

Hazardous materials composting*

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Abstract

Hazardous materials composting involves the addition of hazardous wastes to a solid compost matrix that provides optimal environmental conditions for microbial metabolism. Microbial degradation of organics within the compost matrix proceeds at a rate sufficient to produce significant energy in the form of heat. This self-heating is characteristic of composting and serves to increase the rate of microbial metabolism. The hazardous substance(s) within the compost matrix may be degraded biologically, either directly or via cometabolism; or by chemical means. Parameters which affect the efficacy of aerobic composting include moisture content, porosity, concentrations of biodegradable carbon and inorganic nutrients, hazardous substance(s) loading, and oxygen tension. Composting has been used successfully at the field-scale to decontaminate explosives-contaminated sediments.

Introduction

Composting is a biochemical process in which organic materials are biologically degraded, resulting in the production of organic or inorganic byproducts and energy in the form of heat. Heat is trapped within the composting mass, leading to the phenomenon of self-heating that is characteristic of the composting process.

Historically, composting has been used to degrade solid waste materials such as leaf litter, sewage sludge, and food wastes. More recently, composting has been investigated as a remediation technology for hazardous wastes. Laboratory and field-scale work has been conducted to determine the fate of pesticides, hydrocarbons, and explosives in the composting environment.

As applied to non-hazardous materials, the main objectives of composting

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are (1) to stabilize and oxidize organic materials, (2) to reduce the volume of waste, (3) to reduce the moisture content of waste, and (4) pathogen destruction. While these objectives are also applicable to hazardous materials composting, the main objective is to degrade hazardous substances into innocuous end-products.

Hazardous materials composting involves the addition of known quantities of a hazardous waste into a solid compost matrix that provides an optimal environment for microbial metabolism [1]. The loading rate of hazardous material must be such that inhibition of the heterotrophic microbial population does not occur or is at least minimized.

Principle of composting

The composting process is primarily facilitated by a high concentration of biodegradable organic material in the compost matrix and an active microbial population. Secondary enhancers of microbial activity include moisture, inorganic nutrients, and oxygen. Under these favorable conditions, microbial metabolism accelerates to the point at which a significant quantity of energy is released in the form of heat. Increased temperature serves to further increase the metabolic rate up to approximately 60°C, at which point the pasteurization process begins.

As applied to hazardous materials, aerobic composting systems consist of the following components. The solid material to be composted must have a high biodegradable organic carbon content, be relatively porous, and ideally, have a moisture content of approximately 50 to 60% by weight. The material to be composted is placed into a vessel or formed into a compost pile. Provisions may be made for monitoring the temperature of the compost and for providing aeration. Aeration is commonly provided by forcing or pulling ambient air through the solid matrix using blowers or by mechanically agitating the material.

For some hazardous materials applications, the thermophilic temperature range of 50 to 60°C has proven to be more effective than the mesophilic (30 to 40°C) temperature range [2]. For a porous compost mixture, much more ambient air is needed to cool the compost than is required to maintain adequate oxygen tension [3].

Composition of the mixture to be composted

The majority of the mixture to be composted needs to be a readily degradable solid organic material. Substances such as livestock manure, vegetation, and food processing wastes are possible candidates. The economic feasibility of the process is greatly enhanced if the carbon source is inexpensive and available locally.

In many instances, the porosity of the carbon source needs to be increased through the use of bulking agents. Materials suitable for use as bulking agents include fibrous vegetation (such as straw) and wood chips or bark. The bulking agents may also serve as a supplemental carbon source. Used bedding material from livestock stables has proven useful [4]; the straw provided porosity while the urine and manure provided inorganic nutrients and organic carbon.

In some cases, additional inorganic nutrients (primarily nitrogen and phosphorus) are needed to provide optimal conditions for microbial metabolism. These nutrients can be conveniently provided in the form of agricultural fertilizer.

The hazardous material to be decontaminated may be a solid (such as contaminated soil) or a semi-liquid (such as petroleum-based refinery sludge). The loading rate of this material is crucial. Increasing the loading rate lowers the cost of treating a unit mass or volume of hazardous material. However, too high a loading rate may cause problems; (1) microbial inhibition may occur, depending on the toxicity of the waste, and/or (2) the biodegradable carbon source may be diluted to the point where self-heating is reduced or eliminated.

Finally, the moisture content of the mixture significantly affects the rate and extent of composting activity. A moisture content of 50 to 60% by weight has been shown to be optimal in many applications [5]. While molecular water is produced as organics are mineralized, the loss of water by evaporation at elevated compost temperatures exceeds the rate of water production via mineralization [3]. Therefore, the composting mixture usually needs to be watered periodically to maintain favorable conditions.

Composting applications and process control

Several levels of composting technology are possible. The most basic form of composting may be termed an "uncontrolled static pile". In this process, the mixture to be composted is formed into a pile and essentially left to let nature take its course. The pile may be watered periodically but that is the extent of process control.

The next technological level is the "windrow". The mixture to be composted is formed into one or more long rows. Periodically, the mixture is manually turned to promote aeration and increase the contact between biomass and organic contaminants. Windrows are commonly used in wastewater sludge composting. Again, the mixture may be watered periodically.

The aerated static pile features a built-in aeration system that serves to provide oxygen and also to remove excess heat from the matrix. A typical aeration system consists of a series of perforated pipes that are laid out in a grid and attached to a mechanical blower. The mixture to be composted is placed on top of the grid. Periodically, the blower is turned on and air is either forced or drawn through the composting mass.

In actively composting material, much more air flow is required to remove excess heat than is required to provide adequate oxygen tension [3]. Therefore, it is usually advantageous to connect the blower to a temperature feedback system that automatically activates the blower when the compost temperature reaches or exceeds a specified temperature.

The highest technological level of composting is known as "in-vessel" composting. In this process, the material to be composted is placed inside a large containment vessel which is equipped with a temperature-controlled aeration system. This system provides for complete physical containment of the composting material and is desirable if highly toxic substances are involved. Many in-vessel systems are also equipped with a mechanism to periodically mix or agitate the composting material.

Aspects of these technological levels may be combined to fulfill the requirements of a given application. For instance, if physical containment of the compost material is extremely important and the volume of material to be treated is too large for a commercial in-vessel system, a static pile type system can be built inside a shed or similar containment device.

Regulatory concerns

The basic concerns from a regulatory/environmental point of view are: physical containment of the composting material, formation and migration of leachate, emissions of volatilized chemicals, and ultimate disposal of the compost residue.

Physical containment of solid material and leachate pose no particular problems, especially in an in-vessel system. In a static pile application, leachate formation may be reduced or eliminated simply by building the compost pile(s) under a roof or inside a building to prevent precipitation from hitting the pile.

Air emissions may be of considerable concern, depending on several factors. The volatility of the parent substances to be degraded as well as potential biotransformation products must be considered. If a mechanical aeration system is utilized, the manner in which it is operated (drawn or forced aeration) can have an impact on air emissions.

There is evidence that suggests that forced aeration provides more uniform air flow through the solid matrix than drawn aeration does (3). However, air is forced out of the compost from all points and control of air emissions is difficult unless the whole system is inside an enclosed structure. The use of drawn aeration provides for collection of all exhaust gasses at a central point, the blower. Exhaust gasses may be conveniently passed through an activated carbon scrubber or possibly a pile of uncontaminated compost to remove volatile organics. However, some passive volatilization will still occur at the surface of the composting material when the blower is turned off. If emissions of

this magnitude pose regulatory or safety concerns, the only recourse is to contain the entire operation inside a containment building.

Of paramount importance is the manner in which the final compost residue is disposed of. The primary objective of hazardous materials composting is to produce an innocuous end product from a formerly hazardous material. If the composted residue is considered a Resources Conservation and Recovery Act (RCRA) waste, there is little point in composting the material in the first place.

The obvious starting point for evaluating a compost residue is quantitative analyses of contaminants that were initially present in the waste and also of possible transformation products. However, due to the manner in which organics are degraded in compost, chemical analyses alone may not be adequate to declare the residue "non-hazardous".

There is evidence that chemicals that are not completely mineralized may be biologically transformed to organic products which chemically react with and actually become part of the compost residue [6,7]. Details of this work are presented in the next section. The potential environmental hazard of such a compost residue cannot be objectively analyzed by analytical data alone. Toxicity tests with aquatic and/or terrestrial organisms may be appropriate.

Previous work in composting of explosives-contaminated soils and sediments

The manufacturing and handling of explosives has led to contamination of soil, sediment, and groundwater at some U.S. Army munitions facilities; often as a result of previously acceptable disposal practices. These explosives include 2,4,6-trinitrotoluene (TNT), hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX), and octahydro-1,3,5,7-tetranitro-1,3,5,7-tetraazocine (HMX).

Previous research has shown that the explosive trinitrotoluene (TNT) is microbially transformed but not mineralized in soil and activated sludge environments [6,8,9]. Known transformation products of TNT include diaminotoluene and aminodinitrotoluene isomers.

Past lab-scale composting work with ^{14}C -trinitrotoluene (^{14}C -TNT) has shown that 66.5% of the ^{14}C activity became tightly bound to (or incorporated into) the compost residue after six weeks of thermophilic composting and could not be extracted using conventional solvent-extraction procedures [6,7]. Combustion of the residue resulted in the quantitative release of ^{14}C activity as $^{14}\text{CO}_2$. The exact fate mechanisms involved could not be deduced from the data. Mineralization of ^{14}C -RDX to the extent of 37 to 46% has been demonstrated in lab-scale composting studies [7].

Field demonstration — Louisiana Army Ammunition Plant (LAAP)

A field-scale demonstration of static-pile composting was conducted at the Louisiana Army Ammunition Plant (LAAP) [2,4]. Disposal of munitions pro-

cessing wastes in unlined lagoons had resulted in contamination of sediments and ground water with TNT, RDX, and HMX.

Two aerated static piles were constructed, one was maintained at approximately 35°C (mesophilic) and the other at approximately 55°C (thermophilic). The mixture to be composted consisted of the following materials (in percent by weight); explosives-contaminated sediment, 24%; alfalfa, 10%; used livestock bedding (straw/manure), 25%; and horse feed, 41%. A trace quantity of agricultural fertilizer was also added to provide supplemental nitrogen and phosphorus.

The aerated static piles were of approximately 10 cubic yards (7.6 m³) in volume and were built on concrete pads beneath elevated roofs to minimize leachate formation. An aeration system consisting of 4-inch (10-cm) diameter perforated drainage pipe and a mechanical blower was provided for each pile. The blowers were operated in drawn aeration mode and were controlled by programmable timers. After initiation of the compost piles, the blower timers were periodically adjusted to maintain compost temperatures in the mesophilic and thermophilic temperature ranges, respectively.

The compost piles were maintained for 153 days. Compost temperature was continuously recorded at several points within each pile. Grab samples were periodically taken for moisture content and explosives (and biotransformation product) analyses. The compost piles were periodically watered and remixed to maintain proper moisture content and enhance the homogeneity of the material.

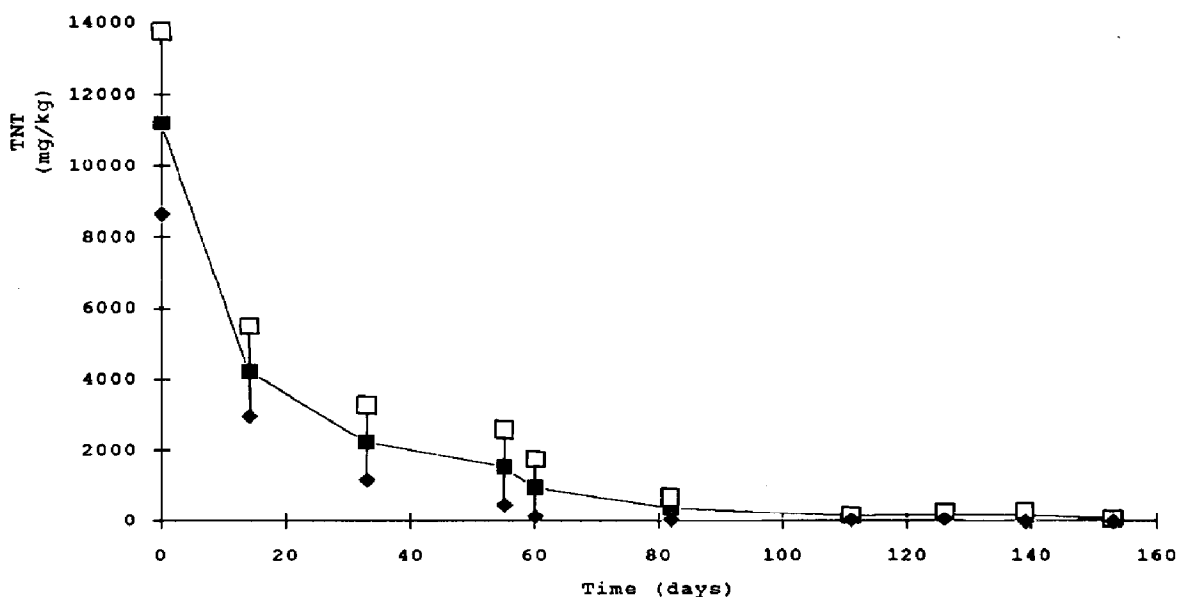


Fig. 1. Degradation of TNT in LAAP mesophilic compost pile (error bars indicate \pm one standard deviation).

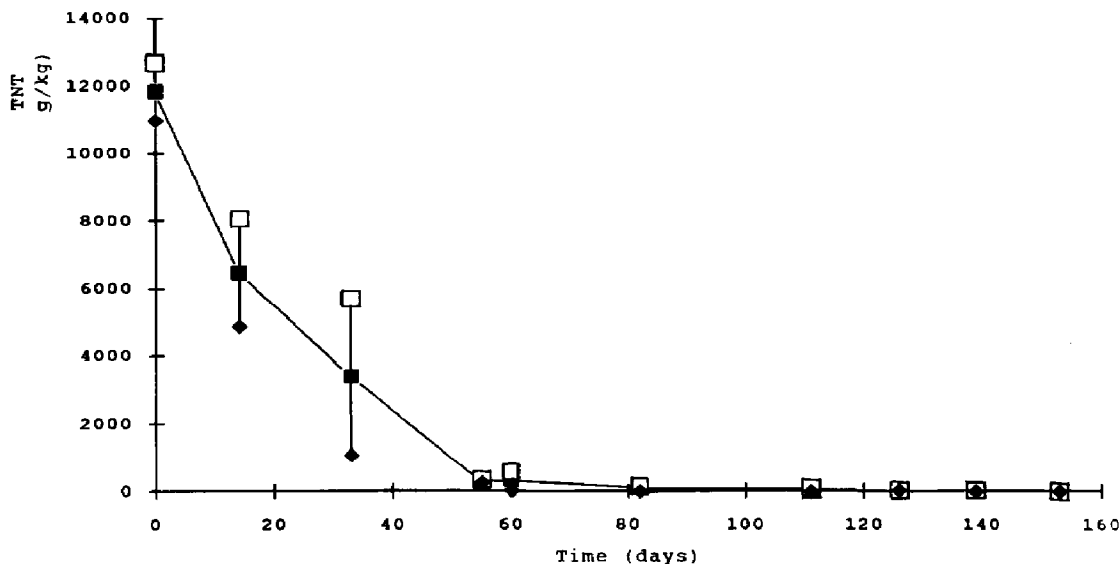


Fig. 2. Degradation of TNT in LAAP thermophilic compost pile (errors bars indicate \pm one standard deviation).

All three of the major explosive contaminants were significantly degraded in both compost piles. The thermophilic temperature range proved more effective than the mesophilic range (Figs. 1 and 2). TNT was degraded to the greatest extent, from an initial concentration of 11,840 mg/kg to 3 mg/kg in the thermophilic pile (Fig. 2). The concentration of known TNT biotransformation products increased rapidly after start-up and decreased to near detection limits after 153 days (Fig. 3).

Moisture was rapidly depleted in both piles (Fig. 4) and the piles had to be watered to maintain the moisture content. It was observed that significant variations in compost temperature occurred in the piles, lower temperatures generally being observed nearest the outer edges. This variability apparently affected the rate of contaminant degradation at different points within the piles. Multiple analytical samples were taken at each sampling point; the variability of the explosives analyses decreased as a function of time after the piles were remixed (Figs. 1, 2, and 3).

This field demonstration was conducted as a "proof-of-concept" study to demonstrate that composting was an effecting means of bioremediating explosives at the field scale. No attempt was made to minimize costs of the carbon sources and bulking agents or investigate the economic feasibility of the process.

At the present time, another field-scale demonstration is being conducted at the Umatilla Army Depot near Hermiston, Oregon. The primary objectives of this study are: (1) demonstrate that composting is an economically feasible alternative to incineration of explosives contaminated soils, (2) demonstrate the utility of a variety of locally available and inexpensive carbon sources and

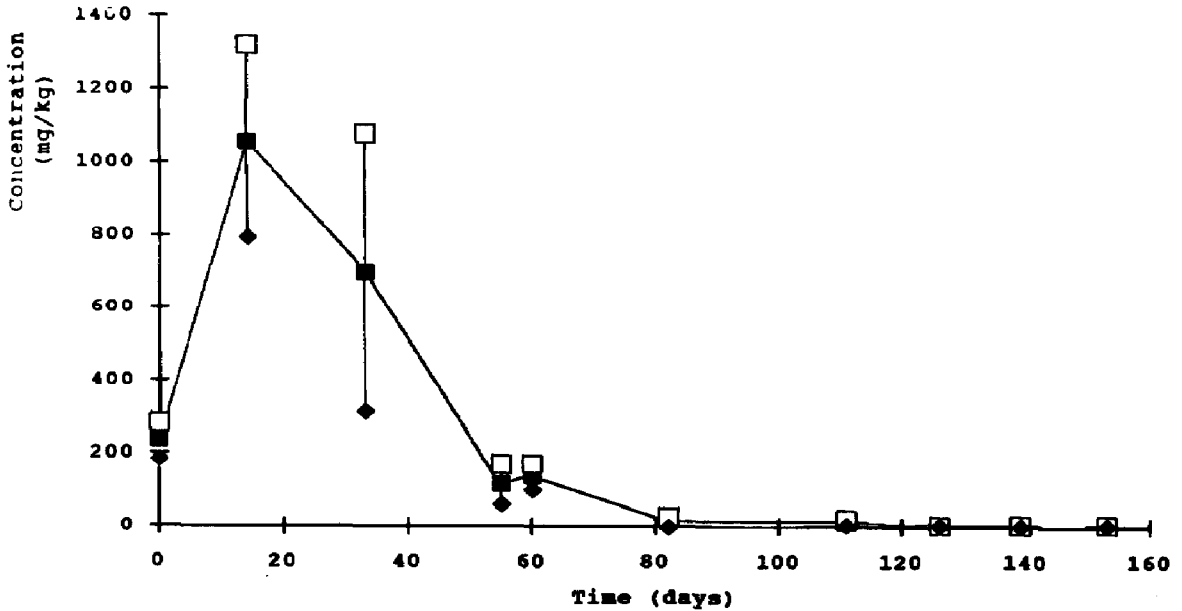


Fig. 3. Concentration of known biodegradation products of TNT in the thermophilic compost pile as a function of time.

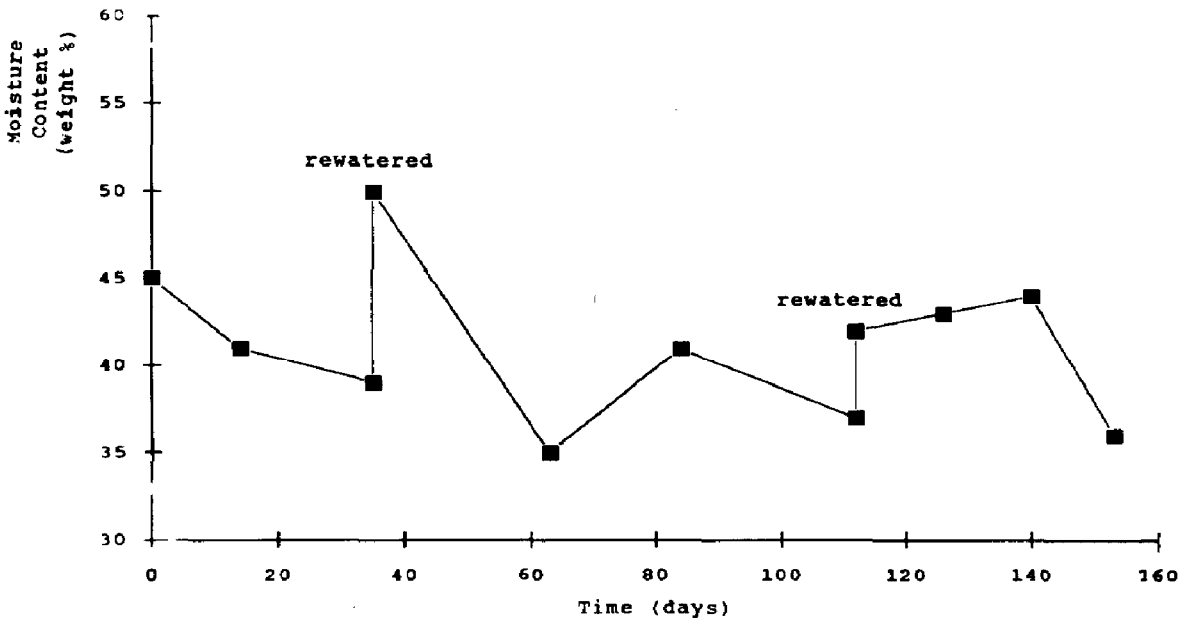


Fig. 4. Moisture content of LAAP thermophilic compost pile.

bulking agents, and (3) compare the utility of static in-vessel composting and mechanically agitated in-vessel composting for remediation of explosives-contaminated soils. Preliminary data are promising, particularly for the mechanically agitated unit.

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