobic conditions. Under aerobic conditions, bacteria use oxygen as the electron acceptor in the oxidation of organic matter. Anaerobic bacteria use other substances as electron acceptors in the conversion of organic matter into methane gas. Fungi are larger aerobic microorganisms, forming networks of individual strands and filaments. Fungi are responsible for the decomposition of wood substances and other decay-resistant materials (Gouin et al., 1992). Fungi flourish under low moisture content and acidic conditions. Actinomycetes form

filaments like fungi, but because of their small size and cell structure they are classified as bacteria. Like fungi, these microorganisms are primarily aerobic and become most abundant when moisture levels are low. Actinomycetes do not flourish under acidic conditions, allowing fungi to become dominant (Gouin et al., 1992).

2.1.2 Phases of Microbial Growth

The type of organism present is a function of a range of environmental factors, including temperature. Composting has 4 distinct phases involving mixed populations of bacteria, fungi and actinomycetes: (1) mesophilic (<40°C), (2) thermophilic (40-60°C), (3) second mesophilic (<40°C), (4) curing (ambient).

Once raw materials or substrates are mixed together, the temperature of compost rises from ambient temperature to 40°C, a mild heating effect which coincides with the appearance and activity of mesophilic species of bacteria, fungi and actinomycetes. A large amount of heat is generated as the microorganisms metabolize low-molecular-weight compounds pushing the pile temperature into the thermophilic range. The thermophilic phase is the dominant phase of the composting process, and thermophilic microorganisms are responsible for most of the degradation and stabilization of organic substrates. Care must be taken to ensure the temperature does not rise above 65°C causing thermal inhibition of the microbial population (Gouin et al., 1992).

As the low molecular weight compounds are depleted, biological activity slows and the temperature drops to start the second mesophilic phase. Fungi and actinomycetes are most important during this phase as they attack the complex molecules such as cellulose and hemicellulose (Campbell et al., 1991). The curing phase begins when the pile returns to ambient temperature. This phase can last

months to several years as the remaining organic carbon is slowly transformed to stable humic compounds.

2.1.3 Environmental Factors which Influence Composting

Composting is a biologically-catalyzed process, and, as such, is affected by range of environmental factors. Included in the list of important determinants of microbial activity are: (1) aeration, (2) essential elements, (3) moisture content, (4) porosity and substrate particle size, (5) temperature and pH.

2.1.3.1 Aeration

After composting begins, oxygen supplies are quickly reduced as aerobic microorganisms consume oxygen and pile settling removes pore spaces. If composting continues without mixing or forced aeration, all available oxygen will be consumed and the process will become anaerobic. Under this condition, 85% of the energy released is in the form of methane gas with the remaining 15% in the form of heat (Gouin et al., 1992). Anaerobic processes occur at a lower temperature and a longer period of time is required to stabilize organic substrates. Odourous compounds such as hydrogen sulfide are produced (Diaz, 1993) which represent socio-economic as well as health and safety concerns for operators. Indicators of anaerobic conditions are a slow temperature rise in the active composting stage or an unexpected drop in temperature in one of the later stages.

Aeration is typically accomplished through mechanical agitation or forced aeration. The optimal rate of aeration is determined by the nature and structure of the raw composting substrate. Theoretically, effective composting requires at least 5% oxygen within the pore spaces; practically,

the oxygen content should be maintained between 10 to 15% of the total bulk material volume (Campbell et al., 1991).

Aeration must not be excessive since pile cooling and excessive loss of moisture due to evaporation reduces microorganism efficiency (Golueke and Diaz, 1990). Other benefits of aeration include the promotion of uniform decomposition and the removal of accumulated carbon dioxide and other by-products of microbial metabolism (Dillon, 1990).

2.1.3.2 Essential Elements

Most micronutrients required to foster microbial growth are typically present in sufficient amounts; however, carbon and nitrogen must be carefully monitored. Carbon (C) is an essential nutrient for oxidization during metabolic processes, while nitrogen (N) is essential for protein synthesis (Gouin et al., 1992). The C:N ratio is measured to ensure that the compost is in the optimal operating range for nutrients (20:1 to 40:1). At C:N ratios lower than 20:1 the available carbon is fully utilized without stabilizing all the nitrogen. Excess nitrogen may be lost to the atmosphere as ammonia or nitrous oxide and odour can become a problem. C:N ratios higher than 50:1 require longer composting times in order for microorganisms to use the excess carbon and may be considered nitrogen limited (Gouin et al, 1992). Compost substrates can be blended to maintain mixtures within the proper C:N ratio range. The addition of a nitrogen-containing waste, such as manure, can reduce the C:N ratio in mixtures, while high carbon content wastes, such as leaves, can be used to increase the C:N ratio (Dillon, 1990).

2.1.3.3 Moisture Content

Moisture is required to support the metabolic processes of microbes. Water is the medium for chemical reactions and the transport of intracellular nutrients. Optimum moisture content for composting of municipal waste is approximately 45 to 55% (Golueke and Diaz, 1990). As the moisture content is decreased below 45%, the composting processes will slow and ultimately cease at approximately 15%. Above 55%, water begins to fill the larger pore spaces and displace air. Composting processes must begin near 55% moisture content to ensure that heat generation and subsequent water evaporation does not force the moisture content below 15% (Gouin et al., 1992).

Moisture content is a function of the structural strength of the particles making up the compost. As compression occurs in the piles, substrate particles with greater structural strength retain pore space and thus aeration qualities. Weaker materials will be compacted, reducing pore space and creating anaerobic conditions. Bulking agents and amendments ensure sufficient structural strength to retain pore size, aeration and optimal moisture content in the compost.

2.1.3.4 Particle Size

Particle size is important because it affects the surface area of wastes exposed for microbial attack. The greater the surface area to mass ratio, the more rapid the rate of decay. Theoretically, the smaller the particle, the more readily it can be broken down. Practically, there is a minimum limit on particle size imposed by the need to ensure the maintenance of porosity for proper aeration. Maintenance of porosity is a function of the structural properties of the compost; rigid, crush resistant materials permit the retention of interspatial integrity with small particle sizes (Diaz, 1993). The optimum size of materials is approximately 5 to 7.5 cm (Dillon, 1990).

2.1.3.5 Temperature and pH

Proper maintenance of the temperature and pH of the microenvironment surrounding microorganisms is essential. Most organic substrates create an environment with a pH in the acceptable range of 6 to 8. Heat is a natural by-product of the composting process and usually the temperature is maintained in the optimal thermophilic range. Thermophilic microorganisms are preferred for municipal and agricultural wastes because temperatures above 45°C ensure that pathogens in the compost are destroyed (Carter, 1983). Most regulations for composting of municipal material set the minimum temperature at 55°C to ensure the removal of all human pathogens (Chase, 1991). It is essential to keep the temperature below 65°C to prevent thermal inhibition and subsequent dormancy of the microorganisms. Once the microorganisms are dormant, composting will cease until the population recovers.

In practice, temperature control is accomplished two ways. In mechanically-turned windrow piles, the temperature will drop 12 to 15°C with each turn (Julyan, 1995). In statically-aerated piles, blowers or fans can be turned on or off as required by controlling them with feedback control loops (Chase, 1991).

2.1.4 Residence Time and Curing

The time required to produce compost depends upon the raw materials and process management. It can vary from a few weeks to several years depending on the type of process, the compost quality desired and the organic substrates present. For example, highly lignified cellulosic wastes will compost at a slower rate than food wastes and municipal sludge (Campbell et al., 1991).

Usually compost is allowed to cure and become stable before it is applied to land. A long curing period is a safety net to overcome the shortcomings of the composting method. Immature compost consumes oxygen and thus reduces the availability of oxygen for plant roots (Gouin et al., 1992). Immature compost can also contain high levels of organic acids, a high C:N ratio and other characteristics which may be damaging to plants and crops. However, if used for agricultural purposes, compost can be cured on fields for several months prior to the planting season.

There are several methods being developed for measuring the stability of compost. Compost is defined as stabilized when the material can be stored without reheating and the material does not inhibit plant growth when used as a soil amendment (Dillon, 1990).

2.1.5 Methods of Composting

There are 3 major methods to process the material in composting: (1) windrow piles, (2) aerated static piles, (3) in-vessel reactors.

2.1.5.1 Windrow Method

In windrow composting, material to be composted is collected and piled into triangular piles or windrows on the ground or on prepared surfaces (Figure 1) (Haug, 1993). In the windrow method, the material is left undisturbed, and aeration is accomplished by natural convection. In large and high piles, anaerobic conditions can result from this static method. When using static windrows, it is generally recommended to use small piles to ensure rapid decomposition and to prevent odour problems associated with anaerobic conditions.

Aeration can be enhanced by mechanical turning. The turning equipment can be a front-end loader, bulldozer, self-contained turning unit or turners attached to regular farming equipment. Oxygen is supplied by natural convection (hot air from windrow comes out and cool ambient air enters) and gaseous transfer during turning. The frequency of turning is determined by the temperature and the moisture content in the pile. Frequent turning and mixing of the compost piles improves the homogenous nature of the piles.

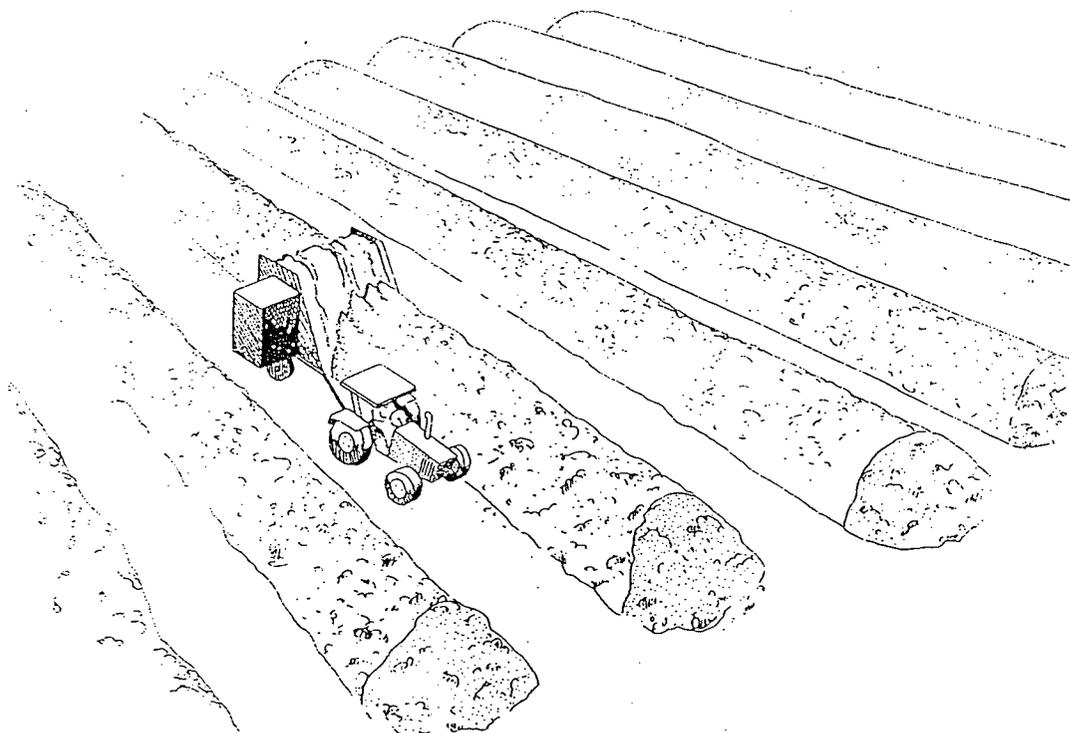


Figure 1. Windrow composting.

2.1.5.2 Aerated Static Piles

Aerated static piles are compost piles built over an aeration system (Figure 2) (Gouin et al., 1992). They are often used for highly porous materials with structural bulking agents added to maintain the porosity of the pile. Aeration systems are usually perforated pipes or a perforated floor. Air is forced through the aeration devices by ventilation fans or blowers, and the flow duration and volume are controlled by feedback control loops and monitoring equipment. Covers on the piles are often necessary to insulate piles to prevent excessive heat loss.

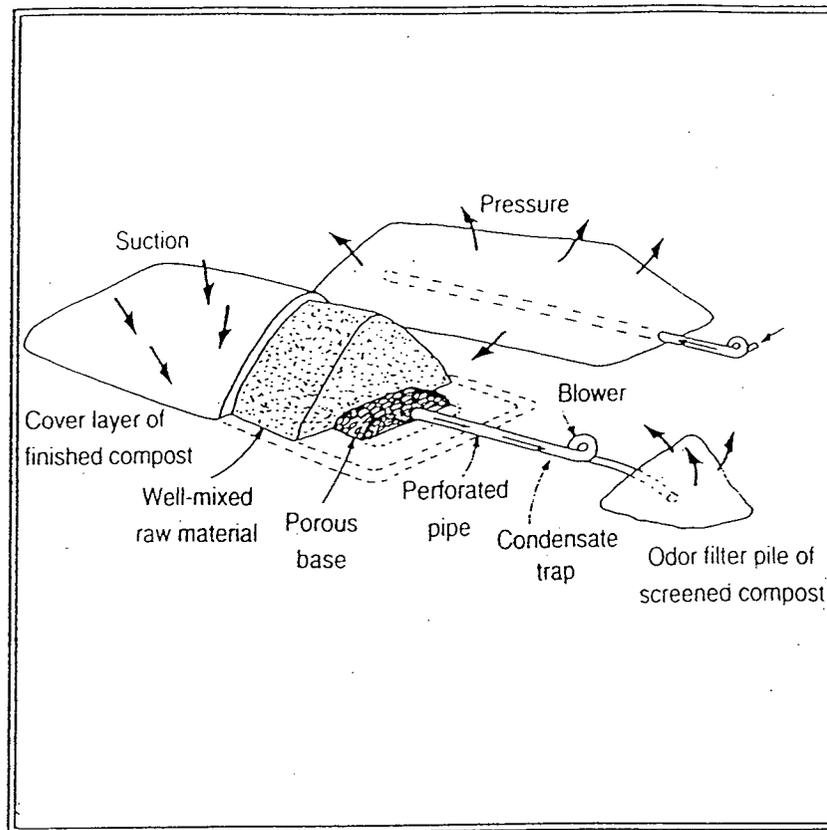


Figure 2. Aerated static piles.

2.1.5.3 In-Vessel Composting

In-vessel composting is the production of compost in an enclosed container or vessel under controlled environmental conditions (Figure 3). Temperature, oxygen content and moisture content

are monitored continuously. The piles are mechanically agitated on a schedule which gradually moves the pile either horizontally or vertically through the system and eventually to the curing area. The constant moving and mixing of the compost improves product quality by ensuring homogeneity. Because in-vessel composting is completed in a closed environment, gases emitted from the compost can be easily collected and treated before release to the atmosphere. Gases are usually passed through bio-filters for treatment (Haug, 1993). Fewer employees are required for in-vessel reactors as the mixing process is automated and the monitoring process is completed via permanent sensors and feed back loops. Adjustments can be made swiftly to ensure that the composting conditions are maintained in the optimal zone to produce a quality product in the least amount of time. This method allows for the most efficient use of space, but capital and operating costs are very high for the in-vessel system (Gouin et al., 1992).

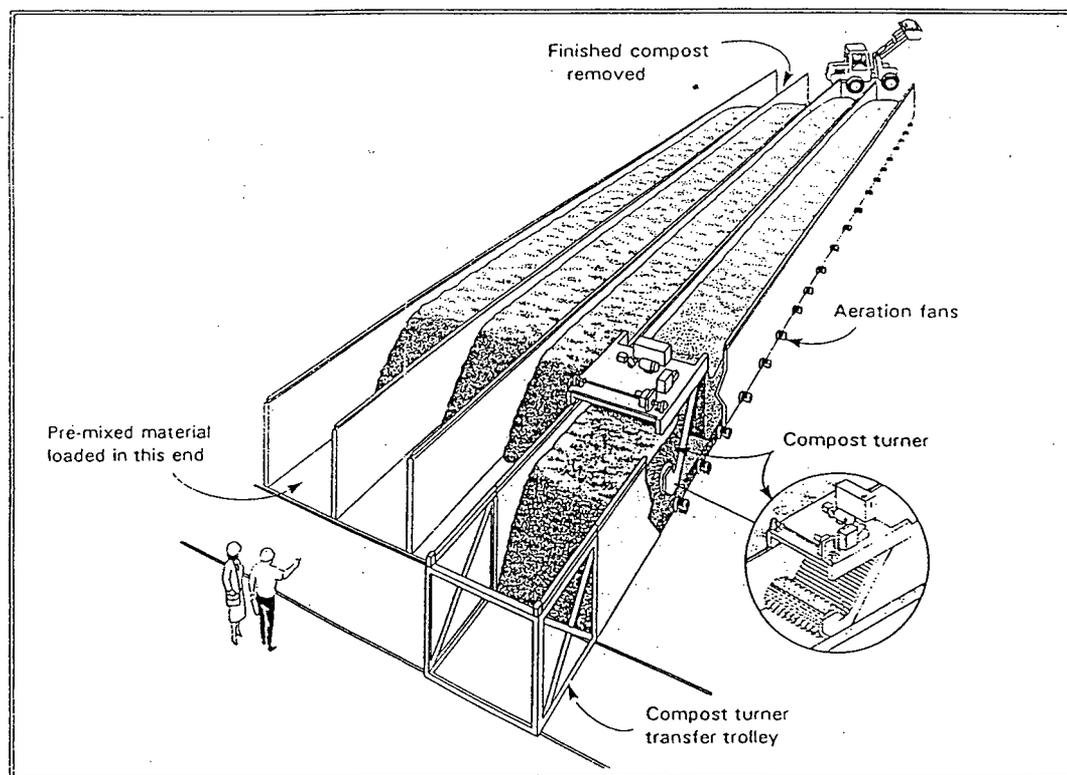


Figure 3. In-vessel reactors.

2.2 Composting of Pulp Mill Sludge and Ash

Composting has shown the potential to reduce and stabilize sludges from high rate wastewater treatment facilities. Pulp and paper mills have experimented with composting processes to reduce sludge mass and volume to increase landfill lifespans or to produce soil conditioners (Campbell et al, 1997; 1996; 1991; Carter, 1983; Julyan, 1995; Linderoth, 1989; PGL Organix Ltd., 1996; Valente et al., 1987; Wysong, 1976). Wood ash has also shown the potential to be used as a soil amendment in its own right (Carpenter and Beecher, 1997; Etiegni et al, 1991; Julyan, 1995; Krejzl and Scanlon, 1996; Someshwar, 1996; Vance, 1996; Williams et al, 1996; Unger and Fernandez, 1989). It can provide many macro and micronutrients to the soil and serves to modify pH. Ash also has the ability to be used as a compost amendment (Carpenter and Beecher, 1997).

2.2.1 Sludge Composting

One of the primary goals of composting sludge is to reduce the mass and volume of sludge to conserve landfill space. Composting also stabilizes the sludge prior to deposit in landfills which may reduce leachate problems. Alternatively composting can be used to produce a product that can be beneficially applied to land.

Crown Zellerbach Corp. conducted pilot scale composting studies over 236 days on a combined primary-secondary kraft sludge from their mill in Wuana, Oregon (Wysong, 1976). Various mixtures of primary and secondary sludge were compared. Volume reductions of 34-52% and total weight losses of 32-46% were reported and it was projected that composting could cut transportation costs by 50%. In the same study, it was noted that west coast rainfall patterns played an important role in total weight reduction. It was suggested that covered compost piles and

transportation of product in late August would produce the greatest reductions in weight and volume.

Boise Cascade Ltd. composted a 65% organic / 35% ash primary sludge with a moisture content of 77-83% (Mick et al., 1982). Large windrows were created from sludge mixed with nitrogenous wastes from a local feed lot and slaughter house (paunch) to increase the nitrogen content. The reaction period for composting the raw materials was 10 weeks during which the piles were mixed mechanically. The purpose of the study was to reduce Boise Cascade's sludge hauling and disposal costs while converting the waste into a useful product. Approximately 500 tons/month of primary sludge were diverted to the composting process and the final product was sold successfully to local farmers. The compost met the EPA regulations for metals and contained high concentrations of nitrogen and phosphorus. Production has reached 50 000 tons/year of compost.

P.H. Glatfelter Co. developed a commercial process in the late 1970's to compost a bleached kraft primary-secondary sludge containing 40% ash and 70-78% water (Carter, 1983). Sludge was first shredded, then mixed with bark to improve porosity, and placed on plastic aeration pipes. Aerated, static piles were composted for three weeks and then cured for several more weeks. After composting, the material was screened and the bark was recycled. The compost was continuously analyzed and it was determined to be an excellent soil conditioner as it loosened clay soil and provided a slight liming effect. The compost was recommended for farmland improvement at an application rate of 100 yd³/acre (75 m³/acre) (Carter, 1983).

Einspahr et al. (1984) conducted a study on the effect of pulp and paper sludge compost on soil properties. Three sources of paper mill sludge including (1) primary clarifier sludge from a mill

using recycling fibers, (2) primary clarifier sludge from a chemi-mechanical mill and (3) modified kraft mill sludges were evaluated as soil amendments in soil column tests. The kraft mill sludges were composted using two different methods (regular and vermi composting) before being evaluated as an amendment. All sludge treatments increased the available moisture content and the cation-exchange capacity in sandy soils. The kraft sludges that were composted and vermicomposted (worm worked) provided greater improvements in soil properties than the unmodified sludge. It was concluded that the addition of pulp and paper mill sludges to sandy soils improved soil properties, reducing the irrigation and fertilizer requirements.

More recent work (Campbell et al., 1991;1995;1996) has been aimed at evaluating process variables that could be used to control the composting process and quantifying the physical and chemical changes in the compost.

Primary-secondary sludge samples from a refiner mechanical pulp (RMP)/chemi-mechanical pulp (CMP) newsprint mill were composted for six weeks using a static pile, forced aeration process in insulated reactors with different control regimes. The six week old compost had physical and chemical properties suitable for plant growth. Germination of lettuce seeds was similar in extracts from compost and peat moss. The growth of tomato plants in media amended with six week old composted sludge was comparable to growth in media amended with peat moss. The physical properties, cation exchange capacity and total humus content, were strongly correlated with compost age and plant growth (Campbell et al., 1991).

A later study by the same group (Campbell et al., 1995), focused on evaluating pulp and paper mill sludge as a soil amendment. The sludge mixed with wood ash and slaughterhouse paunch was

composted in a 91 m long windrow that was turned one or two times per week. The windrow was composted for 14 weeks, followed by a 4 week curing period, then used in trials with tomato and poplar plants. Shoot biomass of tomato plants was found to be only 65% of that found in plants grown in peat moss amended medium. However, shoot weight and height of poplar plants grown in the compost amended medium were equivalent to those grown in the peat moss control. Therefore, Campbell et al., (1995) concluded that the pulp and paper sludge compost could be used as a low quality mulch or soil amendment for poplar plants.

Campbell et al. (1996) evaluated raw and composted sludge as a soil additive and mulch for cottonwood plants. The same process as the 1995 study was used except that the material was composted and cured for a total of 39 weeks. Cottonwood clones were planted in soil that was mixed with raw and composted sludge mixtures at various application rates. The plants were grown for nine weeks in a greenhouse. After nine weeks, the cottonwood plants with raw and composted sludge added were found to have a plant height 40% greater and stem diameters 20% greater than those grown in nonmulched soil. These results further indicate that composted pulp and paper sludge could be beneficial as a soil additive.

Celgar Pulp Co. (PGL Organix Ltd., 1996) investigated the use of composting as a disposal option for combined residuals from their effluent treatment plant and fly ash from the power boilers. The combined residuals and ash products were tested for agronomic properties and environmental parameters. A pilot trial for using the combined residual as a soil amendment for landing revegetation was conducted on site. The active windrow composting trial included three windrow piles: (1) combined residual alone, (2) combined residual and inoculum (commercial compost), (3) combined residual, inoculum and fly ash. The composting trial lasted 15 weeks. The addition

of mature compost inoculum accelerated the compost process; however, the fly ash did not provide any benefits to the composting process with the exception of improved macro and micro nutrients. Composting was determined to be an effective method of solid waste reduction as the volume and weight of the combined residual was reduced by over 50%. Odour and other handling concerns were also mitigated through the composting process. The benefits of using the compost as a soil amendment were demonstrated through the reclamation of an old parking site at the Celgar mill.

2.2.2 Wood Ash Land Applications

Forest products facilities burn large quantities of wood residues to produce steam and electricity. Combustion produces fly ash and bottom ash which represents a solid waste disposal problem. This material is alkaline, with a pH in the range of 8-13, and contains many micronutrients and macro nutrients extracted from the soil during tree growth (Campbell, 1990). Literature comparisons among industrial wood ashes are difficult since the moisture content, carbon content and type of ash collected from combustion systems vary significantly depending on the temperature of combustion, the type of fuel and where ash is collected in the combustion system (Campbell, 1990).

Ashes from wood fired boilers have been found to contain only negligible quantities of organic compounds of potential environmental concern including polychlorinated dibenzodioxins and polychlorinated dibenzofurans (PCDDs / PCDFs) (Vance, 1996). Depending on the intensity of combustion, higher than normal levels of PCDD/PCDF may be found in ashes derived from combustion of salt laden wood (Luthe and Prahacs, 1993) or when bleached kraft paper mill sludges containing chlorides are part of the mixture being burned (Someshwar, 1990).

Much research has demonstrated that ash can be beneficial to agricultural and forest land as a liming agent and soil additive. Ash has also been used effectively as a bulking and odour control agent during composting of municipal sewage sludge.

Naylor and Schmidt (1986) evaluated wood ash liming characteristics and macro and micro nutrient availability in soil. Studies were completed in pots in greenhouses with ash added at different rates to two different soil types. After incubating for several months the extractable phosphorus, potassium, and calcium and the pH of the ash were linearly related to the rate of ash application.

Naylor and Schmidt (1989) continued their work with wood ash by applying wood ash to an acidic field soil in amounts varying from 0 to 50 Mg/ha to evaluate the liming value of the wood ash and to assess the availability of nutrients to plants. Ash was applied with a manure spreader and was tilled before seeding alfalfa. The soil responded with pH increases for two years, reducing the lime requirement to zero. The ash substantially improved the availability of exchangeable potassium, calcium and magnesium in the treated soil. The exchangeable iron and aluminum decreased because of the rise in soil pH. It was noted that once adequate fertilization is established in the root zone, the extra fertility imparted by the higher ash concentrations provided little increase in growth. The quality of the alfalfa produced was also improved by the ash additions. All these results suggest that paper mill wood ash can supply agronomically-important amounts of plant micronutrients and macronutrients while serving as an alternative liming material.

Etiegni et al. (1991) evaluated wood ash as an agricultural fertilizer and liming material. Winter wheat and poplar were grown in a greenhouse in different soil types amended with different ash

concentrations. The wood ash was a composite sample of fly ash and bottom ash produced in the University of Idaho wood-fired combustion system. The ash was mixed with each different soil at one of six different levels and placed in plastic pots before being seeded. Seeds were allowed to germinate and grow for 30 days. At ash levels equal to or lower than 2%, no detrimental plant growth effects were observed and the biomass of wheat and the caliper and height of poplar cuttings increased over those grown in control soils. These results suggest that wood ash could be used as a fertilizer containing potassium and a liming agent.

Huang et al. (1992) further documented in a field study that ash from forest products facilities can be used beneficially as a soil amendment and liming agent without adversely affecting crop growth. A combined bottom and fly ash was collected from a 50MW electrical power plant burning chip and bark residue. The material was air dried, weighed and then applied to field plots. The ash contained the major macronutrients: calcium, potassium, aluminum, magnesium and phosphorus. Essential micro-elements included manganese, zinc, copper and boron. The ash had a composition, pH and lime equivalent similar to other wood ash materials described in the literature (Campbell, 1990). Soil pH and available phosphorus increased with each application rate. Wheat growth, available potassium in the soil and protein and heavy metal content of the grain were unaffected by ash over the application rates examined (0, 0.56, 1.12, 1.68, 2.24, 4.48, 8.96, 17.9, and 35.8 Mg/ha). Wood ash appeared to be a safe liming agent and soil amendment when applied at agronomic rates based on fertility needs and chemical composition of the ash.

Greenhouse studies were conducted by Unger and Fernandez (1989) to provide information on soil and seedling response to wood-ash applications. Ash amendments increased pH and exchangeable base cations and decreased extractable aluminum and iron concentrations in all soil materials. Ash

treatments increased seedling foliar potassium and sodium concentrations but had little effect on growth. Treatment with nitrogen-based fertilizers did not improve seedling growth in soils amended with ash. It was concluded from this study that land applications of wood ash would be a viable approach to recycling solid waste.

Krejzl and Scanlon (1996) evaluated the use of pulp and paper mill combined ashes on growth and nutrient uptake by oat and bean in a greenhouse setting. Ash with a calcium carbonate equivalent of 29.1% and a pH of 12.1 was applied at the rates of 0, 30, 40 and 50 dry Mg/ha to silty clay loam soil with a pH of 5.4. Plants grown on ash-amended soil had higher biomass compared to plants grown in lime-amended and control (non-amended) soils. Ash treatments of 30, 40, 50 dry Mg/ha increased bean dry matter yield over the control by 49, 57, and 64% respectively. The ash was as effective as dolomite lime in raising the pH. Ash amended soils contained higher concentrations of phosphorus, sulfur, and boron compared to lime-amended and control (non-amended) soils. Soil zinc, iron, manganese, and copper concentrations decreased as ash application rates increased. Oat and bean plants grown in the ash-amended soil had increased concentrations of potassium, sulfur, and boron and decreased concentrations of manganese and copper compared with plants grown in the non amended control soil. Overall, oat and bean benefited from the increased nutrient availability and soil pH caused by the application of boiler ash.

While the benefits of ashes used as agricultural lime substitutes are relatively certain, forest land application poses unique challenges since ash-induced changes in soil nutrient availability and cycling could alter site productivity in ways that are not always predictable. Boiler ashes should not be viewed as a complete soil amendment but as part of an overall nutrient management strategy.

Some studies have combined wood ash with biosolids compost in an attempt to reduce odors and to increase the liming ability as well as the micro and macronutrient availability from the compost.

Campbell et al. (1997) collected a mixture of fly and bottom ash from a 75MW wood-fired, electrical generating station and combined it with yard waste and a municipal biosolids chip mixture at a rate of 0, 5 or 8% ash. The ash was investigated as a potential amendment for biosolids composting. Special attention was given to maintaining a pH and electrical conductivity (EC) within an acceptable range. The wood ash had little effect on the composting process, but did raise the EC, pH and nutrient content of the compost. The addition of ash also produced a more aesthetically appealing soil product. Tomato plants grew equally well in the wood ash-amended biosolids compost as in control (non-amended) plots. The use of wood ash as a composting amendment was concluded to be potentially beneficial by reducing odours, controlling pH and moisture content and providing a source of nutrients for plant growth. As expected, salt content and pH would need to be carefully monitored in the amended soils.

These studies all indicate the benefits of using pulp and paper sludge as a compost material. Wood ash is proven to provide nutrient qualities and is an effective addition to soil amendment products. However, a number of important questions remain to be addressed. First, research is required to evaluate the degradation of chlorinated organic compounds during composting. This is a particular concern for composts produced at coastal bleached kraft mills. Second, research is also required to determine the long term effect of compost as a soil additive. The compost must be evaluated as a fertilizer to ensure that repeat applications will not complicate soil management strategies due to accumulating nutrients or contaminants. Third, studies are required to evaluate the potential for, and characteristics of leachate produced from sites treated with composted products. Finally, no

research has combined sludge with ash in a 1:1 ratio, nor has the use of coastal ash been investigated. The gaps in the knowledge base concerning sludge/ash composting provide an incentive for further investigation.

2.2.3 Previous Composting Trials at Elk Falls Pulp and Paper

During the summer of 1995, small-scale windrow composting trials were conducted at Elks Falls Pulp and Paper. Three 70-80 m³ piles with three different proportions of sludge, ash and hog fuel were created and then monitored for temperature, pH, moisture content and volume reduction over a six week period. The windrows were mixed twice per week. Samples were collected and tested for a wide variety of complex organics.

The compost was determined to have a high nutrient content, a good particle size for land application and a low residual concentration of biodegradable material. Tests for contaminants including polycyclic aromatic hydrocarbons, monocyclic aromatic hydrocarbons, polychlorinatedbiphenyls and polychlorinated dibenzodioxins and polychlorinated dibenzofurans (PAH, MAH, PCB, PCDD, PCDF) were completed. With the exception of PCDD and PCDF, the contaminant level proved to be lower than the concentrations that would require soil remediation under British Columbia regulations.

Compost regulations in British Columbia are not for pulp and paper mill composts but do provide guidelines. The metals content of the compost was low enough to allow unrestricted distribution. Complex organics are not regulated in the British Columbia Compost regulations. The Ministry of Environment looks to other regulations in determining whether the concentration of PCDD/PCDF are acceptable for land application. The USEPA stipulates that PCDD/PCDF TEQ cannot exceed

50 pg/g if the compost is to be applied to soil (O'Conner, 1995) The Ontario Ministry of Environment has set the TEQ limit at 100 pg/g for applications to soil (O'Conner, 1995). The dioxin content of the compost produced during the 1995 trials ranged from 100-150 pg/g TEQ (Julyan, 1995).

The short study at Elk Falls concluded that a 1:1 sludge to ash ratio could be used to reduce the land requirement for ash disposal. Little difference in nutrient value was observed between this compost and other ratios tested. It was also noted that hog fuel should not be used as a bulking agent as it increased the level of sodium present and did not improve the nutrient quality. Further tests were recommended using the 1:1 sludge:ash ratio and trying different ash sources to reduce the overall dioxin content (Julyan, 1995).

2.3 Dioxins

The only major contaminant of concern in the final compost produced at Elk Falls in 1995 was dioxin (Julyan, 1995). Polychlorinated dibenzodioxins (PCDD) and polychlorinated dibenzofurans (PCDF's) comprise two structurally similar compounds (Figure 4). Either family of compounds can have between one and eight chlorine atoms attached to the parent molecule to create 75 different dioxin and 135 different furan congeners. All dioxins and furans do not have equal toxicity. Only 7 dioxins and 10 furans are highly toxic. These molecules have chlorine atoms attached at the lateral 2,3,7,8 positions. The most toxic congener is 2,3,7,8 tetrachlorodibenzo-p-dioxin (2,3,7,8 TCDD) (Oostdam and Ward, 1995).

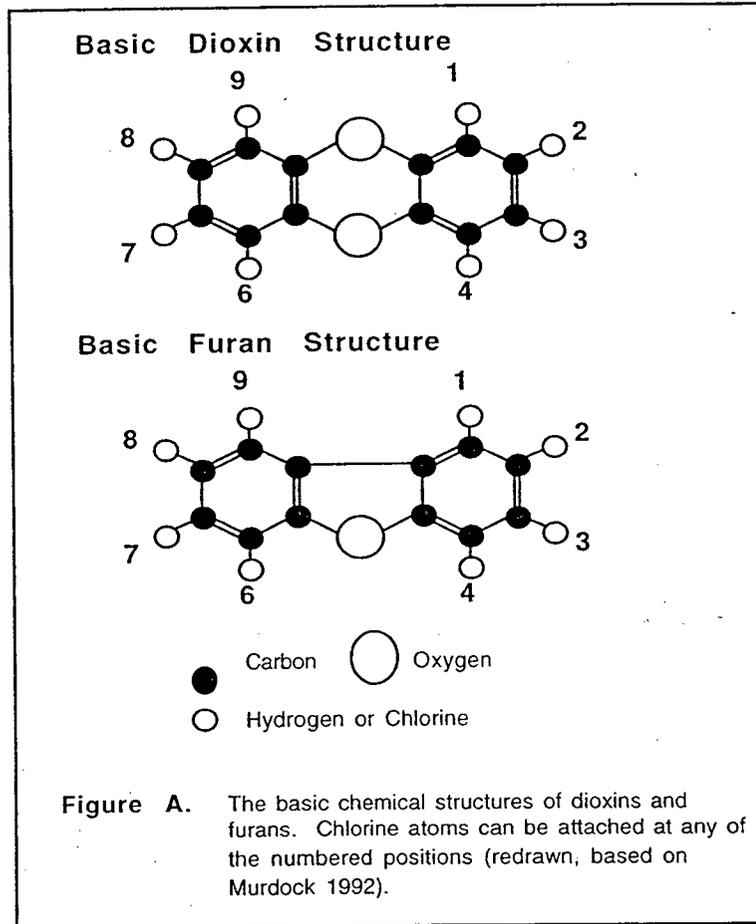


Figure 4. Basic structure of dioxins and furans.

Since food, water, and soil can be contaminated with many different forms of dioxins and furans, a way was needed to quantify the toxicity in a sample with a number of different dioxin congeners present. International Toxicity Equivalency Factors (I-TEFs) have been assigned to the 17 toxic dioxins and furans. The most toxic dioxin, 2,3,7,8-TCDD, is assigned an I-TEF of 1 and the other 16 toxic dioxins and furans are assigned I-TEFs one-half to one thousand times less than that for

2,3,7,8 TCDD (Table 1). The remaining non toxic dioxins and furans are assigned an I-TEF of 0. When dioxin is measured in a sample, the amount of each individual form of dioxin present in the sample is measured. The concentration of each form is multiplied by the toxicity factor for that form to yield a toxic equivalency to TCDD. The individual TEQ are added together to give the total TEQ.

The summary value of 2,3,7,8 TCDD TEQ's will be used throughout this thesis to indicate total dioxins and furans in a sample.

Table 1. International Toxicity Equivalency Factors (I-TEF's)

Congener of Concern	I-TEF
Dioxins	
2,3,7,8 TCDD	1.0
1,2,3,7,8 PeCDD	0.5
1,2,3,4,7,8 HxCDD	0.1
1,2,3,7,8,9 HxCSS	0.1
1,2,3,6,7,8 HxCDD	0.1
1,2,3,4,6,7,8 HpCDD	0.01
Furans	
2,3,7,8 TCDF	0.1
2,3,4,7,8 PeCDF	0.5
1,2,3,4,7,8 PeCDF	0.05
1,2,3,4,7,8 HxCDF	0.1
1,2,3,7,8,9 HxCDF	0.1
1,2,3,6,7,8 HxCDF	0.1
2,3,4,6,7,8 HxCDF	0.1
1,2,3,4,6,7,8 HpCDF	0.01
1,2,3,4,7,8,9 HpCDF	0.01
OCDF	0.001
TCDD/F, PeCDD/F, HxCDD/F, HpCDD/F, OCDD/F indicate tetra- to octa- chlorinated dioxins, furans, respectively	

Chapter 3. Objectives

On the basis of previous research and the initial work done at Fletcher Challenge Canada Ltd. (Julyan, 1995), the following objectives were proposed:

1. To determine the economic and environmental feasibility of composting wastewater treatment sludge with power boiler fly ash in a 1:1 sludge:ash ratio using a static windrow compost process.
2. To determine the effects of different sludge/ash mixtures, mixing frequency and pretreatments on the composting process using small scale reactors.
3. To characterize the leachate produced by the compost for the potential to contaminate surrounding groundwater or well resources.
4. To conduct land application trials of the compost to determine the effects of the material on the soil with special attention directed to the dioxin concentration.

Chapter 4. Materials and Methods

4.1 Materials

To determine the potential end uses of the compost product, it is important to consider the origins of the sludge and wood ash and understand these constituents. For this study wastewater treatment sludge and boiler fly ash were collected from the Elk Falls Pulp and Paper Mill (Campbell River, B.C.) owned and operated by Fletcher Challenge Canada Ltd.

4.1.1 Wastewater Treatment Sludge

The sludge from the wastewater treatment plant is a combination of both primary and secondary sludge. This combination of sludges contains primarily wood fibers and bacteria from secondary treatment. Other constituents include lignin, extractives, lime, organic salts from black liquor spills, bleaching chemicals, polymers, clays and metals. Nutrients added to the secondary treatment system are also found in the sludge (ammonia, sodium polyphosphate).

The sludge was collected over a one week period during a boiler shutdown in early June of 1996. The material was taken from the sludge presses and moved by truck to the old landfill site on the mill property. The material contained 77% moisture at this time.

4.1.2 Boiler Fly Ash

The ash is a product from the combustion of wood and sludge in the power boilers. A variety of complex organic materials can result from the combustion of hog fuel and sludge. Elevated levels of NaCl in hog fuel can result in dioxin and furan formation during combustion (Luthe and Prahacs, 1993).

Ash was collected from the ash silo. Figure 5 gives the schematic for power boiler number 5 at Elk Falls. Grate ash, multiclone ash, and scrubber ash are all collected and transported via conveyor to the ash silo. Grate ash, multiclone ash and electrostatic precipitator ash from power boilers 1-3 are also conveyed to the silo. For this project, the precipitator dust, the finest of all fly ash particles was diverted from the silo in an effort to reduce the dioxin concentration of the ash used for the composting project. The ash is normally sprayed with water for cooling and dust control and was $38.6 \pm 2.4\%$ moisture when moved to the old landfill. Approximately 5 days production (100 truck loads) of ash were moved during the week of June 28-July 4, 1996 (Figure 6).

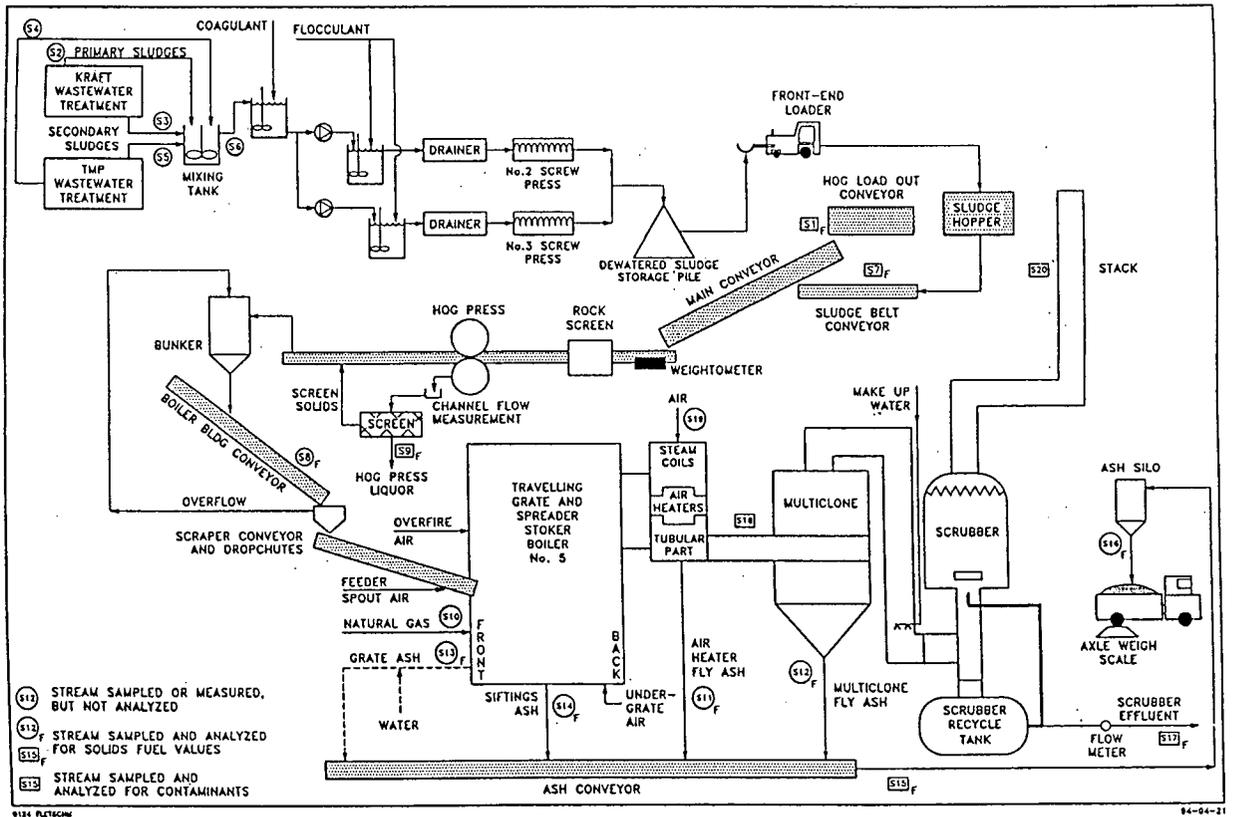


Figure 5. Schematic of power boiler number 5.



Figure 6. Trucking ash to the old landfill.

4.2 Method of Compost Production - Large Scale

The large scale composting study was conducted on the old landfill site at Elk Falls. This site was selected because an existing leachate collection system would ensure that any leachate produced would not pose an environmental hazard. The landfill has 3 distinct layers. The top and middle layers are built on a foundation of waste materials covered by soil. The third and lowest level is a tidal pool separated from Discovery Passage by a dike. The dike has a collection system consisting of several pipes attached to a pumping system which returns all leachate from the landfill to the wastewater treatment system.

The second level of the landfill was equipped with a water source and was leveled by the yard crew for use during this experiment.

Combined primary and secondary sludge and power boiler fly ash were trucked to the site and mixed with a backhoe (Figure 7) and front end loader into triangular windrow piles 50 meters long, 4 meters high and 6 meters wide (Figure 8). One pile was left to compost statically, while the other was mixed with a front-end loader twice a week for the first 3 weeks and once per week for another 7 weeks. Both piles were monitored for another 24 weeks, for a total study period of 34 weeks. The material was then cured for 14 weeks.



Figure 7. Initial mixing of sludge and ash.



Figure 8. Final compost piles.

4.2.1 Dust Control

As the old landfill site is exposed and subject to windy conditions, special efforts were made throughout the trial to maintain the moisture content in the piles at 50%. Wetting was required throughout the summer months for dust control and to replace moisture lost to evaporation. Heavy rainfall beginning at the end of August and continuing throughout the fall hampered efforts to reduce the moisture content during curing.

4.2.2 Mixing

Compost in the turned windrow was rotated between two composting pads. This method was deemed to be the most efficient for ensuring a well mixed pile and also for reducing contractor expenses.

4.3 Method of Compost Production - Small Scale

Small-scale composting studies were conducted to study the effect of: (1) varying sludge:ash ratio (Table 2), (2) frequency of turning (Table 3), (3) various amendments including cellulase enzymes, ligninolytic fungi, chicken manure and hog fuel (Table 4).

For these experiments, small, commercially-marketed backyard composters (The Earth Grower, Norseman Plastics, Buffalo, NY) were used. The composters had external dimensions of 838 mm x 838 mm x 863 mm with a capacity of about 0.3 m³. Aside from two vents which could be opened to increase air flow, these composters provided little means for operator control over the process. Duplicate composters were loaded by volume using 20 liter pails. Except during studies where aeration frequency was an experimental variable, the contents of the composters were manually turned once per week, or whenever the compost temperature exceeded 60°C.

Table 2. Small scale composting - Experiment 1.

Composter	Ratio
1, 2	100 % ash
3, 4	100 % combined sludge
5, 6	1:1 (v/v) sludge:ash
7, 8	2:1 (v/v) sludge:ash

Table 3. Small scale composting - Experiment 2.

Composter	Turning Frequency
9, 10	> 60°C
11, 12	Mon, Wed, Fri
13, 14	Mon, Thur
15, 16	W only
17, 18	no turn

Table 4. Small scale composting - Experiment 3.

Composter	Pretreatment
19, 20	1:1 S:A with Celluclast CCN #1.5L
21, 22	1:1 S:A with <i>T. versicolor</i>
23, 24	1:1:1 S:A:chicken manure
25, 26	1:1:1 S:A: Hog fuel
27, 28	1:1 S:A

The cellulase enzyme Celluclast CCN #1.5L (8 FPU/ml glucanase activity) from Novo Nordisk (Denmark) was added at a loading rate of 0.5 FPU/g dry weight primary sludge. The weight contained in each composter was estimated by weighing several 20 litre pails of sludge and using the average moisture content of $71.5 \pm 0.9\%$. A culture of *T. versicolor* 52J was received from Gary DosSantos of Paprican, Point Claire. The directions for growing the culture are in Appendix 1. An attempt was made to mix the celluclast and fungal (*T. versicolor*) inoculants into the compost. However, difficulties spreading the enzymes and fungi evenly may have limited the effectiveness of these amendments. Chicken manure (%N = 8%, C:N = 6: Gouin et al., 1992) was purchased from Sunshine Acres Poultry in Black Creek, B.C. and mixed with the sludge and ash to create a mixture of 1:1:1 sludge:ash:chicken manure by volume. A single truck load of hog fuel from the mill was dumped at the old landfill and added volumetrically in a 1:1:1 ratio with sludge and ash in composters 25,26.

4.4 Compost Monitoring

A number of parameters were determined to monitor the progress of the composting process and the quality of the final product.

4.4.1 Temperature

The temperature of the large scale compost piles was measured three days per week between 10am-1pm. A 72" thermometer was used, allowing temperature to be measured deep within the pile. The average temperature from measurements taken at 18 different locations along each windrow at various depths was reported to try to gain an accurate representation of the pile temperature. Effort was made to take temperature readings during the mixing cycle to ensure that temperatures in the centre of the piles could be determined.

For the small reactors, the temperature was measured in the center and at two points along the edge of the buckets. The three values were averaged to provide a representative temperature for the composter. The 72" thermometer was used to evaluate the core temperature, while a 12" thermometer was used to evaluate the temperature along the edge of each reactor. Temperature was monitored Monday, Wednesday and Friday in these reactors.

4.4.2 Sample Collection

Samples were collected from the compost piles for analysis. The large scale compost piles were divided into two sections for sampling. Six points were randomly selected in each subsection to provide twelve sample points per pile. Samples (approximately 500 cm³) were taken from depths ranging from 60 cm to 2 m. The twelve grab samples were mixed in a 20 liter pail to

form a single composite sample from each pile for analysis. The pails were sealed, labeled and returned to the Elk Falls Pulp and Paper mill laboratory.

Once in the lab, 1 kg of each composite sample was packaged in ziploc bags, sealed, labeled and then frozen (-20°C) for future transportation to the University of British Columbia Pulp and Paper Center. Samples (1kg each) were sent by overnight courier to one of the several analytical companies used during the study. The remaining material was immediately used for on site tests (MC, pH).

Samples were analyzed for polychlorinated dibenzodioxins and dibenzofurans, polyaromatic hydrocarbons (PAH), chlorophenols, and organochlorines (PCB) by AXYS Analytical Services Ltd. (Sidney, B.C.). Econotech Services Ltd. (New Westminster, B.C.) analyzed the samples for total metals, salinity (EC), chloride, fluoride, total organic carbon (TOC), total nitrogen, and the carbon:nitrogen (C:N) ratio. Pacific Soil Analyses Ltd. (Vancouver, B.C.) performed assays for basic agronomic properties including available nutrients, C:N ratio, and organic matter.

Samples were also collected from the small reactors. Samples were collected from various depths in each bucket, mixed together and then sealed and labeled in small ziploc bags. A portion of the samples were tested immediately onsite (MC, pH), while 1 kg samples were frozen for transport to the University of British Columbia Pulp and Paper Center.

4.4.3 C:N Ratio

Changes in the C:N ratio can help an operator to monitor activity in a compost pile and to ensure that the process is progressing in an acceptable fashion. Final C:N ratio is also an important

measurement of compost quality as described in section 2.1.3.2. The C:N ratio was measured at the University of British Columbia for both the large scale composters. The percent carbon was estimated from the percent ash determined by placing dried triplicate samples in a furnace at 550°C for 4 hours and measuring the percent ash gravimetrically. (SM 2540B,E) (Eaton et al., 1995). The carbon content was estimated to be approximately : $\%C = (100 - \%ash) / 1.8$ (Gouin et al, 1992). Analyses for the percent nitrogen were performed using the FP-228 Nitrogen Determinator-Model 601-700 (Leco Corporation, Mississauga, Ontario). Triplicate samples (0.1-0.2 g) were combusted in pure oxygen at a temperature of 950°C with the resulting combustion gases collected in a ballast volume. The sample gas was then carried (Helium carrier at rate of 400 cc/min) through a reagent train (MgClO₄, NaOH, Cu, N, Fe) and measured by a thermal conductivity detector. The raw results were displayed and corrected for weight, blank, and calibration. The final results were corrected for moisture content. For the small composters, only the percent nitrogen was reported.

4.4.4 Moisture Content

The moisture content was measured once per week for both the large piles and the small bucket composters. This was done according to the method described by Gouin et al. (1992). The compost was placed in crucibles and dried for 24 hours in an oven at 105°C. The moisture content was determined gravimetrically.

4.4.5 pH

The pH of each compost pile and the contents of the small composters was also determined weekly. To measure pH, the compost was mixed with water in a 1:10 ratio by weight. The

material was stirred intermittently for 1/2 hour and then allowed to settle for 1 hour prior to measuring the pH of the supernatant (Brady, 1990).

4.4.6 Stability Test

The stability of the large scale windrow compost was tested qualitatively by thoroughly saturating the compost with water in a bag and sealing the bag. After 5 days at room temperature, the bags were opened and the odours were evaluated. Strong anaerobic smells (reduced sulphur compounds) indicated that the material was insufficiently stabilized (PGL Organix Ltd., 1996).

4.5 Leachate Production

The compost samples used in the leachate study were collected and transported from Elk Falls Pulp and Paper to U.B.C. on February 17th, 1997 using the sampling methods described in section 4.4. These samples were stored overnight in sealed 20 litre pails at 4°C in the Civil Engineering Laboratory. The leachate procedure was initiated on February 18, 1997.

4.5.1 Leachate Procedure

From the wide range of available leachate extraction procedures, the agitated extraction test from BC Environment's Leachate Extraction Procedure (B.C. Ministry of Environment, 1988) was used to produce the leachate for analysis. This method was selected because it is the most commonly used test in this region, it is very rigorous, the required equipment is available in the Civil Engineering Environmental Lab, and the procedure is relatively simple. In selecting a rigorous test for this project, it was anticipated that the estimate of concentration of pollutants in

the leachate would be conservative (i.e. overestimated) and the results would have a quantifiable level of certainty.

The leachate procedure (equipment and methods) is detailed in Appendix 1. However, the following changes were made to the procedure:

1. The procedure specified the use of 1250 ml bottles. The equipment available in the laboratory would not hold 1250 ml bottles. The procedure was adjusted by using 1000 ml plastic bottles for metals and anions and 500 ml amber glass bottles for organic compounds. The volumes and weights of sample and reagents used throughout the procedure were adjusted accordingly.
2. The Separation Procedure was deemed unnecessary as the sample was considered to be a dry solid (i.e. not a slurry).
3. The amount of compost material added was doubled (i.e. equivalent of 100 g dry weight) in an attempt to ensure that the analyte concentrations would not be below detection limits for various analyses. This required that the final results be halved to determine the concentration of each analyte according to the leachate procedure.
4. The leachate was filtered without the need for centrifuging.
5. The leachate was stored in the refrigerator at 4°C after being properly preserved according to Standard Methods (Eaton et al., 1995) for each of the analytes.
6. The Structural Integrity Procedure (section 6) was not required for the experiment.

4.5.2 Leachate Analysis

The following analytes were chosen based on the previous work by Julyan (1995) using similar compost: (1) metals (Cu, Pb, Na, Zn), (2) anions (NO_3^{-1} , total-P, SO_4^{-2}), (3) organic compounds (naphthalene, pyrene, phenanthrene), (4) electrical conductivity.

4.5.2.1 Metals

Copper, zinc, and sodium were analyzed using flame atomic absorption spectrometry following Standard Method (SM) 3111 (Eaton et al., 1995). Analyses were performed on a Video 2e Atomic Absorption Spectrophotometer. An air-acetylene flame (10 cm length) was used with a bandpath length of 1 nm. Hollow cathode lamps were the light source and measurements were made at wavelengths of 324.7, 213.9 and 589.0 nm for copper, zinc and sodium, respectively. Due to the expected low concentrations of lead, electrothermal atomic absorption (graphite furnace) following SM 3113 (Eaton et al., 1995) was employed. A Perkin Elmer Zeeman Atomic Absorption Spectrophotometer 4100ZL was used at a wavelength of 217.0 nm.

All metals were tested using the undiluted compost leachate, except for sodium which required a 1:100 dilution. Both atomic absorption instruments were programmed to test each sample 5 times for 3 seconds each. The average of these five readings was reported by the instrument with the standard deviation. To calculate the error bounds, the standard deviations for all samples were averaged. The programming of the graphite furnace atomic absorption instrument enabled analysis of possible matrix (background) effects in the lead samples by calculating the recovery of a surrogate compound after the analysis. A recovery near 100% indicates negligible matrix effects.

4.5.2.2 Anions

The leachate was characterized for nutritional value (eutrophication potential) by analyzing for nitrate (NO_3^{-1}), total phosphorus, and sulfate (SO_4^{-2}).

These anions were measured using flow injection analysis (FIA) following the Quikchem Method No. 10-115-01-1Z for NO_3^{-1} , 10-107-04-1-E for Total-P, and 10-116-10-1C for SO_4^{-2} (QuikChem, 1990). Nitrate and sulphate were assayed directly while a digestion process was required to convert all forms of phosphorous to ortho-phosphate prior to analysis (QuikChem, 1990).

4.5.2.3 Organic Compounds

Three PAH's were selected based on previous study of the solid compost material (Julyan, 1995). Analyses were made for naphthalene, pyrene, and phenanthrene by gas chromatography/mass spectrometry (GC/MS) according to SM 6210 (Eaton et al., 1995). Analyses were performed using a HP 6890 with a mass selective detector HP 5973. The extraction of these PAH's was completed using C18 solid phase extraction cartridges (Appendix 1) (Tekmar-Dohrmann, 1996). This method is not outlined in Standard Methods, but solid phase extraction has been used successfully for PAH's by Potter and Pawllszyn (1994) and Junk and Richard (1988).

4.5.2.4 Electrical Conductivity

Soluble salts content of the leachate were also measured to assess the potential for salt accumulation in soils due to compost addition. The soluble salt content was measured using the electrical conductivity (EC) technique according to SM 2520 (Eaton et al., 1995).

4.6 Land Application Trials Using Composted Material

Approximately 700 yards of the final composted material produced was supplied to a local sod farm in the Comox Valley. Soils in the valley are known to need both lime and other fertilizer

applications. Sod farmers also incur a loss of soil during every harvest and are therefore interested in sources of low cost soil material.

Four one acre (0.4 ha) test plots, were constructed to test the compost. Two plots were left as control plots. One control received no amendment, while the other received the normal application of 8 yards/acre of fish compost. The two other plots received 8 yards/acre (15m³/ha) of the compost in addition to the fish compost. These plots were evaluated qualitatively for growth by the owner. Samples were collected following Norwest Labs (Langley, B.C.) methodology. This method specifies that subsamples from 10 locations in each test plot be collected from a depth of 6 to 7 inches using a garden trowel and placed in a sample pail. The sample must then be mixed thoroughly. Following mixing, samples were placed into ziploc bags, labeled, sealed and sent by overnight courier to the analytical companies for analysis for dioxin/furans and soil quality (P, K, Ca, Mg, Mn, B, Na, Al, N, S).

This sod farm operated 7 fields as well as a nursery. Once the initial results from the test plots were received, additions of the compost was made on several of the fields. A total of 500 yards of material was used by the farm.

Chapter 5. Results and Discussion

5.1 Characteristics of the Raw Materials

Both sludge and fly ash have properties which, when combined with each other, serve to promote active composting (Table 5). The combined wastewater treatment sludge has three properties essential to a soil amendment. It has a neutral pH, a high concentration of total nitrogen and an acceptable C:N ratio of 16 (Target - 25) (Hoitink et al., 1991). Moisture content of the sludge (77%) was well above the optimal level.

Table 5. Physical characteristics of sludge and fly ash.

		Raw Materials		Raw Compost
		sludge*	ash	1:1 S:A
MC	%	77.1	41.0	53.4
pH		6.7	9.0	8.9
soluble salts (EC)	dS/m	39.2	25.5	16.0
ash	%	6.5	68.0	68.9
C:N		16.1	167.0	70.1
carbon	%	47.8	35.1	35.1
nitrogen	%	2.9	0.2	0.5
*sludge results taken from Julyan, 1995				

The addition of fly ash to a compost mixture has several benefits. The addition of fly ash helps to achieve a targeted solids content (50%) in the compost mixture (Hoitink et al., 1991; Golueke and Diaz, 1990). Ash prevents clumping, which improves porosity and airflow throughout the compost pile. The fly ash also adds many macro and micronutrients to the compost mixture. Negative aspects associated with the addition of fly ash from coastal mills include high EC and dioxin concentrations. In general, fly ash contains a high C:N ratio. These qualities all necessitate monitoring throughout the composting process.

5.1.1 PAH, Organochlorines, Phenolics

The raw compost material meets the criteria for Agricultural Land under the BC Contaminated Sites regulations for all PAH, organochlorines, and phenolic compounds with the exception of naphthalene and phenanthrene (Table 6). However, it is important to note that the regulations do not regulate the level of such compounds in the compost itself, but rather those in the final soil/compost mixture. Addition to the soil would likely reduce the levels of naphthalene and phenanthrene to levels below the agricultural limits.

5.1.2 Dioxins

Under normal operating conditions, the ash contained in the silo (combined precipitator, scrubber, multiclone, grate) had a dioxin concentration of 170.9 pg/g TEQ (Table 7). Based on previous work (Julyan, 1995), it was determined that the fly ash collected in the precipitator contained the highest concentration of dioxin (Table 7). With the fine dust from the precipitator diverted during the experimental period, the dioxin concentration of the silo ash was reduced to approximately 135.5 ± 21.8 pg/g TEQ. The sludge had an initial concentration of 28.0 ± 9.1 pg/g TEQ. It was therefore expected that the initial mixtures of 1:1 sludge:ash would have a dioxin concentration of 81.8 ± 15.5 pg/g TEQ.

Table 6. Regulated compound concentrations in the raw compost mixture (ug/g).

Contaminant	BC Reg 375/96	Raw Compost
	AL	
PAH		
benzo[a]anthracene	0.1	0.0084-0.0150
benzo[a]pyrene	0.1	0.0045-0.0080
benzo[b]fluoranthene	0.1	0.0045-0.0150
benzo[k]fluoranthene	0.1	0.0045-0.0150
dibenz[a,h]anthracene	0.1	ND-0.0047
indeno[1,2,3-c,d]pyrene	0.1	0.0044-0.0077
Napthalene	0.1	0.4200-0.9100
Phenanthrene	0.1	0.1200-0.210
pyrene	0.1	0.0560-0.099
Organochlorines		
1,2-dichlorobenzene	0.1	0.0030-0.035
1,3-dichlorobenzene	0.1	0.0020-0.0021
1,4-dichlorobenzene	0.1	0.0036-0.0040
1,3,5 trichlorobenzene	0.1	0.00094-0.0011
1,2,4 trichlorobenzene	0.1	0.0049-0.0053
1,2,3 trichlorobenzene	0.1	0.0014-0.0015
1,2,3,5/1,2,4,5 tetrachlorobenzene	0.1	0.0036-0.0039
1,2,3,4 tetrachlorobenzene	0.1	0.0013-0.0014
pentachlorobenzene	0.1	0.0019-0.0020
hexachlorobenzene	0.05	0.00043-0.00052
Phenolics		
ortho-chlorophenol	0.05	0.0064-0.0089
2,6 dichlorophenol	0.05	0.0022-0.0023
2,5 dichlorophenol	0.05	0.0063-0.014
2,4 dichlorophenol	0.05	0.0063-0.014
3,5 dichlorophenol	0.05	ND
2,3 dichlorophenol	0.05	ND
3,4 dichlorophenol	0.05	ND
2,4,6 trichlorophenol	0.05	0.047-0.048
2,3,6 trichlorophenol	0.05	ND
2,4,5 trichlorophenol	0.05	ND-0.00044
2,3,5 trichlorophenol	0.05	ND
2,3,4 trichlorophenol	0.05	ND
3,4,5 trichlorophenol	0.05	ND
2,3,5,6 tetrachlorophenol	0.05	ND
2,3,4,5 tetrachlorophenol	0.05	ND
2,3,4,6 tetrachlorophenol	0.05	0.0048-0.0050

Table 7. Dioxin content of raw materials.

Sample	2,3,7,8 TCDD TEQ (pg/g)
Precipitator (ash)	2026.0
Cinder Pond (ash)	1820.8
Multiclone (ash)	78.3
Silo Ash (normal operation)	170.9
Sludge	28.0 ± 9.1
Silo Ash (during experiment)	135.5 ± 21.8

5.2 Physical Changes Throughout the Composting Process - Large Scale Composting

Temperature, moisture content, pH and C:N ratio were measured to monitor the physical changes during the composting study period.

5.2.1 Temperature of the Compost Piles During the Study Period

The initial compost temperatures were observed to be approximately $57.1 \pm 4.2^\circ\text{C}$ (Figure 9). These high temperatures were observed because the biologically active sludge had been stockpiled for one week prior to the combining with ash and the exothermic degradation process had already begun. Composting above 55°C for 15 days is necessary to ensure weed and pathogen destruction (BC REG 334/93). Temperatures between 45 and 60°C promote the growth of a wide range of thermophilic and mesophilic organisms necessary for biological degradation (Julyan, 1995). Pile temperatures remained in this ideal range between week 1-10 and 1-15 for the turned and static windrows, respectively. The temperature profile in the two piles was similar; however, the static windrow maintained a temperature $11 \pm 1.2^\circ\text{C}$ above the turned windrow during the process.

The piles remained at elevated temperatures for much longer than expected. It was estimated based on previous work (Campbell et al, 1995) that the piles would return to ambient

temperature after 10-14 weeks; however the piles did not return to ambient temperature until the 34th week. One possible explanation for this is that the piles were large enough to provide themselves with an insulating layer. Temperature samples taken from the outside edges of the piles did indicate that the edges had cooled (data not shown). A second possibility is that the piles were nitrogen limited. This possibility is discussed in section 5.4.3.

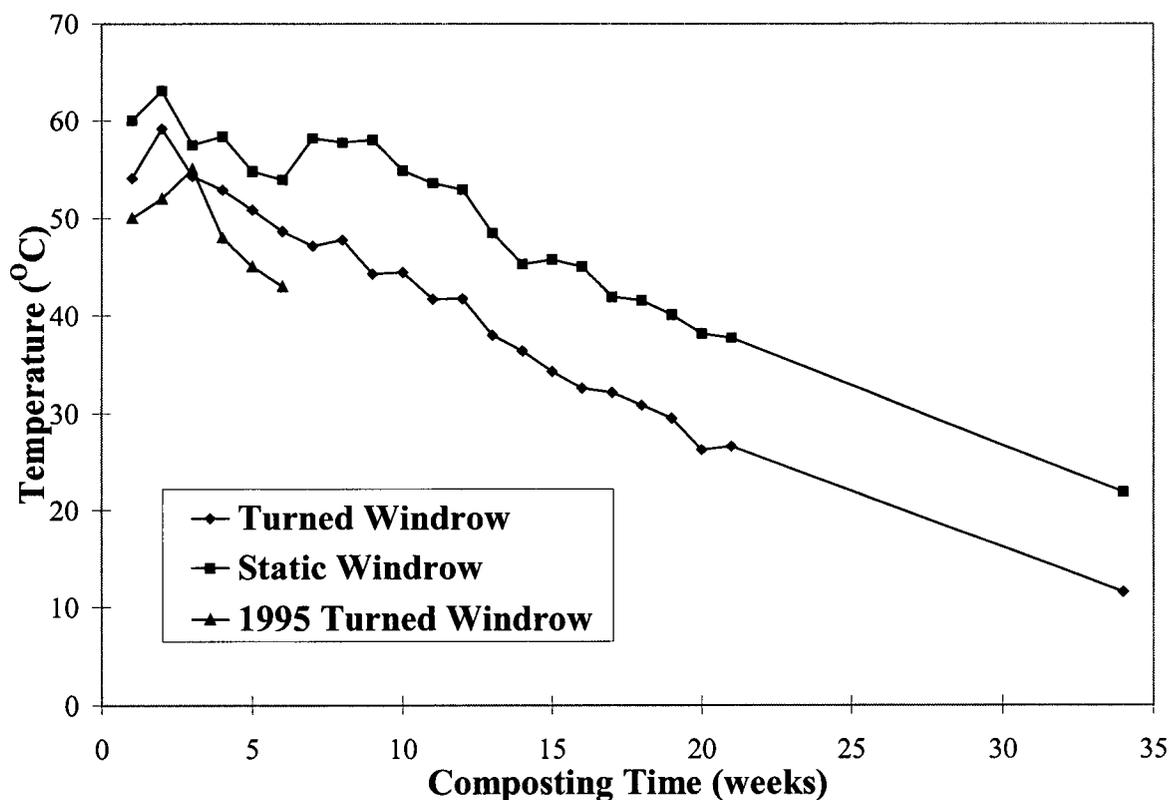


Figure 9. Temperature of the compost piles over the period of study.

While not examined as part of this work, a number of strategies could be employed to possibly reduce the duration of the active composting period: (1) more complete mixing with a windrow turner, (2) turning the piles more often, (3) reducing pile size to allow better aeration, and (4) installing of perforated pipes for forced aeration and better air distribution.

The static pile was expected to become anaerobic as the available oxygen was consumed by microorganisms (Gouin et al., 1992). Since oxygen concentration was not measured, there is no direct evidence that anaerobic conditions existed in the piles. Observation of a sharp decrease in temperature usually indicates the onset of anaerobic conditions (section 2.1.3.1). Such a decrease was not observed during this study. It is possible that the process was proceeding very slowly due to other limiting factors and that the oxygen did not become rate limiting. The size of the piles may also have insulated the pile and thus prevented the temperature at the centre of the piles from decreasing. This insulating capability could be advantageous if composting throughout the winter months in a harsh climate.

A comparison can be made between the current work and the compost temperature profile from the 1995 compost trials (Figure 9). The piles in the 1995 experiments were 30 m long, 3 m wide and 2 m high. They were mixed twice per week or whenever the temperature went above 60°C (Julyan, 1995). The temperature profile during composting of 1:1 sludge:ash was similar for both studies; however, the temperature of the smaller piles used in the previous study was approximately 2.5 ± 4.4 °C cooler throughout the 6 week monitoring period of that study. This comparison suggests that smaller piles mixed more frequently may stabilize more quickly, although the cost of constant mixing and the land required for the smaller piles may offset those advantages.

5.2.2 Moisture Content of the Compost During the Study Period

Moisture content should be maintained above 50% to ensure optimal microbial activity (Gouin et al., 1992). Moisture content in both piles was maintained at $51 \pm 2.4\%$ for the first 10 weeks of

the composting process (Figure 10). Heavy rainfall during the latter half of the composting period increased the moisture content to $63 \pm 1.5\%$ in the final product.

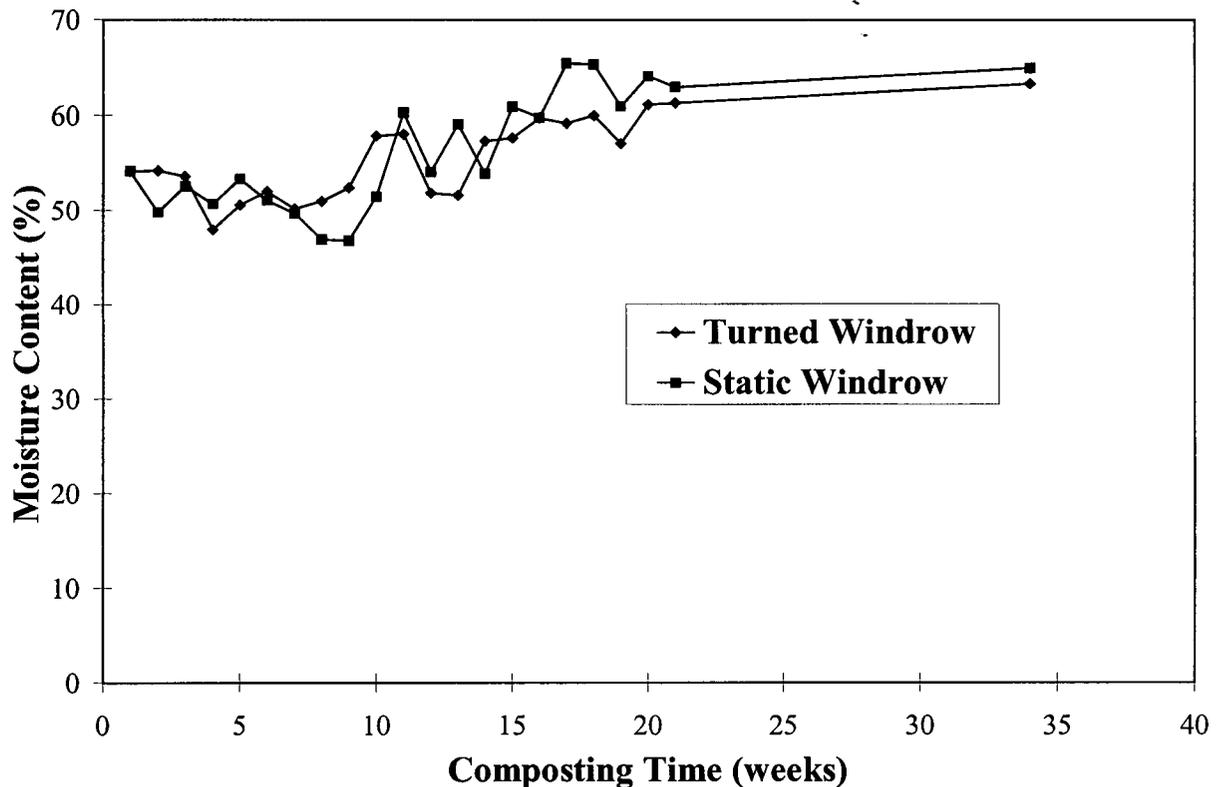


Figure 10. Moisture content of the compost piles over the period of study.

It was expected that the moisture content would decrease throughout the process as high temperatures in the pile would cause the evaporation of moisture from the compost. However, the need to water the piles during the summer months for dust control, and the unusually heavy rain fall which began during week 10 of the study, caused the moisture content to increase as the process continued. The increase in moisture content is a concern because it would significantly increase the cost of transport of the material and the amount of leachate produced by the composting process.

A lower moisture content (30-40%) is preferred for a final compost product to help reduce hauling costs. In order to reduce moisture content, the curing phase of the compost could be completed under cover. This is especially important on the west coast where there is a lot of rainfall throughout the year. As has been previously suggested, it is advisable to schedule the composting process so that the curing phase would be nearing completion in late August before the onset of seasonal rainfall (Wysong, 1976). The final product could then be covered before being transported.

5.2.3 Compost pH During the Study Period

The pH of the compost mixture was approximately 8.9 ± 0.2 throughout the composting process (Figure 11).

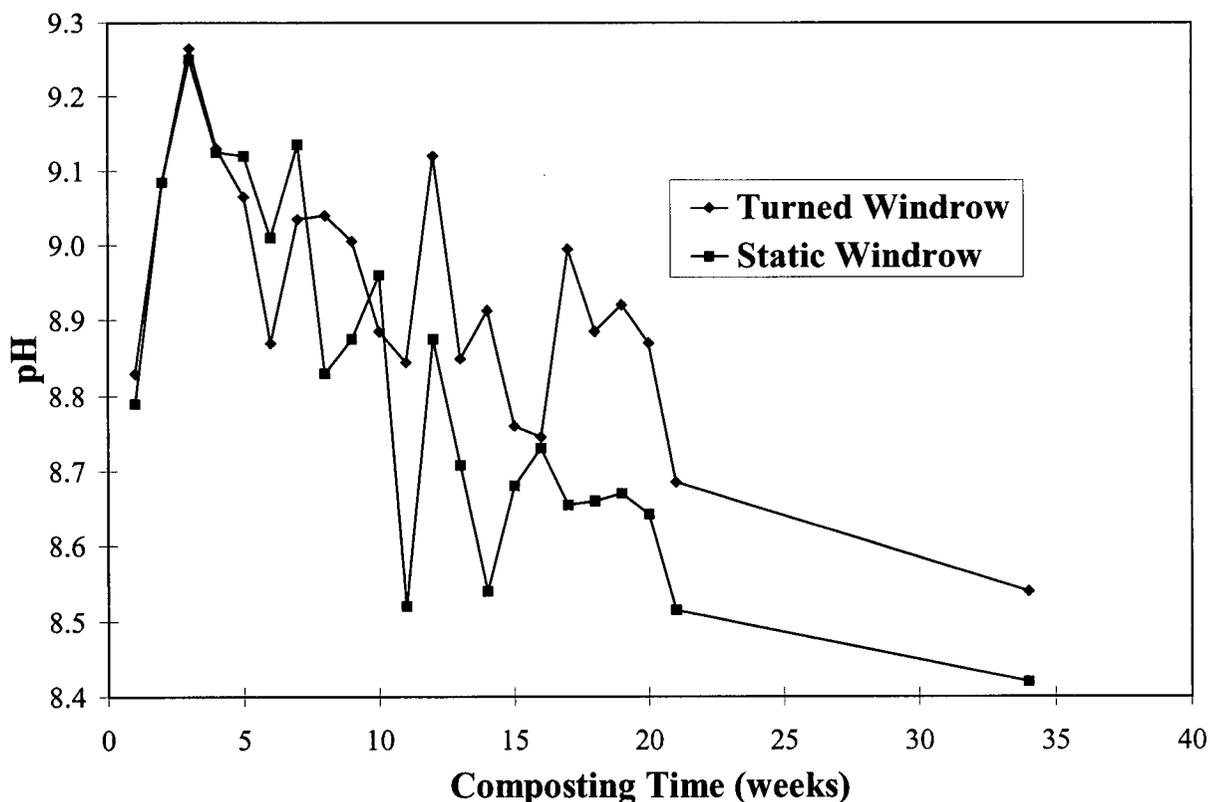


Figure 11. pH of the compost piles over the period of study

The final compost pH was approximately 8.5 ± 0.1 for both piles, slightly higher than the recommended value of 5-8 for municipal compost products (BC REG 334/93). This concern is mitigated by the fact that this particular compost would be used as a liming agent on acidic soils commonly found in the Comox Valley area.

5.2.4 C:N Ratio During the Composting Study

The initial C:N ratio of 70:1 decreased over the composting period to 46:1 and 40:1 in the turned and static windrows, respectively (Figure 12).

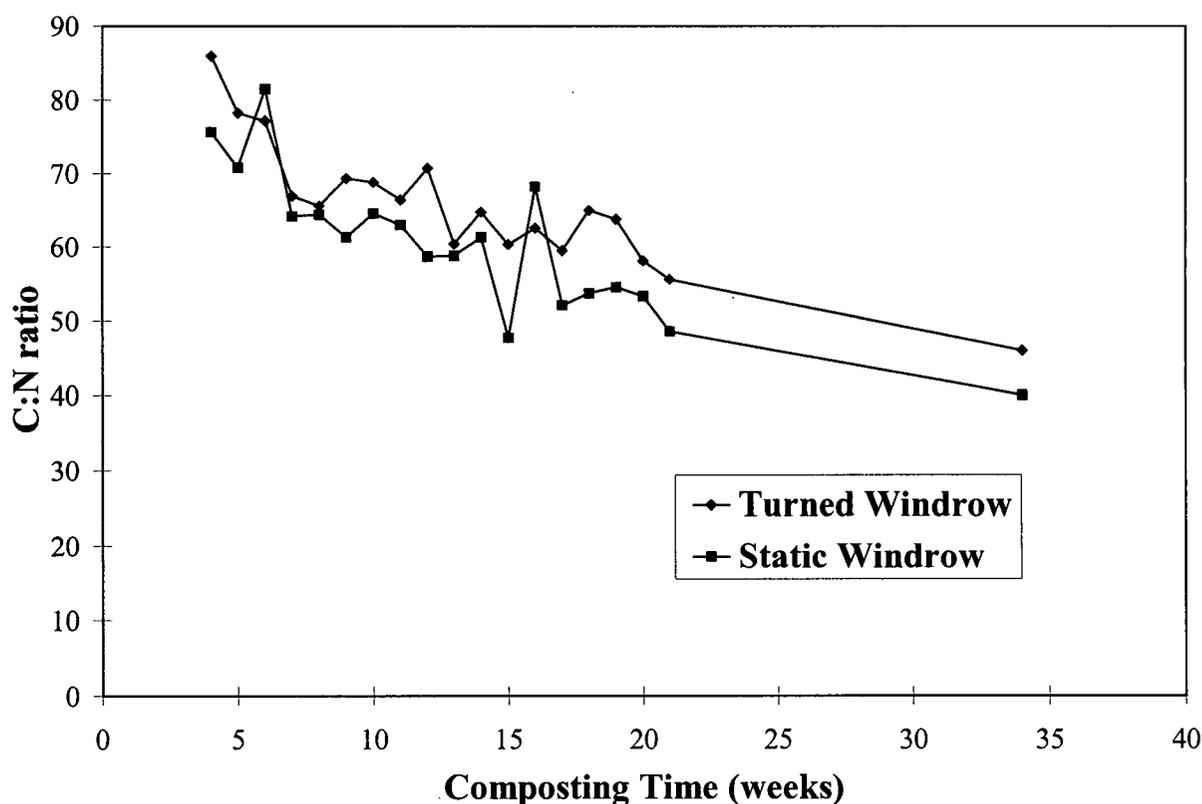


Figure 12. C:N ratio of the compost piles over the period of study.

That the initial C:N ratio was higher than the ideal value of 25:1 (Golueke and Diaz, 1990) likely extended the time required to stabilize the sludge/ash mixture. The addition of a nitrogen-containing waste such as manure would likely reduce the composting time required and make the final product a more effective soil amendment (see section 5.4.3).

5.3 Chemical Characteristics of the Compost Products

The quality of the compost produced during this study was determined by comparing it to regulations contained within the Waste Management Act of British Columbia: (1) B.C. Reg. 334/93, Production and Use of Compost Regulation (BCMOE, 1993), and (2) B.C. Reg. 375/96, Contaminated Sites Regulation (BCMOE, 1996). The former regulation places limits on: (1) foreign matter content, (2) heavy metal concentration, (3) pH, and (4) compost maturity. The latter regulation stipulates criteria for a wide range of parameters in the final soil/compost mixture.

B.C. Reg. 334/93 specifies the following parameters:

1. Foreign matter by dry weight (organic and inorganic constituents such as glass, metal, plastic, rubber, bones, and leather which are not readily decomposed) must be classified within one of the following categories: (i) $\leq 1\%$ (ii) $>1\%$ but $\leq 2\%$ (iii) $>2\%$ but $\leq 10\%$
2. Heavy metal concentrations in the compost determine the appropriate usage classification code (Table 8). If any one parameter falls in a higher concentration grouping, the code for that higher grouping will apply to the compost.

Table 8. Heavy metal concentrations of compost.

Heavy Metals	Codes				units
	1	2	3	4	
Arsenic	≤13	13-30	30-50	>50	mg/kg
Cadmium	≤2.6	2.6-5	5-20	>20	mg/kg
Chromium	≤210	210-250	250-800	>800	mg/kg
Cobalt	≤26	26-50	50-300	>300	mg/kg
Copper	≤100	100	100-500	>500	mg/kg
Lead	≤150	150-500	500-1000	>1000	mg/kg
Mercury	≤0.8	0.8-2	2-10	>10	mg/kg
Molybdenum	≤5	5-10	10-40	>40	mg/kg
Nickel	≤50	50-100	100-500	>500	mg/kg
Selenium	≤2	2.6-3	3-10	>10	mg/kg
Zinc	≤315	315-500	500-1500	>1500	mg/kg

3. The pH range must be between 5.0 - 8.0.
4. The material must be mature. It must be highly stabilized, have been exposed to a long period of decomposition, be brown to black in color and
 - (a) not reheat to greater than 20 degrees above ambient temperature, or
 - (b) have shown a reduction of organic matter of greater than 60 wt %.

From these three criteria the compost can be assigned a grade according to the B.C. Reg 334/93. The Elk Falls compost contains <1% foreign matter, the pH was 8.5 ± 0.1 and heavy metals levels were all within code 1 (Table 9). Ignoring the pH, the compost would have classified as Type A. This material has unrestricted distribution and may be applied on agricultural lands, in home gardens, horticultural operations, parks, the nursery industry and other business requiring a high quality product. However, based on other criteria such as dioxin and salinity not included in these regulations, the compost is more suitable for use as Type B. Type B can be applied to forest land, parks and used in non-food applications in the horticultural nursery industry and land

reclamation projects. The compost pH is above 8.0, violating BC Regulation 334/93. However, with proper management the compost could be used as a liming agent. Soils in the Campbell River/Comox Valley region are acidic and require lime applications (Table 15).

Table 9. Total elemental metal concentrations of compost.

		Regulation**	Raw Compost	Final Compost	
			1:1 S:A	Turned Windrow	Static Windrow
antimony	mg/kg	20	<2	<2	<2
arsenic	mg/kg	13	<2	<2	3.5
barium	mg/kg	750	144	190	196.5
beryllium	mg/kg	4	<0.2	0.2	0.2
cadmium	mg/kg	2.6	0.5	0.4	0.06
chromium	mg/kg	210	16.3	32.5	28.6
cobalt	mg/kg	26	4.7	6.3	5.6
copper	mg/kg	100	31.5	35.8	34.8
fluoride	mg/kg	200	130	NM	NM
lead	mg/kg	150	3	2	5.5
mercury	mg/kg	0.8	0.23	0.09	0.07
molybdenum	mg/kg	5	3	2	2
nickel	mg/kg	50	14.9	18.1	17.7
selenium	mg/kg	2	<2	<2	<2
silver	mg/kg	20	<0.5	<0.5	<0.5
tin	mg/kg	5	<1	<2	<2
vanadium	mg/kg	200	30	44	40.8
zinc	mg/kg	315	61.4	56.7	64.5

**Strictest regulations - BC Reg 375/96, BC Reg 334/93 *NM – Not measured

According to BC Reg 375/96, the mixture of compost and soil must be below the regulated level for the soil to qualify as agricultural. The results presented in Table 9 indicate that the compost itself is below these levels. Table 9 also indicates that the concentration of metals in the compost increases during the composting process. This is due to the digestion of organic matter during the process.

In both composting processes the concentration of dioxin decreased from 74.9 ± 4.9 pg/g TEQ to 41.3 ± 3.5 pg/g TEQ during the first 8 weeks of the process (Figure 13). Further decreases in the dioxin concentration were not noted for the rest of the composting period or during the curing stages. The BC Ministry of Environment does not have blanket regulations regarding the application of solid wastes to soil. Comparison with regulations outside the province of B.C. is useful for characterizing the levels of dioxin and furan in the compost produced at Elk Falls. Under USEPA regulations, waste material with a dioxin concentration less than 50 pg/g can be applied to land (O'Conner, 1995). The Ontario Ministry of Environment has an allowable land application limit of 100 pg/g TEQ (O'Conner, 1995). These levels of dioxin make it necessary to establish a monitoring program for dioxin if the material is applied to agricultural land. To meet the BC criteria for agricultural land, the addition of material containing dioxin must be carefully monitored so that the dioxin concentration in the final soil/compost mixture is kept below 10 pg/g TEQ.

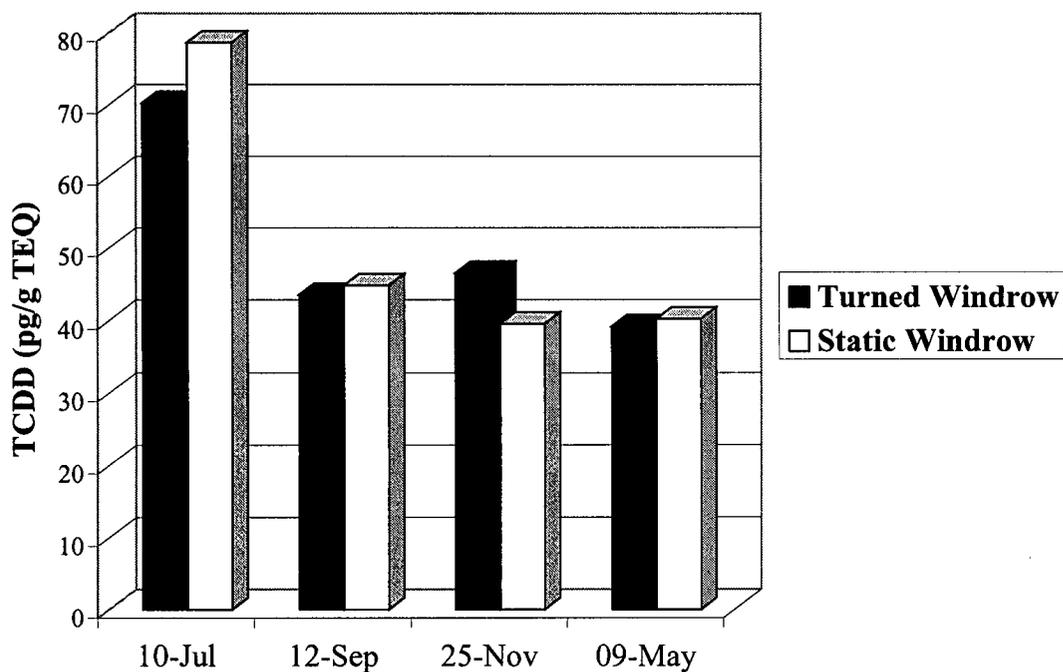


Figure 13. Dioxin concentration of compost over time.

Most nutrients in the composted material were above the target values for a healthy soil supporting plant growth (Table 10). Like all fertilizers, the compost could serve to amend the levels of certain nutrients in nutrient deficient soils. It would be necessary to evaluate soils prior to compost application to determine proper application rates and to determine if other amendments were necessary.

Table 10. Available nutrients in the compost.

		Soil Targets	Final Compost	
			Turned Windrow	Static Windrow
phosphorus	ppm	150	119	100
potassium	ppm	250	970	870
calcium	ppm	2000	3000	3500
magnesium	ppm	250	550	540
copper	ppm	10	0.6	0.6
zinc	ppm	25	16.2	10.6
iron	ppm	150	3	3
manganese	ppm	50	315	205
boron	ppm	1	4.2	4.4
sulfate-sulfur	ppm	25	12.6	10.7
sodium	ppm	50	1300	810
aluminum	ppm	10	150	70
total nitrogen	%	0.550	0.63	0.55
organic matter	%	10	57.8	63.1
total sulfur	%	0.05	0.32	0.14

5.4 Small Scale Compost Trials

The small composting experiments provided a method to examine the impact of some operating parameters which were difficult to manipulate during the large scale composting experiments.

5.4.1 Effect of Varying Sludge to Ash Ratios

The results from the small composters (1,2) indicated that ash on its own does not degrade appreciably, although a brief initial rise in temperature was observed (Figure 14). Possible

reasons for the lack of activity include: (1) lack of a viable population of microorganisms, (2) low moisture content, (3) severe N-limitation, and (4) carbon in a non-biodegradable form. The lack of degradation of ash does not mean that ash is not partially degraded during combined sludge:ash reactions. The temperature profile observed during composting of sludge alone was similar to that observed for sludge/ash mixtures. While this indicates that little degradation of ash occurred, no direct measurements were made which would support this hypothesis.

Table 11. Initial and final pH, MC, %N of composters (1-8).

Composter #	ash only	sludge only	2:1 S:A	1:1 S:A
PH				
Initial	9.27	9.23	8.85	8.85
Final	9.32	8.68	8.22	8.37
Moisture Content				
Initial	40.27	71.54	54.73	56.24
Final	36.98	60.25	53.92	48.83
%N				
Final	0.15	2.14	1.16	0.59

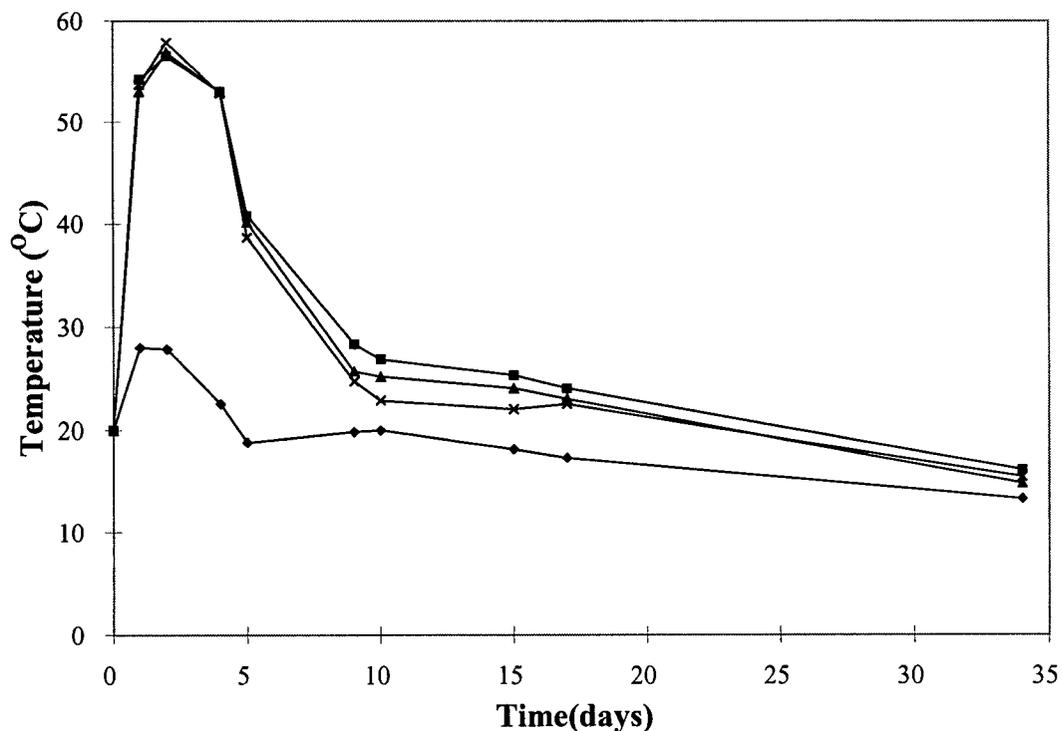


Figure 14. Temperature of composters (1-8) over the period of study.
 (◆) - 100% ash, (■) - 100% sludge, (▲) - 2:1 S:A, (×) - 1:1 S:A

The pH in all the composters decreased slightly during the composting process (Table 11). Although, as expected, the composters containing only ash had the highest pH, only slight pH differences were observed in the different S:A mixtures. The moisture content of all composters decreased due to the loss of water vapour from the exothermic reaction occurring during composting.

5.4.2 Effect of Mixing Frequency on Sludge and Ash Composting

In the small scale trials, different mixing frequencies had no observable effect on the composting process (Table 12, Figure 15). It was expected that increased aeration would improve the biological activity and produce a stabilized product in a shorter amount of time. However, the reactions in the composters proceeded much more quickly than initially expected based on the observations from the large scale experiments. It is possible that the small mass in these composters required more insulation to retain the heat produced by the initial composting reaction. The small size of the piles may have also allowed a greater rate of oxygen diffusion and thus aeration by mixing was not necessary and caused excessive heat loss.

Table 12. Initial and final pH, MC, %N of composters (9-18).

Composter #	>60°C	MWF	MTh	W	no turn
pH					
Initial	8.75	8.76	8.79	8.52	8.63
Final	8.78	8.64	8.41	8.82	8.72
Moisture Content					
Initial	52.97	56.29	53.65	57.79	46.79
Final	53.16	52.39	53.27	52.37	51.36
%N					
Final	0.57	0.58	0.58	0.57	0.58

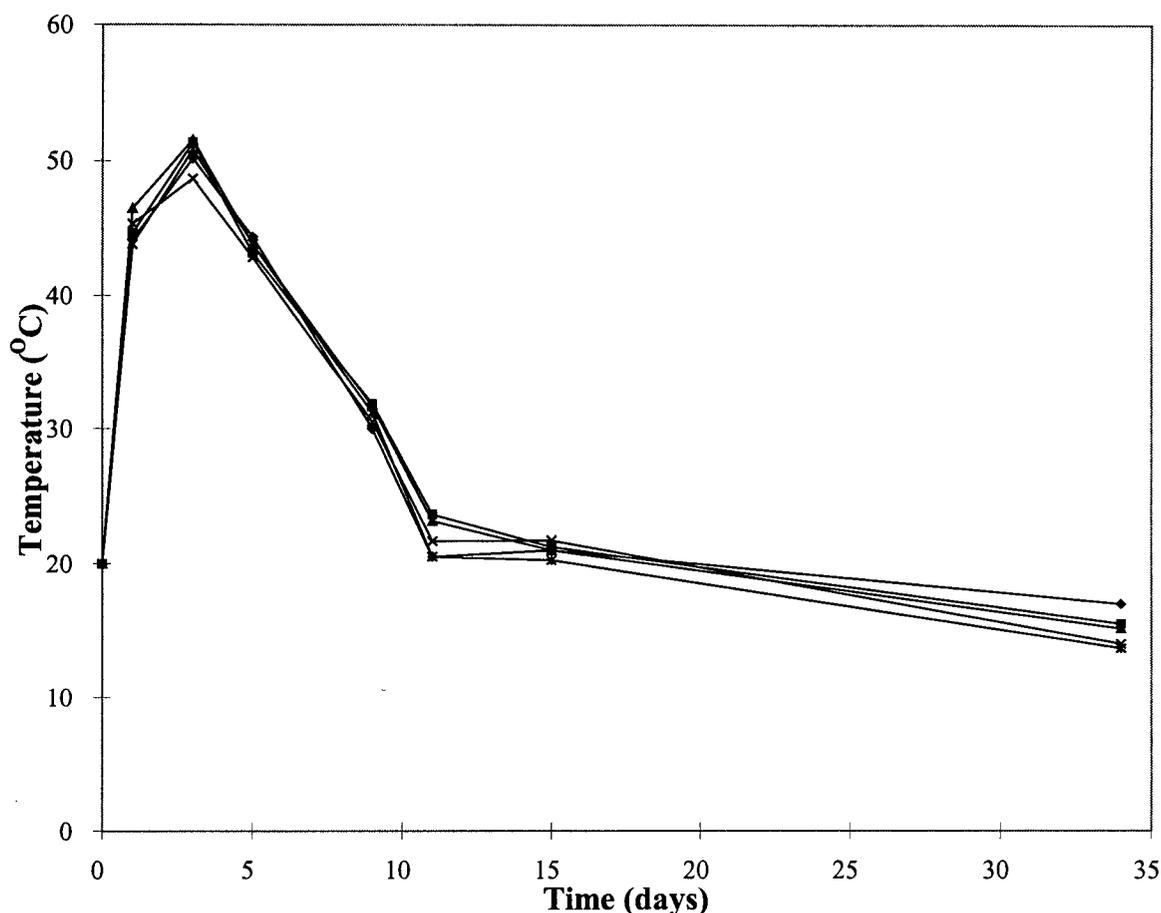


Figure 15. Temperature of composters (9-18) over the period of study.
 (◆) - >60°C, (■) - MWF, (▲) - MTh, (×) - W, (*) - no turn

5.4.3 Effect of Various Amendments on Sludge and Ash Composting

Amendment with chicken manure resulted in an increase in temperature throughout the composting process (Figure 16), indicating an enhanced rate of biodegradation. Manure is often used to lower the initial C:N ratio of compost (Gouin et al., 1992). The % N in the manure amended composters was 2.14 ± 0.02 , as compared to 0.59 ± 0.02 in 1:1 sludge to ash mixtures (Table 13). These results support the hypothesis that 1:1 sludge:ash compost mixtures are N-limited.

Another possible explanation for the improved biological activity may be that the chicken manure provided another source of active bacteria, thus increasing the active biomass. Thirdly, chicken manure is considered more compostable than ash (Gouin et al., 1992).

The experiments seeded with cultures of *T.versicolor* and Celluclast did not show any changes when compared to the other 1:1 S:A composters, while the addition of hog fuel reduced the temperature profile. The lower temperatures observed in the composters which contained hog fuel were expected as the addition of large wood chips should allow better penetration of air through a composting pile. The wood chips (which do not degrade) also replaced some of the sludge in the composter, replacing biodegradable material with an equal volume of recalcitrant wood.

Table 13. Initial and final pH, MC, %N of composters (19-28).

Composter #	1:1 S:A <i>T. versicolor</i>	1:1 S:A Celluclast CCN#1.5L	1:1:1 S:A:chicken manure	1:1:1 S:A:Hog	1:1 S:A
pH					
Initial	8.59	8.87	9.14	8.86	8.87
Final	7.57	7.68	9.31	7.53	7.56
Moisture Content					
Initial	51.78	53.80	58.06	55.62	53.48
Final	52.64	56.42	57.15	55.64	57.41
%N					
Final	0.59	0.65	2.14	0.56	0.58

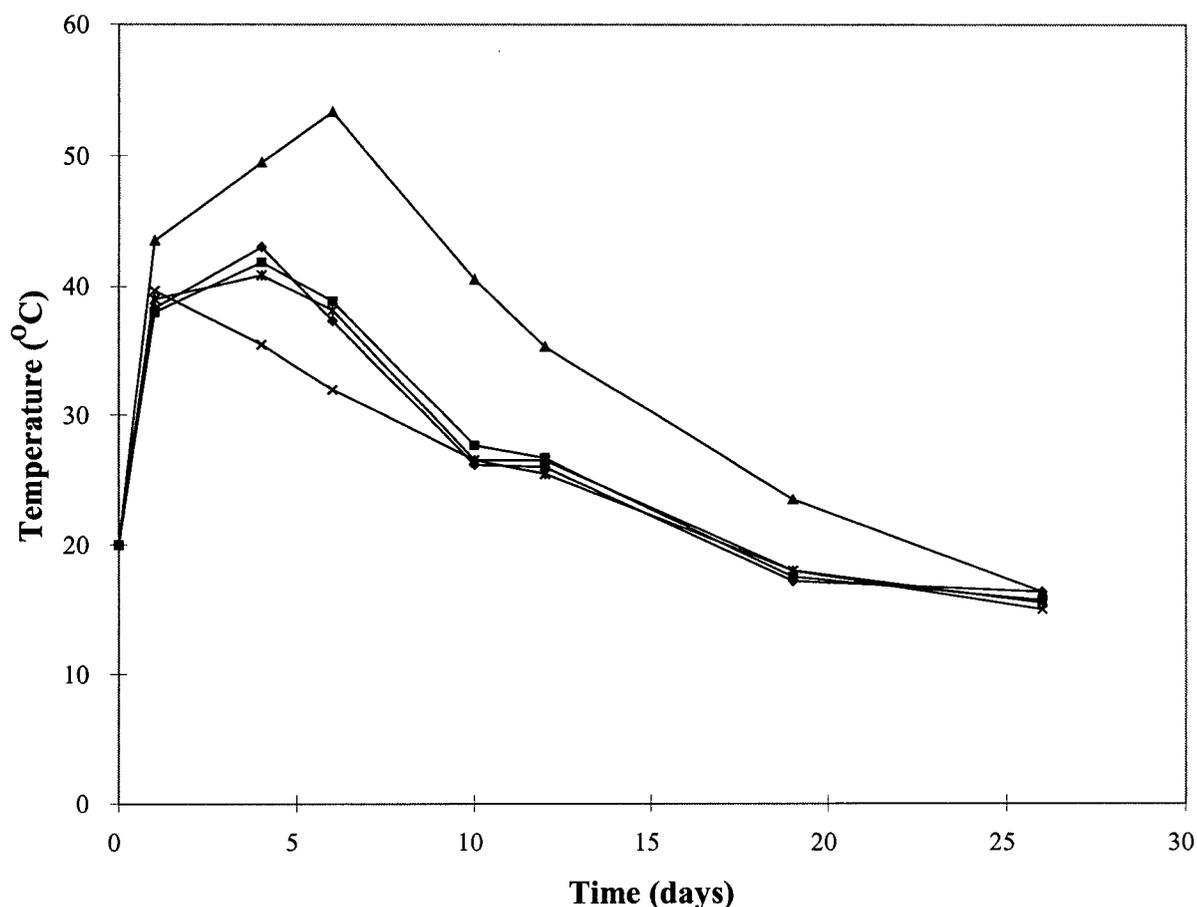


Figure 16. Temperature of composters (19-28) over the period of study.
 (◆) - 1:1 S:A with Celluclast, (■) 1:1 S:A with *T. versicolor*, (▲) - 1:1:1 S:A: chicken manure,
 (×) - 1:1:1 S:A:Hog, (*) - 1:1 S:A

5.5 Characteristics of Leachate Produced from Elk Falls Compost

The results of the analysis of leachate produced in the laboratory from the two large scale compost piles are summarized in Table 14. There are no criteria or regulations for leachate with which to compare the values reported in this study. The Contaminated Sites Regulation (BCMOE, 1996) specifies allowable levels of contamination in a receiving body of water once all discharges (such as leachate) have been received. It is therefore difficult to discuss the results from these experiments. The only regulations pertaining directly to leachate are those in B.C. Reg 334/93, which dictate that leachate must be collected and treated prior to discharge from a compost

production site. The Elk Falls compost was produced on an old landfill site with an active leachate collection system.

Table 14. Results of compost leachate study

	Turned Windrow	Std Dev	Static Windrow	Std Dev	Final Reported Conc.	BC Reg 375/96 Aquatic	Drinking
Analyte							
Metals	mg/L		mg/L		mg/L	Mg/L	mg/L
Cu	0.06	0.02	0.07	0.02	<0.09	0.002	1
Pb	0.004	0.0015	0.0	0.0015	<0.006	0.004	0.01
Na	48	3	35	3	<51	NR ¹	200
Zn	0.09	0.01	0.04	0.01	<0.10	0.3	5
Anions	mg/L		mg/L		mg/L	Mg/L	
NO ₃ ⁻¹	0.9	0.15	3	1.5	<4.5	400	10
SO ₄ ⁻²	14	1	20	2.5	<22.5	1000	500
Total P	4	1	4	0.5	<5	NR	NR
PAH's	mg/L		mg/L		mg/L	Mg/L	
phenanthrene	ND ²		ND		ND	0.003	NR
naphthalene	ND		ND		ND	0.01	NR
pyrene	ND		ND		ND	0.002	NR
EC ³	dS/m		dS/m		dS/m	DS/m	dS/m
	5	0.25	5	0.25	<5.25	NR	NR

1. NR - None Recommend
2. ND - Non Detectable
3. EC less than 4 dS/M is the level found in regular soil
EC range 2-5 dS/M for irrigation waters

5.5.1 Metals

The measured copper concentration in the undiluted leachate (<0.09 mg/L) was above the recommended level for aquatic environments. This criteria is not for leachate but for a body of water, which may have many other discharges to it. Copper is found in some natural water. The restriction on copper in most drinking waters is to avoid the undesirable taste which can occur at concentrations above 1.0 mg/L (Sawyer and McCarty, 1978). There is no evidence to indicate that

copper is detrimental to public health; however, copper is toxic to some aquatic plants and some fish at concentrations near 1.0 mg/L.

Even a brief exposure of any biological organism to lead can be injurious to health (Sawyer and McCarty, 1978). Lead is a cumulative poison, and prolonged exposure to relatively small quantities may result in serious illness or death. The concentration of lead (<0.007 mg/L) in the leachate produced from both compost piles was well below the level specified by B.C. Reg. 375/96 for the protection of aquatic life and poses no toxic concern.

The toxicity of zinc salts is very low. Apart from the undesirable taste it can impart on water, zinc is not considered detrimental to health (Canadian Water Quality Guidelines, 1996). Zinc was included in the leachate study because of the high concentrations found in the solid compost material (Table 9). The leachate produced contained zinc concentrations below the aquatic criteria and thus there should be no concern when applying the compost to soil.

The sodium content of water has a negligible impact on overall salt intake of humans because the intake of salt from other sources is much greater. Therefore, changes in sodium concentration in wells near compost application sites would not be of concern. Sodium salts in the leachate however, are a concern if the water is to be used for irrigation. Most crops can withstand a certain threshold value of salinity before problems occur. Sodium buildup in soil is detrimental to plant growth and can ruin the structure of the soil (Brady, 1990).

The sodium concentrations measured in the leachate (<51 mg/L) would only be a concern if water resources near compost application sites are to be used as irrigation water sources. The electrical

conductivity (EC) measurements exemplify this point. The EC of normal soils is less than or equal to 4 dS/m and irrigation waters should average 2-5 dS/m (Brady, 1990). The leachate has an EC of approximately 5.25 dS/m. Remembering that these concentrations are only in the leachate and not diluted by any groundwater or surface water resources, the water resources near where the compost application site should be monitored periodically to ensure that the salinity of the water is within the proper usage range.

5.5.2 Anions

The nitrate ion is the oxidized form of nitrogen found in natural waters. Nitrate concentrations higher than several hundred micrograms per liter in lake surface waters tend to stimulate algal blooms and indicate eutrophic conditions (Sawyer and McCarty, 1978). Concentrations of nitrates in groundwater supplies may increase due to soil leaching. In deep groundwater, nitrate concentrations increase further because of the absence of plants that utilize nitrates. Nitrate has caused methemoglobinemia in infants who have been given water or fed formulas prepared with water having elevated concentrations of nitrate. A domestic water supply should not contain nitrate concentrations in excess of 45 mg/L (Canadian Water Quality Guidelines, 1996). B.C. Reg. 375/96 sets the criteria for drinking water at 10 mg/L. Nitrates in excess of this levels, often in shallow wells, may be an indication of leaching from farm sites.

The compost leachate contained a nitrate concentration of <4.5 mg/L. This is well below the regulated level for a body of water and thus the leachate should not pose any concern or contribute to eutrophication in a receiving body of water.

Industrial discharges to the aquatic environment are a significant source of sulfates. Sulfate, the stable oxidized form of sulfur readily soluble in water is widely distributed in nature (Sawyer and McCarty, 1978). Dissolved sulfate may be reduced to sulfide and volatilized to the atmosphere as H_2S , precipitated as insoluble salts or incorporated in living organisms. Sulfate can be produced by the bacterial oxidation of reduced sulfur compounds, including metallic sulfides and organosulfur compounds. Sulfates in drinking waters may be undesirable because of their laxative effects on humans, and high concentrations can inhibit some metabolic and life cycle reactions in fish; however low sulfate concentrations (<250 mg/L) are of no concern for surface or groundwater resources (Canadian Water Quality Guidelines, 1996). The compost leachate produced sulfate concentrations of <22.5 mg/L, well below the criteria of 500mg/L for drinking water and 1000 mg/L for bodies of water supporting aquatic life.

Phosphorus is rarely found in high concentrations in surface water because it is actively taken up by plants and microorganisms (Sawyer and McCarty, 1978). It is well established that phosphorus is the nutrient that commonly limits freshwater phytoplankton communities and elevated levels contribute to accelerated eutrophication. Generally, elevated phosphorous concentrations are found in lakes with drainage from sedimentary areas, and lakes rich in organic matter. Phosphorous can occur in numerous organic and inorganic forms and can be present in waters as dissolved and particulate species. Orthophosphates, pyrophosphates, metaphosphates, polyphosphates and organically bound phosphates are found in natural waters and wastewaters (Canadian Water Quality Guidelines, 1996).

Phosphorus is not regulated in the B.C. contaminated sites regulations; however, BC Environment recommends 10 $\mu g/L$ as a maximum concentration in drinking water, recreation waters and for

aquatic life (Nordin, 1985). The leachate would therefore be considered as having the potential to cause eutrophication since the concentration of phosphorus is two orders of magnitude higher than this value. However, the leachate as tested is undiluted and no plants or microorganisms have had the opportunity to absorb phosphorus. Therefore the concentrations in an actual water resource near a site where the compost is applied should be much lower. A monitoring program in water resources around the site where the compost is applied would be prudent to ensure the concentration of phosphorus remains below the above mentioned criteria.

5.5.3 Organic Compounds

Several organic compounds have potential long term and short term toxic effects on the soil and water environments (Knutzen, 1995). Restricted by the time frame for these experiments, analysis of organics was limited to polyaromatic hydrocarbons (PAH) which have several characteristics making them potentially hazardous. They have high solubility in lipids and high acute toxicity when in solution or finely dispersed (Knutzen, 1995). In the dark, and under anaerobic conditions they are very persistent, especially in sediments.

Damage from PAH to organisms is mainly a result of two mechanisms: (1) association or reaction with lipids in cell membranes or other cellular constituents, (2) reaction with macromolecules like nucleic acids and proteins. PAH does have the ability to bioaccumulate and be magnified throughout the food chain.

PAH assayed in the compost leachate were non detectable. There are two possible explanations for this. Either, the leachate procedure was not rigorous enough to extract these compounds from the solid compost materials, or there are simply negligible amounts of the materials in the compost.

The leachate test used in this study was very rigorous and can be considered to be very effective when compared to natural rainfall in extracting compounds such as PAH. Therefore, it was concluded that the latter explanation was more likely. This was supported by previous work in which the concentration of PAH in the solid material was found to be very low (Table 6). Therefore, there is little or no concern for these types of organic materials to be released in the leachate and to find their way into groundwater resources or surface water environments.

All of the analytes tested were below the criteria specified in the B.C. contaminated sites regulations. These criteria allow land and water to be classified based on contaminant level evaluated. These regulations were chosen because they were readily available, but also because they provide numerical distinctions for aquatic life, irrigation waters, drinking water and livestock water. It is important to note that the leachate numbers were compared directly to these standards. These criteria are actually for the water bodies once all sources of contamination have been received. Thus the concentration of contaminants quoted could be expected to decrease once the leachate was diluted in a receiving water body. It is also important to note that no regulations directly related to the leachate test were found. Therefore, there is no way to directly quantify the results as there is no reference standard in the BC Waste Management Act - Schedule 4.

5.6 Characteristics of Soil from Land Application Trials

The land application study of the compost was initiated in February, 1997 with the trucking of compost from the turned windrow at Elk Falls to a sod farm in the Comox Valley. The material was stored in piles at the farm until it could be spread in the early spring. Initial soil testing began in March, 1997 and was completed in December, 1997.

5.6.1 Available Nutrients

The soil prior to application of the compost was deficient in several minerals, and required lime application to bring it into the optimal range for sod growth (Table 15). After the application of compost at 8 yards/acre (15 m³/ha), the soils were improved; however, the target values for a 'sod growing' soil were still not met. Although careful integration of the compost with fertilizer and lime applications would be required, the compost was a useful soil amendment. It was easily spread, contained essential nutrients and would provide an inexpensive source of soil material.

Table 15. Sod farm soil samples.

		Soil Targets	Soil Only 0 yard/acre	Turned Windrow	Soil/Compost 8 yard/acre
phosphorus	ppm	150	25	119	36
potassium	ppm	250	75	970	175
calcium	ppm	2000	2500	3000	2750
magnesium	ppm	250	230	550	195
copper	ppm	10	1.5	0.6	1.7
zinc	ppm	25	2.9	16.2	5.3
iron	ppm	150	24	3	23
manganese	ppm	50	59	315	65.5
pH		7	5.8	8.5	6.6
C:N		25	14.2	46	17
EC	dS/m	1	0.37	1.32	0.48
total nitrogen	%	0.5	0.63	0.63	0.55
organic matter	%	10	6.9	57.8	7.9

5.6.2 Dioxin

Dioxin concentrations in the final soil/compost mixture was 3.0 pg/g TEQ and the concentration stayed constant over the 6 months following the application of the compost (Figure 17). Since the limit for dioxin in the soil/compost mixture is 10 pg/g TEQ, these soils qualify as agricultural soil. However, repeated applications of the compost must be carefully monitored to ensure that dioxin does not accumulate beyond permitted levels in the soil.

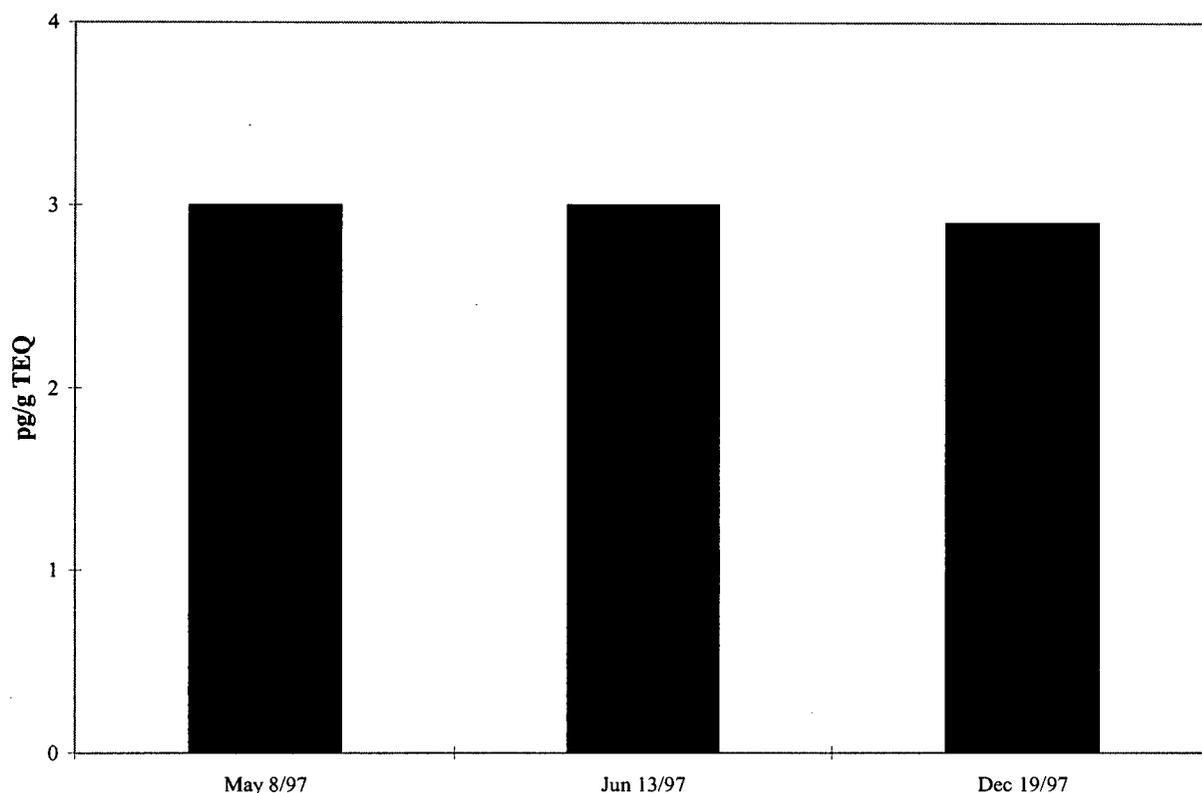


Figure 17. Dioxin concentrations in soil/compost mixture over time after 8 yard/acre application.

Follow up was completed on a previous study involving the application of compost containing dioxin on soil (Julyan, 1995). Sixty yards of compost containing 87.2 pg/g TEQ was delivered to a sod farm in the Comox Valley. Background dioxin concentrations of the soil were 1.5 pg/g. The compost was spread at a rate of 12 yards/acre using a manure spreader. The compost was not tilled into the soil, but spread as a top layer less than 1 cm thick. Samples taken immediately after application revealed a dioxin concentration of 15.1 pg/g TEQ. The dioxin concentration of the soil one year later (Sept 1996), following a single harvest of sod was 4.2 pg/g. These 5 acres of the farm were then left fallow for a year, and a sample was collected in December, 1997. The dioxin concentration was 5.2 pg/g TEQ (Figure 15). These results indicate the need to carefully monitor compost application to ensure that farm land remains below 10 pg/g TEQ. Dioxin is very stable

and these results indicate that it may be many years before a return to the initial dioxin concentration in the soil is reached. The mechanism for destruction of dioxin during this experiment is not known; however, it is expected that ultraviolet light or anaerobic bacteria are responsible (Arienti et al., 1988).

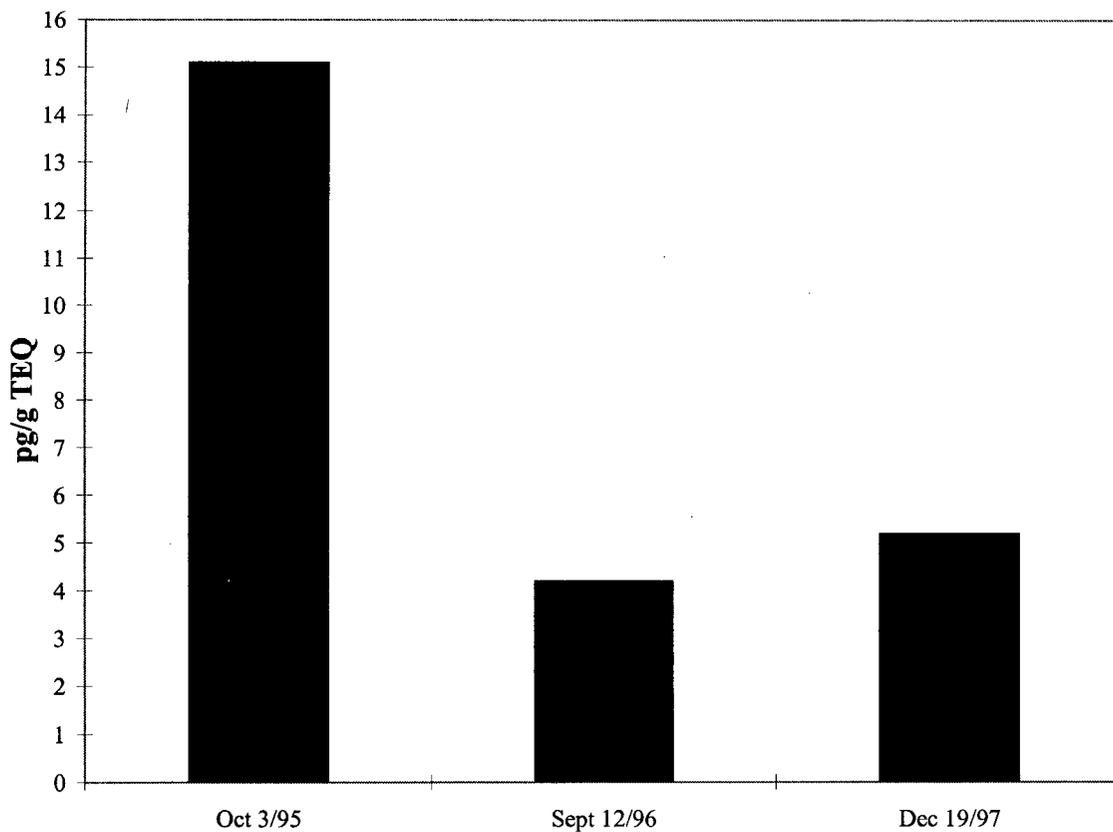


Figure 18. Dioxin concentrations in soil sample from previous (Julyan, 1995) application study.

Chapter 6. Compost End Use and Safety Concerns

6.1 Marketing

A previous survey (Julyan, 1995) indicated that there was a market for the Elk Fall's compost in the Campbell River, Comox Valley area. Further investigation during the present study revealed several other potential users and also led to an investigation of economic arrangements. The following companies all showed interest in the compost: Devonshire Turf Farm (Courtenay), River Meadows Farms (Courtenay), Kitty Coleman X-Mas Tree Farm (Courtenay), Pacific Regeneration Technology (Campbell River), TopGro (Campbell River), Westmin Resources (Campbell River), Sylvan Vale Nursery Ltd (Black Creek), and the Brinco Coal Mining Corporation (Campbell River).

All companies were very interested in receiving information on the compost and testing the material in small quantities. General concerns of all these potential users included price and transportation cost of the material. Many of the representatives of the companies felt they should be able to charge a tipping fee if the mill was trying to rid itself of a 'waste' stream. None of the representatives was concerned about possible contamination as they expected that the compost would have to meet government approval before a proposed land use.

Of greatest interest to Elk Falls was the potential to sell the compost to Brinco Coal Mining Corp. for their land reclamation requirements. An initial trial of the compost was very successful at promoting plant growth on the very poor soil/rock surface. The mine operates a coal dock beside the mill site and could potentially back-haul the compost in the trucks used to haul coal from the mine to the port site. Unfortunately, a change in the mine trucking procedures removed this possibility and a mutually acceptable economic agreement could not be reached.

Transportation costs appear to be the largest obstacle to marketing of the compost. Several backhauling arrangements were investigated to try and reduce the economic burden of compost transportation. Several hog fuel truckers were contacted as well as many of the local saw mills which routinely send chip trucks to the mill. Most of the companies were concerned with rerouting trucks and changing scheduled deliveries and pick ups to handle the compost. Other concerns included health, safety and insurance responsibilities.

6.2 Health and Safety Considerations

There are concerns for employee safety when composting sludge and ash. Due to the high winds in the composting area, dust particles were always airborne at the site. Mixing and other pile disturbances also sent particulate matter into the air. This problem can be mitigated by ensuring that the outside edges of the pile are moist.

Gaseous emissions such as hydrogen sulfide and carbon monoxide from the compost piles are also of some concern to the operators of a compost facility. Previous testing at Elk Falls (Julyan, 1995) indicated that exposure to gaseous emissions were below Worker's Compensation Board Health and Safety Regulations (Table 16).

Table 16. Worker's Compensation Board Health and Safety regulations for gaseous emissions.

	Hydrocarbons	Oxygen	Hydrogen Sulfide	Carbon Monoxide
Peak Values Obtained	1%	21.1%	2.5 ppm	5 ppm
12 Hour Exposure Limit	10%	22.0%	5 ppm	12.5 ppm

Other concerns for safety during composting include pathogen and fungal spore exposure. Pathogens are organisms which are harmful to humans, animals, or plants. Of particular concern are human pathogenic organisms found in sewage sludge. As this project focused on pulp and paper sludge, there was no concern with these pathogens.

Several fungal species are also associated with composting. *Aspergillus fumigatus* is a pathogenic mold which is naturally present in decaying organic matter and will colonize any waste material handled at a compost facility. Airborne *Aspergillus* spores can readily penetrate into the deepest part of the lung creating a condition referred to as aspergillosis. Symptoms of aspergillosis range from allergic reactions such as mild coughing, wheezing, chills, aches and pains, to death in people with impairment to the immune system.

The final concern is that the compost does contain dioxin and furans. Compost facility operators and employees may be subject to exposure during routine monitoring, sampling and mixing procedures. Dioxins and furans do not readily break down in the environment and tend to accumulate in fatty tissue. Human exposure should be avoided. Although no data exists from the composting study, information from the steam plant and boilers at Elk Falls can be used to demonstrate the risk of exposure to dioxin.

In the Elk Falls' Steam Plant, total airborne dust concentrations have been measured. The measurements of the dust levels were broken down into $\leq 7 \mu\text{m}$ particle size and $\geq 7 \mu\text{m}$ particles sizes. The concentrations are 0.431 mg/m^3 and 0.823 mg/m^3 respectively, for an average 8 hour exposure in the boiler area where sludge and hog fuel is burned (Moffat, 1994). Dust in these areas is very thick and very visible. Concentrations of dioxin/furan are 1561.2 and 765.9 pg/g TCDD

TEQ for particle sizes $\leq 7 \mu\text{m}$ and $\geq 7 \mu\text{m}$, respectively. Thus concentration of dioxin/furan increases with decreasing particle size. The daily exposure limits for dioxins is 10 pg/kg/day. The exposure to dioxins in the boiler area is calculated to be 0.428 pg/kg/day (Appendix 2).

It is important to note that Environment Canada has evaluated background exposures of dioxin to residents of Campbell River. Assuming a 70 kg person under normal environmental and dietary exposure (average fish consumption), the background exposure to dioxin is 0.047 pg TEQ/kg/day (Moffat, 1994). Assuming the same conditions, but high fish consumption, the background exposure rises to .13 pg TEQ/kg/day.

For carcinogenic substances, risk analysis can be performed. The USEPA has defined acceptable risk for carcinogens as within the range of 10^{-4} and 10^{-6} . Risk was calculated to be 1.57×10^{-5} for the boiler room area at Elk Falls (Appendix 2).

Due to the elevated moisture content the concentration of airborne dust in a composting facility would be well below that found in the boiler area. Therefore the risk for the inhalation pathway should be much lower. With proper hygienic practice (i.e. wearing gloves and washing hands before eating), other pathways of exposure due to digestion and skin absorption can be avoided. The use of standard half facepiece respirators with a dust attachment affixed should prevent overexposure of employees working with the sludge/ash compost (Moffat, 1994). These simple precautions will also prevent exposures to the mixed microbial community present at composting sites (i.e. *Aspergillus*).

Other safety concerns in composting relate to equipment. Grinders, front end loaders, and other windrow turning equipment require normal safety precautions including eye and ear protection. Spontaneous combustion can occur at moisture contents of 25-45%, especially in very large piles where internal heat may initiate the required chemical reactions (Gouin et al., 1992). Proper attention to moisture, temperature and pile size is the best protection against this safety issue.

Chapter 7. Conclusions and Recommendations

Composting a 1:1 volume ratio of fly ash and sludge is a viable option for disposal of solid wastes from a pulp and paper mill. The material produced has excellent potential for use as a soil supplement. The nutrient concentrations are sufficiently high to enhance soil if used as part of a careful soil management system.

Although less homogeneous, an acceptable compost product can be produced using a static windrow process involving only the initial mixing of the raw materials. Static windrow composting requires a longer stabilization time as indicated by the $11 \pm 1.2^{\circ}\text{C}$ temperature difference between the turned and static windrows. Compost moisture content was maintained above 50% for both piles throughout the composting process, ensuring enough moisture was available for biological metabolic processes. The final pH of both piles was 8.5 ± 0.1 , a level which allows the compost to be considered for its liming potential, although this level is higher than the range of 5-8 given in BC Reg. 334/93. C:N ratio in the piles decreased throughout the active composting process from 70:1 to an average of 43:1 for both piles. The decrease in C:N indicates that carbon was being lost as CO_2 due to microbial activity. The excessive duration (34 weeks) of the process may be explained by N-limitation indicated by the high C:N ratio. Heat loss may have been limited by the thermal boundary produced in the large compost piles.

There are no specific regulations for the application of compost made from pulp mill sludge and ash. According to the compost regulations for municipal solid and yard waste, and the criteria in the B.C. Contaminated Sites Regulation, the compost produced was found to contain acceptable concentrations of metals, PAH (except naphthalene and phenanthrene), organochlorines and phenolic compounds. Although dioxin concentration decreased from an initial value of 74.9 ± 4.9

to 41.4 ± 3.5 pg/g TEQ during the composting study, these values are still well above the 10 pg/g TEQ limit. It is important to note that these criteria do not apply directly to the compost product itself but rather to final soil mixtures after the addition of compost. As indicated by the results from the land application experiments, careful application of the compost will result in mixtures of soil with dioxin concentrations below the agricultural level. A final note on the compost dioxin concentration is that the regulations are less strict for applications in urban parks, residential, commercial and industrial soils. The criteria for these applications are 1000, 1000, 2500, 2500 pg/g TEQ respectively.

The small composting experiments, although lacking significant control, did provide some useful data. It can be concluded that the ash itself was not biologically active although it is unknown whether ash is degraded throughout the process. The ash did not prevent biological activity from occurring. Different amendments may be successful in improving the biological activity of the compost. Addition of the N-containing waste (chicken manure) improved the biological activity of the sludge and ash compost.

Based on the data collected, the leachate produced from the compost would not pose an environmental threat to water resources. Again, it is difficult to draw many conclusions about the compost leachate as the regulations used for comparison represent the criteria for bodies of water which receive water from many sources.

Compost applications at a rate of 8 yard/acre resulted in a soil/compost mixture with an improved nutrient profile and a dioxin concentration of 3.0 pg/g TEQ, enabling it to qualify as an agricultural

soil. The compost spread easily, reduced the liming requirement from dolomite, and was welcomed to improve soil colour.

Based on the information gathered in this study the following recommendations for further study are made:

There is a need to improve the biological activity of the compost piles. The results indicate two possible avenues for further study: (1) improved air flow, and (2) reduction of C:N ratio. Experiments should be conducted using: (1) different sized piles, (2) piping to improve air flow, (3) addition of forced aeration, and (4) addition of nitrogen containing wastes. In all future experiments, piles should be turned a minimum of 3-5 times to improve the homogeneity of the final product. It would also be useful to determine if ash is degraded at all by using it as the sole carbon source in degradation trials.

Experiments which directly investigate the mechanism of dioxin degradation would be useful to improving the compost quality. Future small scale experiments should account for all possible dioxin escape routes by collecting and testing gaseous emissions and leachate for dioxin.

Further investigation into the creation of dioxin in the raw materials is important to eliminating dioxin from the compost. If dioxin could be removed, the compost would classify as agricultural soil and would have unrestricted use. Study of steam plant operations, or change in the combustion process could potentially reduce the amount of dioxin produced in the ash. Process changes to chlorine free bleaching would remove the dioxin from the sludge.

Further study of the leachate could be completed in the lab. Soil samples from compost application sites could be collected and subjected to the leachate test and examined for the same analytes to provide a comparison of the compost with real soil. Background concentrations of contaminants could be determined and their effect on the compost application could be studied. Other metal concentrations and dioxin and furan concentrations could be useful in further investigations into the usage of industrially produced compost. It would be prudent to continue the search for criteria directly related to the leachate produced rather than trying to make comparisons to water quality criteria.

The land application trials could be continued. Dioxin could be continually monitored to determine if any decrease or dioxin destruction is occurring in the soil environment. Further studies could be made to increase the usage of the compost in other applications. Mine application, forest reclamation are two very large markets for the compost and experimentation on such a site may improve the image of the compost. It is important to note that the dioxin concentration found in the compost is really only restrictive for agricultural land. The main concern is public image and concern with the dioxin. I would recommend an improvement in the public education surrounding dioxin in general. Based on current regulations, the compost should qualify for use as a soil in most industrial, commercial and residential projects.

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Appendix 1- Additional Procedures

Schedule 4 - Analytical Methods - Waste Management Act (BCMOE, 1988)

Leachate Extraction Procedure

(1) Sampling

Collect a sufficient amount of sample to provide 100g of solid material using techniques which ensure that the sample is representative of the waste.

(2) Equipment

2.1 Sieve, 9.5 mm mesh opening, stainless steel or plastic material

2.2 Stainless steel filtration unit, 142 mm diameter, minimum 1 litre capacity, capable of sustaining a pressure of 5 kg/cm², applied to the material to be filtered.

2.3 Membrane filter, 142 mm diameter, 0.45 µm diameter pore size, made of synthetic organic material such as cellulose acetate, cellulose nitrate, nylon or polycarbonate and which is compatible with the leachate to be filtered. Teflon is recommended for organic constituents.

2.4 Glass fibre prefilter, 124 mm diameter 3 µm to 12 µm pore size range.

2.5 Vacuum filtration unit, 90 mm diameter.

2.6 Membrane filter 90 mm diameter as per Step 2.3

2.7 Glass fibre filter 70 mm diameter as per Step 2.4

2.8 Solid waste rotary extractor - a device that rotates the bottles end over end about a central axis through 360°, with a speed of 10 rpm. The dimensions of the box will depend on the needs of each laboratory.

2.9 Structural Integrity Tester with a 3.18 cm diameter hammer weighing 0.33 kg and having a free fall of 15.24 cm.

2.10 pH meter, with a readability of 0.01 pH unit and accuracy of ± 0.1 pH units

2.11 Cylindrical bottles, wide mouth, 1250 ml capacity, polyethylene or glass with Teflon lined cap for inorganic constituents; glass with Teflon-lined cap or Teflon bottles or organic constituents.

2.12 Cleaning Procedure

All glassware and equipment that comes into contact with the sample should be cleaned in the following way before each use:

2.12.1 Wash with a non-phosphate detergent solution.

2.12.2 Rinse twice with tap water.

2.12.3 Rinse twice with reagent water.

2.12.4 Wash with 10% nitric acids.

2.12.5 Rinse several times with reagent water.

2.12.6 Store bottles filled with 10% nitric acids, until ready to use.

2.12.7 Rinse several times with reagent water before use.

2.12.8 Rinse clean oven dried bottles with methylene chloride, followed by methanol, for organic constituents.

(3) Reagents

3.1 Acetic acid, 0.5 N. Dilute 29.4 ml of concentrated acetic acids (ACS grade) to 1000 ml with reagent water.

3.2 Reagent water, Type IV (ASTM Specification D 1193). For organic parameters, the reagent water should be free of any organic substances to be analyzed (ASTM Type 1).

3.3 Nitric acid, 10% (v/v). Add 100 ml of concentrated nitric acid (ACS grade) to 900 ml of reagent water.

3.4 Nitrogen gas, pre-purified, scrubbed through a molecular sieve.

(4) Separation Procedure

If the sample is not a dry solid separate it into its component phases using the following procedure:

4.1 Determine the dry weight of the solids in the sample at 60°C, using a well homogenized sample. Use this weight to determine the amount of material to be filtered.

4.2 Assemble the filtration unit with a filter bed consisting of a 0.45 µm pore size membrane filter and a coarse glass fibre pre-filter upstream of the membrane filter (per manufacturer's instructions).

4.3 Select one or more blank filters from each batch of filters. Filter 50 ml portions of reagent water through each test filter and analyze the filtrate for the analytical parameters of interest. Note the volume required to reduce the blank values to acceptable levels.

4.4 Was each filter used in the leach procedure with at least this predetermined volume of water. Filter under pressure until no water flows through the filtrate outlet.

4.5 Remove the moist filter bed from the filtration unit and determine its weight to the nearest ± 0.01 g.

4.6 Re-assemble the filtration unit, replacing the filter beds, as before.

4.7 Comminute the sample, with a mortar and pestle, to a size that will pass through the opening of the filtration unit (less than 9.5 mm).

4.8 Agitate the sample by hand and pour a representative aliquot part of the solid and liquid phases into the opening of the filtration unit. Filter a sufficient amount of the sample to provide at least 60 g of dry solid material.

4.9 Pressurize the reservoir very slowly with nitrogen gas by means of the regulating valve on the nitrogen gas cylinder, until liquid begins to flow freely from the filtrate outlet.

4.10 Increase the pressure in increments of 0.5 kg/cm² to a maximum of 5 kg/cm², as the flow diminishes. Continue filtration until the liquid flow ceases or the pressurizing gas begins to exit from the filtrate outlet of the filter unit.

4.11 De-pressurize the filtration unit slowly using the release valve on the filtration unit. Remove and weigh the solid material together with the filter bed to ± 0.01 g. Record the weight of the solid material.

4.12 Measure and record the volume and pH of the liquid phase. Store the liquid at 4°C under nitrogen until required in Step 5.13.

4.13 Discard the solid portion, if the weight is less than 0.5% (w/v) of the aliquot part taken. If not, proceed to Step 5.1.

Note: For mixtures containing coarse grained solids, where separation can be performed without imposing a 5 kg/cm^2 differential pressure, a vacuum filtration unit with a filter bed as per Step 4.2 may be used. Vacuum filtration must not be used if volatile organic compounds are to be analyzed.

(5) Extraction Procedure

5.1 Prepare a solid sample for extraction by crushing, cutting or grinding, to pass through a 9.5 mm mesh sieve. If the original samples contains both liquid and solid phases, use the solid material from Step 4.13. The structural integrity procedure, Step 6, should be used for monolithic wastes which are expected to maintain their structural integrity in a landfill, (e.g. some slags and treated solidified wastes).

Note: Do not allow the solid waste material to dry prior to the extraction step.

5.2 Determine the moisture content of the de-watered sample, by drying a suitable aliquot part to constant weight at 60°C in an oven. Discard the dried solid material.

5.3 Place the equivalent of 50 g dry weight of the de-watered and undried material into a 1250 ml wide mouth cylindrical bottle. Use additional bottles if a larger volume of leachate is required for analysis.

5.4 Add 800 ml (less the moisture content of the sample in ml) of reagent water to the bottle.

5.5 Cap the bottle and agitate it in the rotary extractor for 15 minutes before pH measurement.

5.6 Measure and record the pH of the solution in the bottle using a pH meter calibrated with buffers at pH 7.00 and pH 4.00. The solution should be stirred during the pH measurement.

5.7 Proceed to step 5.10.1, if the pH is less than 5.2

5.8 Add a sufficient volume of 0.5 N acetic acid if the pH is greater than 5.2 to bring the pH to 5.0 ± 0.2 .

Note: Maximum Amount of Acid: No more than 4 ml of 0.5 N acetic acid per gram of dry weight of sample may be added during the entire procedure. If the pH is not lowered to 5.0 ± 0.2 with this amount, proceed with the extraction.

5.9 Cap the bottle and place it in the tumbling apparatus. Rotate the bottle and its contents at 10 rpm for 24 hours at room temperature (20°C to 25°C).

5.10 Monitor, and manually adjust the pH during the course of the extraction, if it is greater than 5.0 ± 0.2 . The following procedure should be carefully followed:

5.10.1 Measure the pH of the solution after 1 hour, 3 hours and 6 hours from the starting time. If the pH is above 5.2, reduce it to 5.0 ± 0.2 by addition of 0.5 N acetic acid. If the pH is below 5.0 ± 0.2 do not make any adjustments

5.10.2 Adjust the volume of the solution to 1000 ml with reagent water, if the pH is below 5.0 ± 0.2 after 6 hours.

5.10.3 Measure and reduce the pH to 5.0 ± 0.2 , if required, after 22 hours and continue the extraction for an additional 2 hours.

5.11 Add enough reagent water at the end of the extraction period so that the total volume of liquid is 1000 ml. Record the amount of acid added and the final pH of the solution

5.12 Separate the material into its component liquid and solid phases as described under the Separation Procedure, Step 4. Discard the solid portion.

Note: It may be necessary to centrifuge the suspension at high speed before filtration, for leachates containing very fine grained particles.

5.13 Calculate the amount of free liquid from Step 4.12 corresponding to 50 g of the dry solid material. Add this amount to the leachate from Step 5.12.

Note: If the analysis is not performed immediately, store separate aliquot parts of the leachate at 4°C, after adding appropriate preservatives for the analytical parameters of interest.

5.14 Analyze the combined solutions from Step 5.13 for contaminants listed in Table 1 of this Schedule that are likely to be present.

5.15 Report concentrations of contaminants in the combined leachate and the free liquid solution as mg/l.

5.15 Carry a blank sample through the entire procedure, using dilute acetic acid at pH 5.0 ± 0.2 .

(6) Structural Integrity Procedure

6.1 This procedure may be required prior to extraction for some samples in Step 5.1. It may be omitted for wastes with known high structural integrity.

6.2 Fill the sample holder with the material to be tested. If the sample of the waste is a large monolithic block, cut a portion from the block measuring 3.3 cm in diameter by 7.1 cm in length. For a treated waste (e.g. solidified waste) samples may be cast in a form with the above dimensions for the purposes of conducting this test. In such cases, the waste should be allowed to cure for 30 days prior to further testing.

6.3 Place the sample holder in the structural integrity tester, then raise the hammer to its maximum height and allow it to fall. Repeat this procedure 14 times.

6.4 Remove the material from the sample holder, and proceed to step 5.2. If the sample has not disintegrated, it may be sectioned; alternatively use the entire sample (after weighing) and a sufficiently large bottle as the extraction vessel. The volume of reagent water to be initially added is 16 ml/g of dry sample weight. The maximum amount of 0.5 N acetic acid to be added is 4 ml/g of dry sample weight. The final volume of the leachate should be 20 ml/g of dry sample weight.

Polyaromatic Hydrocarbons from Water - Using Solid Phase Extraction

Procedure using C18, 500mg:

A. Conditioning

1. Rinse column with 6ml of 2-propanol/deionized water (15:85)
2. Rinse column with 6ml of deionized water (do not allow column to dry before next step)

B. Sample Application

1. Apply 100 ml sample to the top of the column and draw through the packing bed

C. Column Wash

1. Wash with 2ml of 2-propanol/deionized water (15:85).

D. Elution

1. Elute analyte into a collection tube with 1ml methylene chloride

(for further explanation - refer to Method 3535 - Tekmar-Dohrman, 1996)

Growing Procedure for *T.versicolor* 52J

Media:

MB (mycological broth) Agar: per liter

10 g soytone

40 g D-glucose

2 ml trace metal solution

15-20g Bacto malt agar

Add water, bring pH to 5.0 with H Cl, bring volume to 1 litre, autoclave, pour plates.

TMS (trace metal solution): 500X

FeSO₄-7H₂O: 2mM

Na₃citrate: 40 mM H₂O

CuSO₄-5H₂O: 1 mM

ZnCl₂: 5 mM

MnSO₄-4H₂O: 20 mM

MgCl₂-6H₂O: 50 mM

CoCl₂-6H₂O: 5 mM

NiCl₂-6H₂O: 0.1 mM

(NH₄)₆Mo₇O₂₄-4H₂O: 0.5mM

Adjust pH to 2 using HCl

Add nutrients in the order given or you may get precipitates. The final solution should be slightly pinkish.

To maintain growing cultures, transfer small fragments of mycelia from the growing edge of a old colony onto a new plate. For liquid cultures, take 1 inch diameter colonies from solid plates and blend them twice for 20 seconds in liquid MB. Grow the colonies with shaking (200 rpm) for several days. Note that this liquid culture can be saturated with growth in 2 to 3 days. If problems arise with bacterial contamination, add antibiotics to the liquid medium. Kanamycin (30 micrograms per ml) and ampicillin (50 micrograms per ml) are preferred. To freeze, cut out chunks of mycelia and place them in a sterile cryotube with 1 ml of complete medium. No glycerol is necessary.

Appendix 2 - Health and Safety Calculations

Exposure to Dioxin and Furans - Calculations		
Particle Size	Average concentration of dust particles 8hr exposure	Dioxin Concentration of dust particles
≤ 7μm	0.431 mg/m ³	1561.2 pg/g TEQ
≥ 7μm	0.823 mg/m ³	765.9 pg/g TEQ
Concentration at exposure point (C) $C = (0.431 \times 10^{-3})(1561.2) + (0.823 \times 10^{-3})(765.9)$ $C = 1.303213 \text{ pg TEQ/m}^3$		
Contact Rate (CR) $CR = 23 \text{ m}^3/\text{d}$		
Daily exposure = C * CR $\text{Daily exposure} = 29.9739 \text{ pg TEQ/d}$		
Average Body Weight (BW) $BW = 70 \text{ kg}$		
Daily Exposure Limit = 10 pg TEQ/kg/d (Moffat, 1994)		
Exposure = 0.428 pg/kg/day		

Risk Calculation - Dioxins and Furans - Carcinogenic Model	
Variable	Value
Target Risk (TR)	10⁻⁴ → 10⁻⁶
Frequency (EF)	260 days/year
Exposure Duration (ED)	30 years
Body Weight (BW)	70 kg
Averaging Time (AT)	255000 days
Intake (I)	$(C \cdot CR \cdot EF \cdot ED) / (BW \cdot AT)$ $I = 0.130978 \text{ pg/kg/day}$ $I = 1.31 \times 10^{-10} \text{ mg/kg/day}$
Slope Factor (SF) - Inhalation Pathway	$120000 (\text{mg/kg/day})^{-1}$ (Moffat, 1994)
Risk = I * SF	Risk = 1.57 * 10⁻⁵
Assumes 100% bioavailability Assumes 100% dust in air inhaled Assumes work 8 hours/day, for 30 years, 260 days year	