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DESIGN AND TESTING OF AN EXPERIMENTAL IN-VESSEL COMPOSTING SYSTEM

Carl L. Potter and John A. Glaser
U.S. Environmental Protection Agency
Risk Reduction Engineering Laboratory
Cincinnati, OH 45268

Majid A. Dosani, Srinivas Krishnan, Timothy A. Deets, and E. Radha Krishnan
IT Corporation
11499 Chester Road
Cincinnati, OH 45246

INTRODUCTION

Composting has received much attention as a potential technology for treating solid waste. Most of that attention has been focused on treatment of municipal solid waste, sewage sludge, yard trimmings, and agricultural 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 (Ziegenfuss *et al.*, 1991).

In the composting of non-hazardous materials, the objectives are to stabilize and oxidize organic materials, reduce the volume of waste, reduce the moisture content of waste, and destroy pathogens. Composting of hazardous waste includes the same objectives plus detoxification of hazardous substances into innocuous end-products.

Optimal application of biotechnology to large-scale compost systems is based on a working understanding of processes and mechanisms involved in composting of organic material. Currently, commercial compost operations are operated as black-box systems where optimization is largely achieved through trial and error. Large-scale treatment of hazardous waste will require optimal controls to meet the specified end points.

Some proponents of compost treatment have claimed significant success in destruction of hazardous wastes without strong data to support their claims. Disappearance of parent compounds has been used to claim that microorganisms successfully degraded waste chemicals. However, some toxic chemicals could potentially adsorb to, or react with, humic substances in the compost and become undetectable by chemical analysis. Such toxicants might later desorb from humus and migrate to the biosphere. This emphasizes the need for well controlled studies to rigorously document degradation rates and identify metabolic products of hazardous chemicals, metabolically active microbial species, and mechanisms of hazardous chemical transformation in compost systems.

We have designed and tested closed bench-scale compost reactors to evaluate composting processes using contaminated soils. Identification of suitable co-compost and bulking agents, appropriate ratios of soil to organic components and effective aeration strategies and rates have been selected as major factors requiring investigation.

This research program is designed to develop a thorough engineering analysis and optimization of composting as a process to treat soil contaminated with hazardous waste. Bench-scale composters serve as diagnostic tools to predict treatment effectiveness of larger systems. Fully enclosed, insulated reactors permit reliable data collection on microbial population dynamics and fate of toxic chemicals during soil composting.

The goal of the compost study is to evaluate the potential use of compost systems in remediation of soils contaminated with hazardous chemicals. In pursuit of this goal, we have developed bench-scale composters to model large-scale systems. We are currently studying the ability of compost microorganisms to biodegrade polynuclear aromatic hydrocarbons (PAHs) in in-vessel reactors located at the U.S. EPA Test & Evaluation (T&E) Facility in Cincinnati, OH. Soils contaminated with PAHs have been obtained from the Reilly Tar Pit Superfund site in St. Louis Park, MN for use in these studies.

BACKGROUND

Optimum conditions for composting may vary depending on a number of factors, but generally aerobic conditions with 45° - 55°C temperature, 40% - 60% moisture, and a carbon to nitrogen ratio of 20:1 to 30:1 have been considered best. Mesophilic composting (35° to 55°C) might prove to be the most effective for destruction of wastes. However, it may not always be practical to maintain temperature below 55°C from an economic standpoint if it requires too much energy to maintain lower temperature.

Composting differs from other *ex-situ* soil treatment systems in that bulking agents are added to the compost mixture to increase porosity. This allows air to flow through the contaminated soil and maintain aerobic conditions. Microbial metabolism of substrate generates heat raising the temperature. Temperature changes in the pile bring about changes in the microbial ecology. Some microbes will fare better at one temperature, while others will take over as the temperature rises or falls.

The conventional aerobic compost process passes through four major microbiological phases identified by temperature: mesophilic (30° - 45°C); thermophilic (45° - 75°C); cooling; and maturation. The greatest microbial diversity has been observed in the mesophilic stage.

The early stage of composting, where the temperature rises rapidly, is called the active stage of composting. In an active compost pile, temperature can easily exceed 55°C, and temperatures as high as 70°C have been reported. Compost temperature above 55°C becomes lethal to most bacteria. Microbes found in the thermophilic stage have been spore forming bacteria (Bacillus spp.) (Nakasaki, et al., 1985) and thermophilic fungi (Strom, 1985; Fogarty and Tuovinen, 1991).

As aerobic microbes are killed during the thermophilic stage, aerobic activity (heat production) slows and temperature declines back into the mesophilic range below 45°. Microbial recolonization during the cooling phase brings the appearance of mesophilic bacteria and fungi whose spores withstood the high temperatures of the thermophilic stage.

A maturation, or curing, phase is the final compost stage. By this stage, most digestible organic matter has been consumed by the microbial population, and the composted material is considered stable. Fungi and Actinomycetes may dominate the eco-system during the curing stage.

REACTOR DESIGN

Prototype composter evaluation at the U.S. EPA T&E facility has proceeded through several different designs. The performance of each design was evaluated by conducting a treatability experiment using PAH-contaminated St. Louis Park soil. For our design criteria, one particular prototype offered considerable versatility. This design was used to build stainless steel reactor units.

Ten 55-gal, insulated, stainless steel composters have been fabricated to perform closely monitored treatability studies. These fully enclosed, computer monitored, bench-scale reactors hold about 1/4 cu. yd total compost mixture.

The reactor units stand upright with air flowing vertically through the compost mixture. Enclosed units permit online analysis of oxygen, carbon dioxide, and methane at inlet and exit locations. A data capture system accumulates these data and transmits them to the central computer that monitors and controls each reactor. XAD traps in the exit line of each composter permit trapping of volatile organic compounds (VOCs) for analysis.

The bottom of each reactor consists of 2 in. gravel contained above a conical collection system for periodic sampling of any leachate leaving the reaction mixture. Mass balance studies on soil contaminants are possible by direct sampling of the reaction mixture at different depths through bung holes in the lid, together with capture of VOCs and leachate leaving the reactor.

Periodic determination of compost moisture content in each reactor unit permits adjustment of total moisture content in the compost matrix to 40% to 50%. Moisture condensers inside compost units promote recycling of moisture. Otherwise, with typical air flows, each unit could lose significant amounts of water daily. If moisture falls below 40%, a water distribution system inside the reactor may be used to facilitate water addition to the reaction mixture without opening the reactor.

Cylindrical reactor design permits mixing of reactor contents by rolling each unit on a drum roller at desired intervals. Mixing can be used to break up anaerobic pockets and to avoid packing of the compost mixture. All reactors are mixed simultaneously by placing them on rollers over a modified conveyor belt that forces the reactors to turn in unison. Baffles inside reactors promote mixing of the compost during rolling.

An insulated space between the reactor core and the outer shell reduces heat loss from the reactor during aerobic activity. Heating coils in this space provides the option of warming the reactor to accelerate composting during startup. Each composter houses five thermocouples connected to a central computer for online temperature measurements. Thermocouples reside at four equally spaced locations within the compost mixture and a fifth thermocouple tracks ambient temperature outside the reaction vessel.

One operational scheme permits temperature control by introduction of ambient air through a computer controlled valving system. If the mean temperature of the middle two reactor thermocouples exceeds a predetermined high value, the computer switches that unit to high air flow (20 L/min) to cool the reaction mixture. After the high-temperature unit cools to a specified low temperature, the computer switches the unit back to low air flow (5 L/min) to reduce further heat loss from the reaction mixture.

CURRENT RESEARCH

Current studies focus on defining acceptable operating conditions and process characteristics in order to establish suitable parameters for treatment effectiveness. Parameters of interest include aeration, moisture dynamics, heat production, and physical and chemical properties of the compost mixture.

Aeration studies evaluate porosity (air flow) in the compost system, and attempt to discover relationships between free air space, forced air flow, and composting rate. Aeration studies also investigate roles of anaerobic and aerobic metabolism in chemical degradation. Anaerobic pockets may benefit the process by initiating degradation of recalcitrant compounds, especially highly chlorinated compounds, via reductive metabolism. After an initial reductive step, aerobic biodegradation of toxicants may proceed more readily. The research program will attempt to identify optimal aeration rates and pile mixing frequency for the most effective combination of anaerobic/aerobic conditions for biodegradation of recalcitrant substrates. These studies will investigate whether forced anaerobiosis and inoculation with a facultative anaerobe prior to development of aerobic compost conditions enhances biodegradation of toxic wastes.

Moisture dynamics studies evaluate rates of change in moisture content for different regions of the compost reactor. Moisture may be lost through evaporation and convection. Changes in moisture content are attributable to factors such as aeration rate, temperature, and compost composition (e.g., soil type and co-compost material).

Heat production may be highly variable throughout the compost reactor. We have devised a method to continually monitor temperature changes (heat production) at various reactor locations. Bench-top composters are insulated to control heat loss, thereby mimicking a large scale compost pile where heat is lost by ventilation and water evaporation more than by conduction.

A preliminary study was performed on PAH-contaminated soil mixed with 1% by weight fresh cow manure and 50% by volume ground corn cobs. Reactor core temperature ranged from 20°C to 60°C when moisture content was below 52%. However, when moisture content exceeded 57%, temperature remained below 30°C, suggesting that aerobic metabolic activity was inhibited at moisture content 57% under these conditions.

Critical properties of the compost mixture include density (g/cc), pH changes in various reactor locations, pressure drop across the pile if it is actively aerated, solids fraction, moisture content, and concentrations of organic compounds. These investigations focus on potential to enhance biodegradation by manipulation of physical and biological parameters that influence the process. These studies will also investigate whether recycling mature compost material into fresh compost enhances biodegradation of contaminants.

Early microbiological studies have focused on enumerating total microorganisms and determining the presence of PAH degraders. Current studies focus on characterizing changes in biological activity during the four stages of composting and identifying microbial species responsible for significant biodegradation of PAHs during each compost stage. Reappearance of fungi and other mesophiles (e.g. Actinomycetes) during the cooling stage is also of interest.

FUTURE RESEARCH

Future investigations will include treatability studies on pentachlorophenol and other soil contaminants. Research on technical developments necessary to improve composting applications for degradation of hazardous waste will remain as a primary objective. To judge the abilities of microorganisms to degrade hazardous wastes in soil under various compost conditions, emphasis will be placed on determining mass balance of contaminants and degradation products in compost, and identifying microbial species responsible for biodegradation of contaminants.

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FOR MORE INFORMATION

Carl L. Potter, U.S. Environmental Protection Agency, Risk Reduction Engineering Laboratory, Cincinnati, Telephone (513) 569-7231, FAX (513) 569-7105.