BIOREMEDIATION USING COMPOSTING

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INTRODUCTION

Composting is a process during which organic materials are degraded, or eaten, by microorganisms, resulting in the production of organic and/or inorganic by-products and energy in the form of heat. Several key attributes make the environment in an actively composting mass especially suitable for the destruction of biodegradable hazardous contaminants. This article will discuss the application of composting for biologically remediating contaminated environmental matrices (bioremediation) and present the results of field demonstrations conducted to treat explosives-contaminated soil and sediment.

At present, composting is widely used to treat wastewater sludges, processing wastes, and municipal refuse. The primary benefits gained by composting these materials are reduction of the volume and moisture content of the waste, destruction of pathogens and odor producing nitrogen- and sulfur-containing compounds, and stabilization of the waste for ultimate disposal or use as a marketable product.

In contrast, the objective of hazardous materials composting is solely to convert hazardous substances into innocuous end products. This shift in objectives has several important consequences. For example, operating parameters such as treatment time may need to be modified to ensure acceptable contaminant destruction. In general, the requirements for containment and reduction of hazardous contaminants to acceptable levels require that a more tightly controlled and aggressive approach be employed for composting hazardous substances than for composting wastewater sludges and refuse.

The potential for bioremediation of contaminated environmental matrices using composting is promising primarily because of the intensity of the microbial activity within a composting matrix. This activity is facilitated by the generally warm, moist, aerobic, and nutrient and carbon rich environment. The production of metabolic heat and the insulative properties of the physical matrix create a self-heating environment that serves to further stimulate microbial activity. Microbial communities develop and turnover in response to this metabolism driven temperature rise.

The specific contaminant destruction capabilities possessed by microorganisms in a composting mass may not differ from those in, for example, soils at ambient temperature. However, the overall transformation potential for contaminants within a composting mass is worthy of consideration for several reasons. First, elevated (thermophilic) temperatures facilitate a higher reaction rate than that generally achievable at ambient conditions. Second, the opportunity for cometabolism (degradation of a recalcitrant compound while a microorganism is obtaining its carbon and energy from more utilizable compounds) is enhanced due to the range of alternative substrates present and the high level of metabolic activity. Third, the changing physical/chemical microenvironments within a composting mass result in a diversity of microbial communities and metabolic activity, thereby increasing the number and type of microorganisms to which a contaminant is exposed. Finally, elevated temperatures typically result in increased contaminant solubility and higher mass transfer rates, making contaminants more available for metabolism.

As a result of these factors, the likelihood that a biodegradable hazardous material or mixture will be attacked at a significant rate is high in an actively composting mass. Toxic contaminants may be attacked by microorganisms while readily utilizable organic matter is still available within a microsite, or after readily utilizable materials have been degraded. In either case, the large, active microbial population facilitates contaminant degradation.

APPLICABLE COMPOSTING TECHNOLOGY

The three general levels of composting technology (windrow, static pile, and in-vessel) have been investigated for their bioremediation potential to different degrees. Any of those technologies employed for military wastes, for example, must not only be economical, but also satisfy requirements for explosive safety, hazard containment, and destruction efficiency. Windrows are currently being studied as part of our investigative program. With adequate process control (temperature and oxygen in particular), windrows may prove capable of economically achieving high rates of contaminant destruction and system throughput for composting contaminated soils. However, rigorous standards with regard to moving parts must be met by windrow turning machines for material contaminated with explosives.

Aerated static piles have been extensively employed to test the concept of composting explosives-contaminated soil. Although effective in demonstrating the microbiological process, problems maintaining good contaminant to biomass contact and achieving effective mass transport of oxygen and water are possible with this approach on a large scale. A mechanically agitated pilot unit was specifically designed and constructed to determine if the potentially higher rates of soil throughput achievable in this type of system would negate the higher capital costs. This system was utilized in a field optimization program described below.

CASE STUDY: COMPOSTING OF EXPLOSIVES AND PROPELLANT CONTAMINATED SEDIMENTS

Louisiana Army Ammunition Plant

The manufacture and handling of explosives and propellants has resulted in soil and sediment contamination at U.S. Army munitions facilities, often as a result of previously acceptable waste disposal practices. Composting is being investigated as a candidate technology for decontaminating these contaminated soils.

TABLE 1 MATERIALS BALANCE OF MIXTURE COMPOSTED AT LAAP

Material	Volume (cu yd)	Mass (lb)	Percent Volume	Percent Mass
Sediment	1	2,300	3	24
Alfalfa	13	940	38	10
Straw/manure	16	2,480	47	25
Horse Feed	4	4,000	12	41
Total	34	9,720	100	100

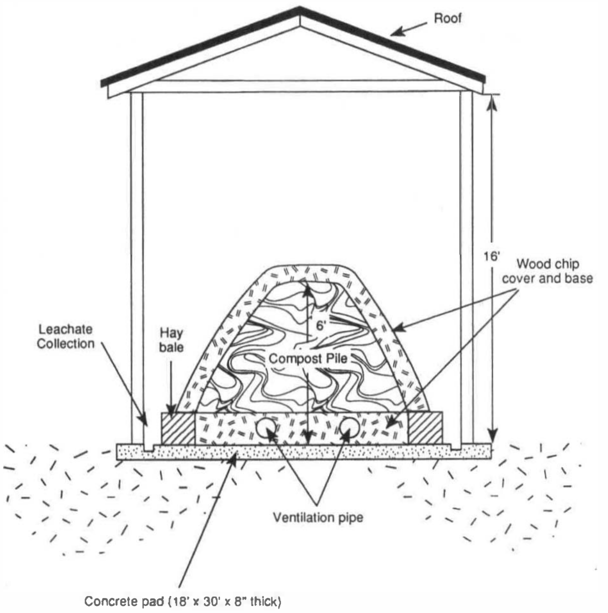
Contaminants of concern at the Louisiana Army Ammunition Plant (LAAP) included 2,4,6-trinitrotoluene (TNT), hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX), octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX), and N-methyl-N,2,4,6-tetranitroaniline (tetryl). These explosives were present as contaminants in lagoon sediments as a result of the disposal of "pink water," which was generated during munitions packing and loading operations.

The primary objective of the LAAP study was to prove the concept of composting as a technology for remediating soils and sediments contaminated with explosives. Secondary objectives included evaluating different materials handling and process control strategies and determining transformation products when Standard Analytical Reference Materials (SARMs) were available.

Concrete test pads were constructed adjacent to the pink water lagoons at LAAP. Drainage channels in the pads were connected to a sump and water from the sump was reapplied to the compost piles as necessary.

The mixture to be composted was prepared using horse manure and soiled bedding (straw), alfalfa, horse feed, and contaminated sediment (Table 1). Sawdust, wood chips and baled straw were used to construct the compost pile base and insulating cover (Fig. 1). A mechanical feed system, developed initially to meter explosives-contaminated soil into an incinerator, was used to homogenize sediment and to mix the material to be composted.

Temperature and oxygen in the compost piles was controlled using a system of perforated and nonperforated polyethylene drainage tubing placed in a wood chip base and connected to an explosion-proof radial-blade blower. The blower was used to pull air through the



Note: Schematic only, not to scale

FIG. 1 CROSS-SECTIONAL SCHEMATIC OF COMPOST PILE WITH ROOF, LOUISIANA ARMY AMMUNITION PLANT

compost piles so that a discrete exhaust source existed in case treatment was required. Blower cycling was controlled by both timer and temperature feedback systems. Both mesophilic and thermophilic temperatures were investigated to determine if the higher microbial diversity (and assumed metabolic diversity) present at mesophilic temperatures would result in greater overall contaminant destruction than that observed at thermophilic temperatures. Thermophilic temperatures were assumed to result in higher rates of transformation mediated by a narrower range of microorganisms.

Pile construction was completed and the temperature control system and recorder were started on February 25, 1988. The compost piles were individually dismantled, remixed, and remoistened on days 33, 60, and 111.

A linear plot of total explosives concentration versus time for the thermophilic pile is presented in Fig. 2. Degradation of TNT, RDX, and HMX approximated first-order decay kinetics. Calculated half-lives (days) were 12 for TNT, 17 for RDX, and 23 for HMX under thermophilic conditions. Under mesophilic conditions, the values were 22, 30, and 42 days, respectively.

Badger Army Ammunition Plant

A second field demonstration was conducted in Wisconsin at the Badger Army Ammunition Plant (BAAP) for nitrocellulose (NC) contaminated soils. Four piles were constructed, and soil loading rates as high as 32.5% by mass were investigated. In addition, nonspecification grade NC was blended with amendments (nonsoil additives) and enclosed in mesh bags within the piles to test destruction at elevated concentration (as high as 20%). These BAAP studies were successful. NC was reduced 98% from 3039 mg/kg to 54 mg/kg in one of the four piles. In one set of mesh bags, NC was reduced 98% from 114,500 mg/kg to 2550 mg/kg.

The appearance of the compost changed considerably over the test periods. When the compost was initially mixed, it had a highly fibrous appearance, a rough texture, and it smelled conspicuously of the manure and feed used to prepare it. After approximately 100 days, the compost had become more soil-like and less fibrous in appearance. At the end of the test period, the compost had both the appearance and smell of loamy soil.

The results of these field demonstrations indicated that composting was a feasible technology for reducing the concentrations of contaminants in soils and sediments. A cost analysis indicated that if the cost of amendments could be kept below $50/ton and a soil fraction of above 20% utilized, that the treatment cost per ton of soil would be approximately $100. This would compare favorably with incineration costs, which typically are $250/ton or higher.

Umatilla Army Deport Activity

An optimization field demonstration program was conducted at the Umatilla Army Depot Activity (UMDA) in Umatilla, Oregon. The objective was to maximize soil throughput. Amendments and mechanically agitated versus static pile technology were investigated to maximize reaction rates. A range of soil percentages within the mixtures to be composted was evaluated in order to maximize soil content. Results from the UMDA field demonstration have provided data needed for full-scale implementation of the technology.

An amendment selection and evaluation study was conducted with the ongoing assistance of William Brinton, President of Woods End Research Laboratory, Mt. Vernon, Maine. Significant differences have been observed between amendments. In addition to various waste materials, microbial bioaugmentation was also

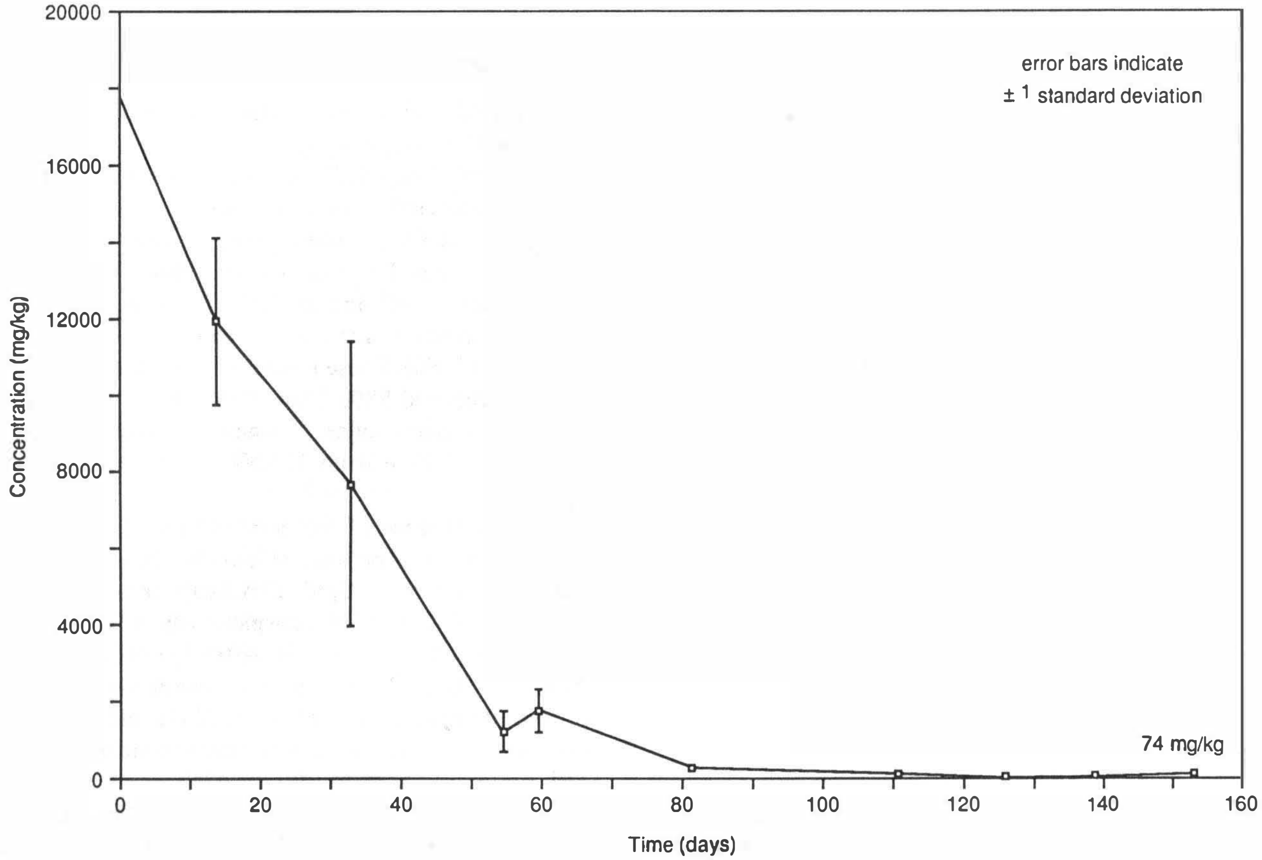


FIG. 2 MEAN CONCENTRATION OF TOTAL EXPLOSIVES IN COMPOST PILE 4

investigated. A special 7-cu yd pilot system was constructed by Fairfield Engineering Co., Marion, Ohio. The pilot unit has a rotating cover with a feed hopper and six overlapping augers. A water seal around the cover was incorporated to permit sampling of exhaust air. The system was designed and constructed according to rigorous safety standards required for operations involving explosives.

Seven 3-cu yd fiberglass tanks were modified to serve as static pile model systems. Forced aeration (bottom to top) with humidified air was used to provide oxygen and remove excess heat.

The static pile and mechanically agitated systems were monitored/controlled using a system designed and constructed by C.B. Ives, King of Prussia, Pennsylvania. Temperature was controlled at 55°C and exhaust air automatically sampled for oxygen and moisture. In addition, explosive concentration, pH, moisture, microbes, toxicity, and other parameters were measured from the mixtures over the course of the study. The program was completed in December 1991, and the results were not ready for release when this paper was prepared.

Future Considerations

During the next 10 years composting, if successful, has the potential to save the U.S. Army hundreds of millions of dollars over the cost of incineration for treating explosives-contaminated soil. Although the final residue has the appearance of good quality compost, the material will likely remain on post and be used as backfill.

CONCLUSIONS

Bioremediation using composting is a promising technology. However, the limits of composting as a bioremediation method must be kept in mind when evaluating its use. Volatile contaminants may be released during composting requiring additional treatment equipment and increased costs. Microorganisms have yet to be effectively utilized for the remediation of heavy metal contaminated matrices. Consequently, a careful evaluation is required when hazardous concentrations of metals or volatile organic compounds are present. Finally, the final fate of the contaminants must be addressed satisfactorily, which is often difficult in light of the complexity of the compost matrix.