

State University System of Florida
Florida Center for Solid and Hazardous Waste Management
PROJECT SUMMARY

TITLE: Control of Odors from Construction and Demolition Debris Landfills

COMPLETION DATE: August 31, 2003

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OBJECTIVES: Odors at landfills can result from both waste materials and their degradation products emitted from the landfill during routine operations and as landfill gas is produced. While many compounds can cause malodorous conditions, hydrogen sulfide has been identified as a major contributor to odors at landfill sites that receive wastes with high levels of sulfur. In particular, construction and demolition debris has been found to contain significant amounts of wallboard (the major component of wallboard is gypsum or calcium sulfate). The objective of this research, therefore, is to estimate the amount and variation of H₂S production at C&D landfills and to evaluate the impact of alternative cover materials to mitigate H₂S emissions.

METHODOLOGY: Project objectives will be met by conducting a literature search, constructing a flux chamber, measuring H₂S emissions at C&D landfills, evaluating the effect of alternate covers in reducing emissions, and preparing a guidance document for C&D landfill operators.

RATIONALE: Few waste management issues create more public displeasure than the production of odors at landfills, particularly landfills located near residential areas. While many compounds can cause malodorous conditions, hydrogen sulfide has been identified as a major contributor to odors at landfill sites that receive wastes with high levels of sulfur. The data generated from this study will quantify sulfide emissions from several Florida C&D landfills. These data will permit an evaluation of the magnitude of sulfide emissions from landfills experiencing odor complaints. The application of experimental covers will be investigated relative to the reduction in sulfide emissions providing a quantifiable measurement of odor reduction. The research will provide design and operational guidance related to odor generation at landfills receiving waste with high sulfur content. This information can make landfilling safer and reduce nuisance complaints.

ACCOMPLISHMENTS: The PIs are completing an estimate of the amount and types of C&D waste generated in the state of Florida. Dr. Townsend is completing laboratory work evaluating alternative covers for odor control.

Control of Odors from Construction and Demolition Debris Landfills

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Co-Principal Investigator: Dr. Timothy G. Townsend, University of Florida

Introduction

Few waste management issues create more public displeasure than the production of odors at landfills, particularly landfills located near residential areas. While many compounds can cause malodorous conditions, hydrogen sulfide has been identified as a major contributor to odors at landfill sites that receive wastes with high levels of sulfur. Responsible landfill owners and operators must remain vigilant against situations that can lead to adverse impacts on neighboring communities.

Odor Causing Compounds. Over 100 compounds have been identified as contributors to landfill odors. These compounds are either components of waste placed in the landfills (such as halogenated hydrocarbons and aromatic hydrocarbons found in fuel products) or are degradation products (such as H₂S, sulfonated organic compounds, esters, volatile acids, or alcohols).

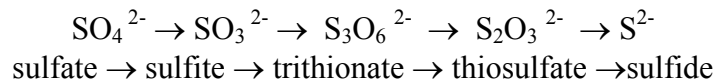
The production of odor causing compounds is a function of many variables, including the rate of gas production, types of waste landfilled, waste chemical composition, moisture content, landfill operations, local topography, depth of the site. Odor dispersion and the effect on local areas are determined by temperature, wind conditions, meteorological conditions, atmospheric stability and pressure (Hobbs et al, 2000).

H₂S in Landfill Gas. H₂S in landfill gas is regulated as a Hazardous Air Pollutant under the New Source Performance Standards of the Clean Air Act. Most are familiar with the “rotten egg” odor associated with H₂S, however the gas can lead to immediate fatality at 1000 ppm. Even short exposure at lower concentrations can have long-lasting adverse health effects. While its odor can be detected at concentrations as low as 50 ppb, at higher concentrations, H₂S can no longer be smelled (Flynn, 1996).

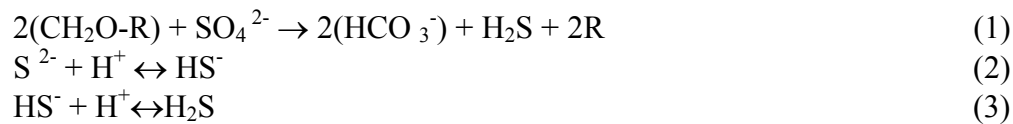
Hydrogen sulfide is produced naturally in various locations including hot sulfur springs, in anoxic sediments and mud, bogs and marshes, and lower water layers of freshwater, marine, and hypersaline environments (Atlas, 1997). Anthropogenic sources of hydrogen sulfide include wastewater treatment and agricultural water as well as the industries of kraft paper manufacturing, oil refining, petroleum coke manufacturing, and tanneries (Vesilind et al., 1994). The source of sulfate in the environment is organic sulfur-containing compounds. In the sulfur cycle, reduction of sulfur compounds occurs in anaerobic environments and oxidation of sulfur compounds occurs in aerobic environments.

Landfills may contain many of the same microorganisms that inhabit the natural environment where hydrogen sulfide is produced. The microorganisms responsible for generating hydrogen sulfide include sulfate-reducing bacteria and sulfur-reducing bacteria. They are divided into four subgroups. The first subgroup consists of spore-forming sulfate-reducing bacteria. The second subgroup consists of sulfate-reducing bacteria that produce acetate from the incomplete oxidation of organic substrates. The third subgroup consists of sulfate-reducing bacteria that produce carbon dioxide (CO₂) from the complete oxidation of organic substrates. The fourth subgroup consists of sulfur-reducing bacteria.

Many microbes are capable of metabolizing sulfates and taking sulfur into their cell structure. The sulfur is assimilated into the organisms' protein or built into co-factors such as panthothenic acid and biotin. These microbes release a small amount of hydrogen sulfide. Sulfate-reducing bacteria are different, however, in that they use the sulfur as electron acceptors when oxidizing organic matter during sulfate respiration. Sulfate respiration only occurs with sulfate-reducing bacteria. They assimilate a small amount of sulfur, as virtually all of the sulfur they use is released as hydrogen sulfide. Sulfate respiration (dissimilatory sulfate reduction) generates many times the amount of hydrogen sulfide than assimilatory sulfate reduction and subsequent desulfuration (Postgate, 1984). Sulfate-reducing bacteria use electrons to reduce sulfate in the following equation:



This dissimilatory sulfate reduction gives adenosine triphosphate (ATP), a major carrier of phosphate and energy, to cells (Atlas, 1997). The sulfate ion may be biochemically reduced to form hydrogen sulfide by the following bacterial reaction (Dohnalek and FitzPatrick, 1983):



In reaction 1 $\text{CH}_2\text{O-R}$ represents organic matter and SO_4^{2-} is the sulfate ion. The products are bicarbonate (HCO_3^-), hydrogen sulfide (H_2S), and an undefined radical (R). Reactions 2 and 3 are not related to bacterial action. S^{2-} is sulfide and HS^- is the bisulfide ion.

Hydrogen Sulfide Chemistry. Hydrogen sulfide is a soluble gas and may volatilize from its aqueous solution into the gas phase in accordance with Henry's law (Henry's Constant of 550 atm @ 25°C). The presence of hydrogen sulfide and other reduced sulfur species is dependent on pH. At pH levels above 8, most of the sulfur species exist as sulfide (S^{2-}) and bisulfide ion (HS^-). At a pH between 6 and 7, which has been observed in C&D laboratory simulations (Townsend et al., 1999; Jang, 2000) and field studies (Weber, 1999), hydrogen sulfide and bisulfide ion are the predominate species. At a pH of 7.1 and at 25°C, H_2S and HS^- are present in equal concentrations.

Construction & Demolition Debris Landfills. While gas is most often thought of as an issue with municipal solid waste landfills (methane and carbon dioxide as a result of anaerobic waste decomposition), recent experience indicates that gases are also emitted from C&D waste landfills. The primary constituents in the gas creating problems are hydrogen sulfide (H_2S) and other reduced sulfur compounds (mercaptans, methyl sulfides). The primary raw ingredient for these compounds is gypsum drywall. Gypsum drywall is composed of gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) and paper. When exposed to water, the sulfate in the gypsum becomes solubilized in the leachate. Under reduced conditions, a group of bacteria known as sulfate reducing bacteria utilize the sulfate as an electron acceptor and produce hydrogen sulfide as a by-product. Hydrogen sulfide possesses a very strong odor at very low concentrations (10 – 100 ppb) and is known to be toxic at high concentrations. Other sulfur gases produced by similar reactions possess similar foul-smelling characteristics.

C&D waste landfills often offer an ideal environment for H₂S production. They contain moisture, little or no oxygen, and other waste components provide organic matter. When large amounts of gypsum drywall are present in a landfill, and a sufficient amount of water is available, hydrogen sulfides are produced at high concentrations. The formation of hydrogen sulfide was the subject of several research studies by the author's group (Townsend et al., 2001). In one study (Lee, 2000), ten C&D waste landfills around Florida were sampled for concentrations of H₂S and other gases. In all cases, H₂S was detected at very high concentrations within the landfill. The ambient concentrations varied as a function of weather conditions. In another study (Yang, 2000), the C&D waste landfill was simulated in the laboratory and H₂S concentrations were measured. Concentrations were found sometimes greater than 10,000 ppm. Other results of interest included the fact that gypsum drywall alone (i.e. without another source of organic matter) was sufficient to result in high H₂S concentrations and the fact that concrete played a major role in the migration of the gas.

Odor at Florida Landfills. Several landfills throughout the State of Florida have had odor problems that are believed to be caused by the degradation of gypsum drywall. The landfills with the most public attention have been C&D or Class III facilities, although one MSW landfill received publicity when H₂S odors became a problem as a result of C&D debris disposal.

Sunset Sand Mine and Landfill. The Sunset Sand Mine and Landfill is a 75-acre C&D landfill located in Pasco County, Florida, and was a combination sand mine and C&D debris landfill. The site began operating as a C&D landfill in 1990, and one year later residents started complaining about an odor problem. In January 1995 the landfill was closed due to high concentrations of H₂S. Residents near the landfill were evacuated twice. In February 1995 county officials reported that the H₂S level was 3 ppm at a quarter mile around the landfill (Crosson, 1995). Levels reaching 205 ppm were found on site at ground level. At a height of more than 4 feet off the ground the H₂S concentration decreased to 50 ppm. The landfill owner had a cover layer of soil and clay placed over the exposed waste (Conner, 1995). On May 7, 1995 in the *St. Petersburg Times* reported that neighbors of the Sunset Landfill still experienced problems associated with H₂S (Smith, 1995).

Material Exchange Landfill. The Material Exchange Landfill is a C&D debris landfill in Citrus County, Florida. Originally, the site was a sand mine in the 1970s (Florida Department of Health, 2000). The site received 1.25 million tons of fly ash from a coal-fired power plant from 1980 to 1990, and a second C&D cell began receiving waste in 1993. Residents began complaining about odors and respiratory problems in 1994. In April 1999, a resident petitioned for the Agency for Toxic Substances and Disease Registry to evaluate the site's potential health threat (Florida Department of Health, 2000).

Pine Ridge Recycling and Disposal Facility. Pine Ridge Recycling and Disposal Facility in Orange County, Florida, received a Class III landfill permit in 1990. The disposal area covers 68.3 acres. A preliminary H₂S monitoring was undertaken in 1995 in response to residents' complaints concerning health and safety issues (Atwood and Tessitore, 1995). Three on-site monitors measured average ambient H₂S concentration over 1-minute intervals. From August through September 1995, the average H₂S concentrations from the three monitors were 0.26 ppm, 0.25 ppm, and 0.48 ppm. The maximum 24-hour average H₂S concentrations were 0.58 ppm, 0.58 ppm, and 1.25 ppm. A portable H₂S meter was used in areas surrounding the landfill. H₂S concentrations ranged from 0.1 to 0.3 ppm. The preliminary H₂S monitoring report concluded that the H₂S concentrations found were well below health and safety standards. In addition, the report concluded that several off-site sources of H₂S were the responsible sources of

odor in approximately 74 percent of the complaints reported from August through September of 1995.

G.E.L. Corp. C&D Recycling. G.E.L. Corp C&D Recycling is a C&D facility in Volusia County, Florida. The landfill processed materials on site, including wood and concrete. The Class I landfill closed in June 1983 (FDEP, 1983) and was permitted to accept C&D waste. Odor complaints started in 1997 (Burns, 1997), resulting in an air quality assessment performed in March 1998 (Atkins, 1998). Gas from the gas collection system was sampled. The laboratory analysis showed that the H₂S concentration was below the detection limit of 0.015 ppm. The testing also determined that the gas sample contained 0.11-ppm ammonia and 8.9-ppm methane.

Municipal solid waste (MSW) landfills. The Naples landfill in Collier County, Florida, is a Class I landfill that used material processed from C&D debris as an alternative daily cover. In 1998, an odor evaluation found H₂S at 15 ppm in areas of no active gas collection (Moore, 1998). In addition, "pockets" of odorous gas were detected in a range of 30 to 250 ppm at gas points of escape identified by yellow residue on the surface. At these points, surface faults with a leachate seep or a crack in the cover were observed. Seven samples were taken in March, and two samples were taken in June for volatile organic compound (VOC) analysis. The H₂S concentrations in the samples ranged from 12 ppb to 5,600 ppm in all the samples. Five samples had concentrations of carbonyl sulfide ranging from 4.9 ppb to 32 ppm. Methyl mercaptan was detected in two samples, at 4 ppb (Moore, 1998).

The Central Sanitary Landfill and Recycling Center in Broward County, Florida, is an MSW landfill. C&D debris from Hurricane Andrew's aftermath was disposed at the Central Sanitary landfill. A severe odor problem began shortly afterwards. H₂S in the landfill gas was measured up to 5,000 ppm. The H₂S caused odor problems in the surrounding residential area.

Out of State Landfills

Landfills from Florida to New York have had problems with rotten egg odors. In Princetown, New York, residents formed a group called Citizens Against the Dump in protest of a landfill with H₂S odors (Gardiner, 1998). The residents started complaining in 1995 and sent over 300 letters to the state Department of Environmental Conservation. The landfill was a MSW landfill recently turned into a C&D debris landfill. In 1998 a company was hired to monitor H₂S sulfide emissions.

A landfill in Danbury, New York, presented a problem beginning in August 1996. The rotten egg odor caused health problems, decreased property values, and in one extreme case, forced a family out of their home. The 40-acre MSW landfill that used a gas collection and flares, closed in December 1996. Florida Department of Environmental Protection (FDEP) officials say heavy rainfall, 17 inches more than normal in 1996, contributed to the odor problem.

Residents near an odorous landfill in Caroline County, Virginia, filed a \$7.5 million lawsuit against county officials (The Washington Post, 1996). The Caroline Landfill Closure Group is seeking damages from "...the release of noxious, unhealthy and toxic emission" from the landfill. The cause of the odor is believed to be from the use of a state-approved landfill cover mixture of drywall material and compost.

Odor Control. The National Resource Council recommended five odor control methodologies (Howard et al, 1985):

- Process modification,
- Dilution in the atmosphere,
- Dissolution of odor causing compounds in liquid,
- Oxidize odor causing compounds, and
- Modify odor potential.

Current landfilling practices have adopted all of these approaches. Landfill face area is minimized to the extent possible and daily cover is applied to contain odors. Fine grained material such as sawdust and pulverized fly ash have been shown to attenuate landfill odors (Gendebien et al, 1992). At many landfills gas is collected and treated using thermal and chemical oxidation, wet gas scrubbers (Francoeur, 1993), activated carbon adsorption, and biofilters (Nagl and Cantrall, 1996). Passive venting through open bed biofilters constructed as part of landfill covers is a well-established method of destroying H₂S (Damman et al, 1999). Short-term remedies involving odor masking have been frequently attempted. Odor neutralizing oils have been used as well (Otieno and Magagula, 1999).

Objectives

Odors at landfills can result from both waste materials and their degradation products emitted from the landfill during routine operations and as landfill gas is produced. While many compounds can cause malodorous conditions, hydrogen sulfide has been identified as a major contributor to odors at landfill sites that receive wastes with high levels of sulfur. In particular, construction and demolition debris has been found to contain significant amounts of wallboard (the major component of wallboard is gypsum or calcium sulfate). Consequently C&D landfills can be major sources of H₂S and are frequently the target of complaints from unhappy neighbors. The objective of this research, therefore, is to estimate the amount and variation of H₂S production at C&D landfills and to evaluate the impact of alternative cover materials to mitigate H₂S emissions.

Methodology

The approach proposed for conducting this research includes the following tasks (Table 1 provides a timeline for project completion):

Task 1. Literature review. The technical literature will be searched for information regarding control of odors from C&D debris and municipal solid waste in landfills.

Task 2. Construction of flux chamber. A flux chamber specifically adapted for this project will be constructed. The flux chamber is a device that has been used to make direct emission rate measurements from land or liquid surfaces such as MSW landfills, chemical spill sites, surface impoundments, and natural sediments (Rash, 1993). The flux chamber technique was originally developed for quantifying sulfur dioxide emissions from biogenic sulfur sources and later modified to measure emission rates of nitrous oxide and VOCs (Hwang, 1985). The technique uses a small diameter enclosed chamber mounted on top of an emission source. A controlled flow of clean, dry "sweep" air is added to the chamber, allowed to mix, and then released through the chamber exit ports. The concentrations of the emitted species of interest are measured in the exit gas, which are then used to calculate the emission rate of each species.

The emission rate of each species can be determined via two methods, both of which are based on a mass balance describing the chamber concentrations of each species. The mass balance equation is based on the processes shown in Figure 1. In Figure 1, Q_L and Q_S represent the flow rates of all emitting gases and sweep air respectively; C_L , C_E , and C_S represent the subsurface gas, chamber

exiting gas, and sweep air gas concentration of a given gas species respectively, V represents the chamber volume, and A represents the emission source area enclosed by the chamber.

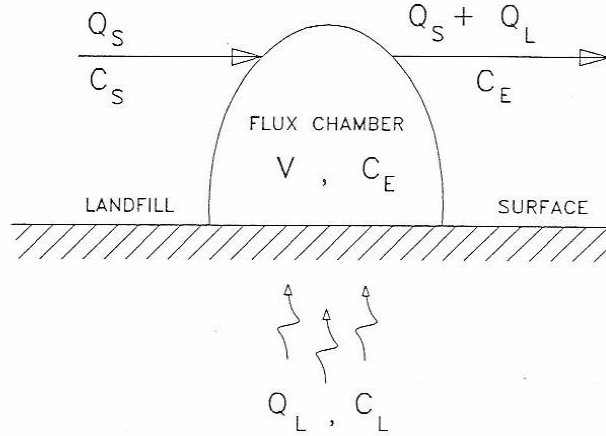


Figure 1. Schematic Flow Diagram of a Flux Chamber

Equations 1 and 2 are developed on the assumption that the chamber can be represented as a continuously stirred tank reactor (CSTR) and that C_S equals 0.

$$\frac{VdC_E}{dt} = Q_L C_L - (Q_L + Q_S) C_E \quad (1)$$

$$\text{Solving for } C_E: C_E = \frac{Q_L C_L}{Q_S + Q_L} [1 - \exp(-t/\tau)] \quad (2)$$

$$\text{Where: } \tau = \frac{V}{Q_L + Q_S}$$

The first method ("steady-state method") of determining gas emission rates is based on steady-state exiting gas concentrations, C_E , and the assumption that Q_L is much smaller than Q_S . Thus Q_L can be neglected in the denominator of the non-exponential term. At steady state, the exponential term becomes zero. Practically, this is achieved at time equal to 4τ . Thus Equation 2 collapses to Equation 3.

$$C_E = \frac{C_L Q_L}{Q_S} \quad (3)$$

$$\text{Thus: Flux} = \frac{C_E Q_S}{A} \quad (4)$$

The second method ("slope method") of determining gas emission rates is based on Equation 1 and the assumption that C_E is approximately 0 at time close to 0. In this case, Equation 1 collapses to Equation 5.

$$\frac{dC_E}{dt} = \frac{Q_L C_L}{V} \quad (5)$$

The proposed flux chamber for landfill gas emission measurements features a stainless steel, spherical, half-dome geometry chamber which serves as a completely mixed reactor. The chamber will be clamped to a stainless steel cylindrical skirt that can be inserted into the landfill surface. Detachable skirts lighten the chamber, and facilitated sampling at multiple locations. The dome will be 32 cm in diameter and 41 cm in height. Peripheral supporting equipment includes a sweep air cylinder, a sweep air rotameter, a chamber pressure gauge and thermometer, and a Gerome meter for H₂S measurement. Figure 2 provides a diagram of the chamber and peripheral equipment. The materials used to construct the flux chamber will be stainless steel and Teflon. These inert materials provide excellent corrosion resistance properties. This design has been thoroughly tested at UCF (Rash, 1993).

Task 3. Flux measurement at C&D debris and Class III landfill sites. While previous Center-funded studies have collected information on the concentration of H₂S at C&D debris landfill sites, actual emission rate of H₂S from landfills have not been measured (gas from C&D debris landfills is not controlled the same way MSW landfill gas is). The flux chamber constructed in Task 2 will be used to measure emission rates from C&D debris landfill surfaces. Approximately five sites will be identified for H₂S flux measurement. At least 20 measurements will be taken at each site to examine temporal and spatial variations. Several target sites are under consideration, including a site in Highlands County and a site in Orange County.

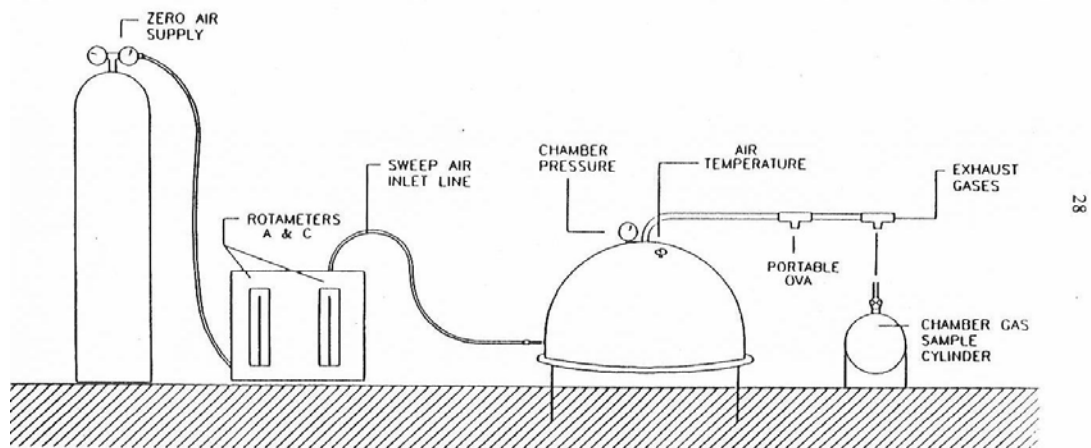


Figure 2. Proposed Flux Chamber and Peripheral Equipment.

Task 4. Small-scale cover alterations. Previous research (Townsend et al. 2000) found that some materials naturally present in C&D debris have the ability to react with H₂S to remove it from the gaseous phase (particularly concrete). This observation led the investigators to test the idea of amending landfill cover soil with an inexpensive material (e.g. crushed concrete fines, lime) to create a “filter” for removing the H₂S. This concept is currently being tested (under a project sponsored by the Center) in the laboratory. Several different laboratory columns have been constructed and filled with size-reduced gypsum drywall. Different cover soils have been placed on top of the waste and the flux of H₂S out the surface of the columns is being measured. The cover soils that have been evaluated to date include a sandy, a clayey and an organic soil. A lime-amended sand is also being evaluated as well as different sizes of crushed concrete. Preliminary results indicate that fine crushed concrete and the lime-amended soil reduce the flux of H₂S through the soil significantly greater than unamended soils.

The proposed project will evaluate this concept in the field. Small-scale cover alteration will be performed at one site in an area recognized to be emitting relatively high levels of H₂S. Task 4 will therefore begin after task 3 has been underway for a few months. The cover soil used at most C&D debris landfills consists of soil excavated on site. Since cover requirements are less stringent for C&D debris landfills as compared to MSW landfills, the cover practices at sites may differ. Landfills that have had odor complaints often use more cover than other facilities, and thus the landfill where the alternative soil test will be conducted is likely to large areas where testing can occur. A test area on the surface of the landfill will be identified and divided into a sampling grid. The available area at the site will determine the size of the sampling grid, but a 10 ft by 10 ft grid size is a preliminary target. The number of different covers tested at the site will be determined by the results that are currently underway, but a minimum of 4 scenarios will be investigated:

1. Existing cover soil
2. Existing cover soil amended with lime
3. Crushed concrete fines
4. Compost or similar highly organic material

A minimum of three grid areas will be designated for each cover type (for a total of 12 test sections). Flux measurements (at least one per section) will be taken before and after applying the cover materials. Special care will be taken to note the conditions of the site. The occurrence of recent rainfall could have a great impact. Flux chamber measurements will be taken biweekly.

Task 5. Technical Guidance Document. A guidance document will be developed to aid landfill operators in mitigating odors using cover modifications.

Timeline and Milestones

Table 1 provides a proposed timeline for completion of the project.

Table 1. Project Gantt Chart

Task	Month (Start Date August 1, 2002)											
	1	2	3	4	5	6	7	8	9	10	11	12
Literature Search	█	█										
Flux Chamber construction	█	█	█									
Flux Measurements			█	█	█	█	█	█	█	█		
Cover Alterations						█	█	█	█	█	█	
TAG Group Meetings	█			█			█				█	
Final Report											█	█

Technical Results

The data generated from this study will quantify sulfide emissions from several Florida C&D landfills. These data will permit an evaluation of the magnitude of sulfide emissions from landfills experiencing odor complaints. The application of experimental covers will be investigated relative to the reduction in sulfide emissions providing a quantifiable measurement of odor reduction.

Anticipated Benefits for End Users

The research will provide design and operational guidance related to odor generation at landfills receiving waste with high sulfur content. This information can make landfilling safer and reduce nuisance complaints.

Deliverables

Deliverables include quarterly reports, an annual report, minutes of TAG meetings, a project web site, and papers for presentation and publication.

Related Work

The Principal Investigators are both involved in a Center-sponsored project Management of construction and demolition (C&D) debris is a growing concern, however, C&D waste has not been well characterized. Only recently (1997) did the U.S. EPA publish an estimate of C&D generation rates on a national basis. These results may not, however, be representative of C&D waste generation in Florida. Florida is one the most rapidly growing states in the nation and does not have the aging infrastructure typical of other states. This research provides a more accurate estimate of Florida C&D waste generation rates *and* composition by addressing possible differences in Florida C&D generation. The same methodology used for the national study has been applied to Florida. Where appropriate, the study has been modified to produce a more accurate estimation. The research will be completed in 2002.

The Co-Principal investigator is currently involved in a Center-sponsored project that is evaluating the true impacts of C&D debris landfills in Florida, along with the lab-scale testing of economic control techniques. A major focus of the work is the laboratory simulation of land disposed gypsum drywall, the production of H₂S, and the use of alternative or amended cover soils for the removal of H₂S. The cover soils that have been evaluated to date include a sandy, a clayey and an organic soil. A lime-amended sand is also being evaluated as well as different sizes of crushed concrete. Preliminary results indicate that fine crushed concrete and the lime-amended soil reduce the flux of H₂S through the soil significantly greater than unamended soils. This work provides a background for the field-testing of this concept.

Possible Follow Up

Several avenues of follow up work could be pursued upon the successful completion of this research proposed here. Scaling the fieldwork up to larger areas or sites would be a logical step. Working with a landfill operator to implement this technique and to assist them in developing operating protocols would be a great help to those in the industry desiring to implement this technology. Additional materials could also be used. Several waste byproducts have characteristics that make them potential candidates for removing H₂S. One example would be drinking water sludge from a lime softening facility.

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