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In-Situ Municipal Solid Waste Composting Using an Aerobic Landfill System

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Abstract

Municipal solid waste (MSW) landfills worldwide are experiencing the consequences of conventional landfilling techniques, whereby anaerobic conditions are created within the landfill waste. Under anaerobic conditions, slow stabilization of the waste mass occurs, producing methane, (an explosive, "green house" gas) and toxic leachate over long periods of time. In attempts to reduce the production of this leachate, composite soil cap systems are constructed over landfilled waste. To reduce the release of leachate into the environment, many landfills use sophisticated subsurface liner and leachate collection systems. However, these cap, liner, and collection systems ultimately fail, potentially releasing methane gas and leachate to air and groundwater. As a result, this design approach only postpones the inevitable risks associated with landfills.

As a solution, it was demonstrated that aerobically degrading MSW within a landfill can significantly increase the rate of waste decomposition and settlement, decrease the production of methane gas, reduce the level of toxic organics in the leachate, and decrease quantities of landfill leachate that need treatment. Through a technology transfer initiative supported by the U.S. Department of Energy (DOE), an aerobic landfill system (ALS) was installed and operated within a 16-acre Subtitle D MSW landfill near Augusta, Georgia (USA). Readily integrated into the landfill infrastructure, an ALS can safely and cost-effectively convert a MSW landfill from anaerobic to aerobic degradation processes, thereby composting much of the organic portions of the waste. As a result of increased waste decomposition, stabilization, and settlement, not only are landfill operating costs reduced, but the life of the landfill can be extended, potentially increasing revenues. It was also shown that by properly controlling the injection of air and leachate into the waste mass, waste mass temperatures remained stable between 40 and 60 degrees C. Through the continued development of this technology, the ALS will foster a new perspective on landfilling waste, and, at the same time, reduce the cost burdens of landfill operations and/or site remediation.

I. Introduction

A. The Consequences of Anaerobic Waste Decomposition

Many of the world's landfills are becoming significant risks to the environment. Past and present day landfill designs include soil and/or plastic barriers above and below the waste in an attempt to reduce the infiltration of moisture into the waste mass and thus into the environment. This design approach creates a "dry-tomb" environment within the landfill and induces anaerobic degradation of the waste. Over time, anaerobic decomposition of sanitary wastes can have effects on landfill operations which actually increase the potential for risks to human health and the environment. These risks include:

- the potential for an increase in leachate strength, as well as organic and metals compounds concentrations in the leachate;
- possible formation of toxic daughter compounds in the leachate, such as vinyl chloride; and,
- slow stabilization of waste mass, increasing the potential for leachate releases through the landfill's liner systems.

In addition, anaerobic conditions within a landfill result in the production of methane, an explosive, odorless gas, and vapor-phase VOCs. Considered a "greenhouse gas" under the Clean Air Act, methane generated in landfills is typically in excess of 40% of the total landfill gases. In some cases, VOCs present in the landfill gas have been identified as a source of groundwater contamination. At many landfills, these gases are required to be collected, controlled (flare or other end use), and monitored to minimize the risks of gas build up and/or fires as well as to comply with environmental regulations.

Although the "dry-tomb" approach is an attempt at reducing toxic releases from a landfill, this approach is a temporary solution. According to the EPA, "liner and leachate collection [systems] ultimately fail due to natural decomposition..."[1] (EPA, 1988). In 40 CFR 258, EPA recognizes that "Once the unit is closed, the bottom layer of the landfill will deteriorate over time and consequently, will not prevent leachate transport out of the unit." As a result, leachate collection systems and impermeable caps do not decrease the risk that toxic constituents, typically found in aging landfill leachate, will reach local groundwater. To prepare for this, landfill owners are required to set aside funds for their own cleanups. Once the landfill begins releasing leachate, remediation must be initiated, and the waste mass is "managed" once again. The net effects of this "dry-tomb" approach can be costly, even beyond the landfill's closure.

Ironically, landfills are required to be designed using the "dry-tomb" approach. As a result, landfill owners find themselves using a solid waste management approach that will most likely fail, and only postpone high landfill costs and long-term liabilities. Although there are relatively a few landfills where waste-to-energy (WTE) is cost-effective (discussed below), the anaerobic, "dry-tomb" approach to landfills appears to be the wrong answer to long-term solid waste planning.

B. Aerobic Degradation of MSW

Active aerobic biodegradation processes, such as composting, have demonstrated for years that the biodegradable portion of MSW can be stabilized in a significantly shorter time frame (than under anaerobic conditions) by adding the proper proportions of air and moisture to the waste mass. In addition, the recirculating of the waste's own leachate through the waste mass improves degradation, whereby the recycling of moisture, and nutrients are continually made available to the respiring microorganisms indigenous to the waste.

In a landfill environment, this concept of *in-situ* aerobic biodegradation of MSW is being evaluated worldwide. Laboratory experiments, such as those conducted at the University of South Florida, have demonstrated that, in an aerobic environment, respiring bacteria convert the biodegradable mass of the waste and other organic compounds to mostly carbon dioxide and water, instead of methane, with a stabilized humus remaining[2]. Reportedly, several European and Asian countries are evaluating this approach and have begun their own aerobic landfill studies. In these cases, the landfill itself serves a large closed vessel or bioreactor, is operated as a cell, and is managed to control leachate, landfill gas (LFG), and waste recycling.

As many wastewater treatment facility operators know, aerobic treatment processes reduce concentrations of organic compounds typically found in wastewater. Compounds such as toluene, MEK, vinyl chloride, as well as many odor-causing compounds (e.g. ammonia) can be treated in aerobic lagoons, rotating beds, and fixed media systems. Using the landfill waste as a treatment bed, the ALS also promotes the aerobic treatment of the leachate in a similar manner, whereby air, moisture, and nutrients are combined together. Since the concentrations of these compounds are reduced, the need for subsequent leachate treatment could also be reduced, depending on applicable regulations. As an additional benefit, there is an increase in the rate of waste stabilization (the point at which risks associated with the waste are minimized) as well an increase in the rate of waste subsidence. This creation of landfill "air space" can maximize the useful life of a landfill.

C. Demonstration of the ALS at a Subtitle D Landfill

Through a technology transfer initiative funded by the U.S. Department of Energy (DOE), American Technologies Inc. (ATI) demonstrated the effectiveness of this concept by implementing an Aerobic Landfill System (ALS) within an active 16-acre portion of the Columbia County Baker Place Road Landfill (CCBPRL) near Augusta, Georgia (USA). Based on aerobic studies conducted to date, ATI designed, installed, and presently operates an 8-acre ALS. Since January 1997, the ALS demonstrated that this municipal sanitary landfill could cost-effectively be converted from anaerobic to aerobic degradation processes, and that aerobic degradation of the MSW can provide short- and long-term benefits for landfill operators.

With a minor modification of the landfill's operating permit, the ALS was approved by the Georgia Environmental Protection Division (EPD) within a relatively short timeframe (30 days). The system was then installed in approximately two weeks and has been operational since. Presently, designs are being developed for expansion of the system in the 16-acre landfill and discussions are currently being held with EPD for implementation of a second ALS within the 60-acre unlined landfill which lies adjacent to the Subtitle D area.

D. How the ALS Process Works

The ALS is a natural process via the addition of air (providing oxygen to the waste mass) and the recirculation leachate (providing moisture and nutrients for the indigenous, respiring microorganisms). A reliable, flexible system for adding air and leachate was designed based on several leachate recirculation studies conducted to date as well as on practical environmental remediation systems that treat soils and groundwater *in-situ*. Using readily available materials and equipment, the system was readily integrated into the existing CCBPRL infrastructure. The key to the ALS effectiveness is the proper control of aerobic conditions, whereby waste mass temperatures and moisture are maintained within optimal ranges. This is accomplished by balancing airflow and leachate recirculation into the waste mass in a manner that effectively stabilizes the waste in a much shorter time frame than under conventional anaerobic conditions.

The air injection system is comprised of electric blowers and PVC piping, connected to the existing landfill infrastructure. For landfills with an existing leachate collection system (LCS) (e.g. such as in the floor of the CCBPRL Subtitle D cell), the ALS incorporates the LCS to provide oxygen to the waste mass (it was demonstrated that the LCS could still collect leachate during air injection). Where needed, vertical air injection wells were also installed directly into the waste to provide additional oxygen. Landfills with no leachate collection systems, can be readily retrofitted with horizontal and/or vertical air injection wells.

Leachate, collected in the landfill's holding tank was pumped into the system through a PVC and flexible hose leachate recirculation system to the top of the waste. The system then injects leachate through the intermediate clay cap (which covers the waste) and into the waste mass. The leachate then percolates downward contercurrent to air that has been forced into the waste by the blowers. Leachate that is not utilized during aerobic decomposition migrates downward to the landfill's leachate collection system or recovery wells, is pumped to the tank, and recirculated through the waste mass. Landfills with no leachate collection systems, can be retrofitted with horizontal and/or vertical leachate recovery wells at locations where leachate is likely to collect. This "closed-loop" configuration reduces the potential for operator exposure to leachate and minimizes operator involvement. A schematic of a typical ALS is shown in Figure 1.

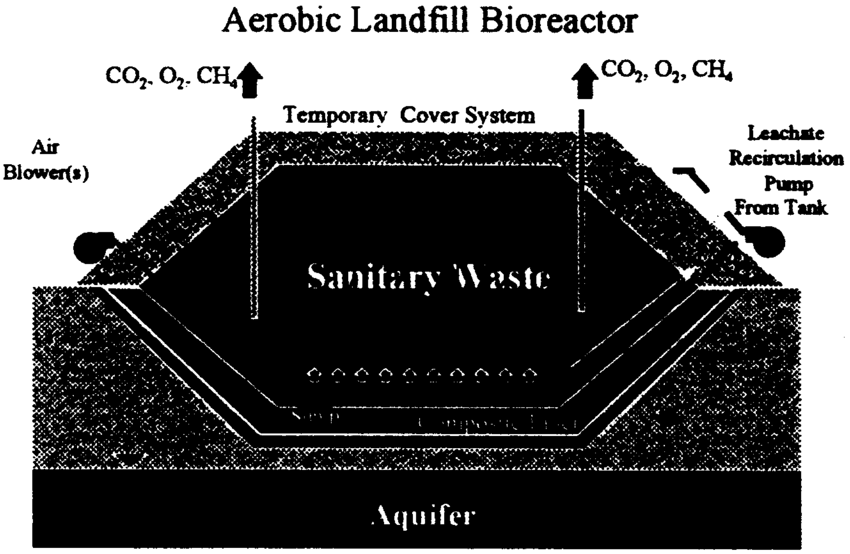
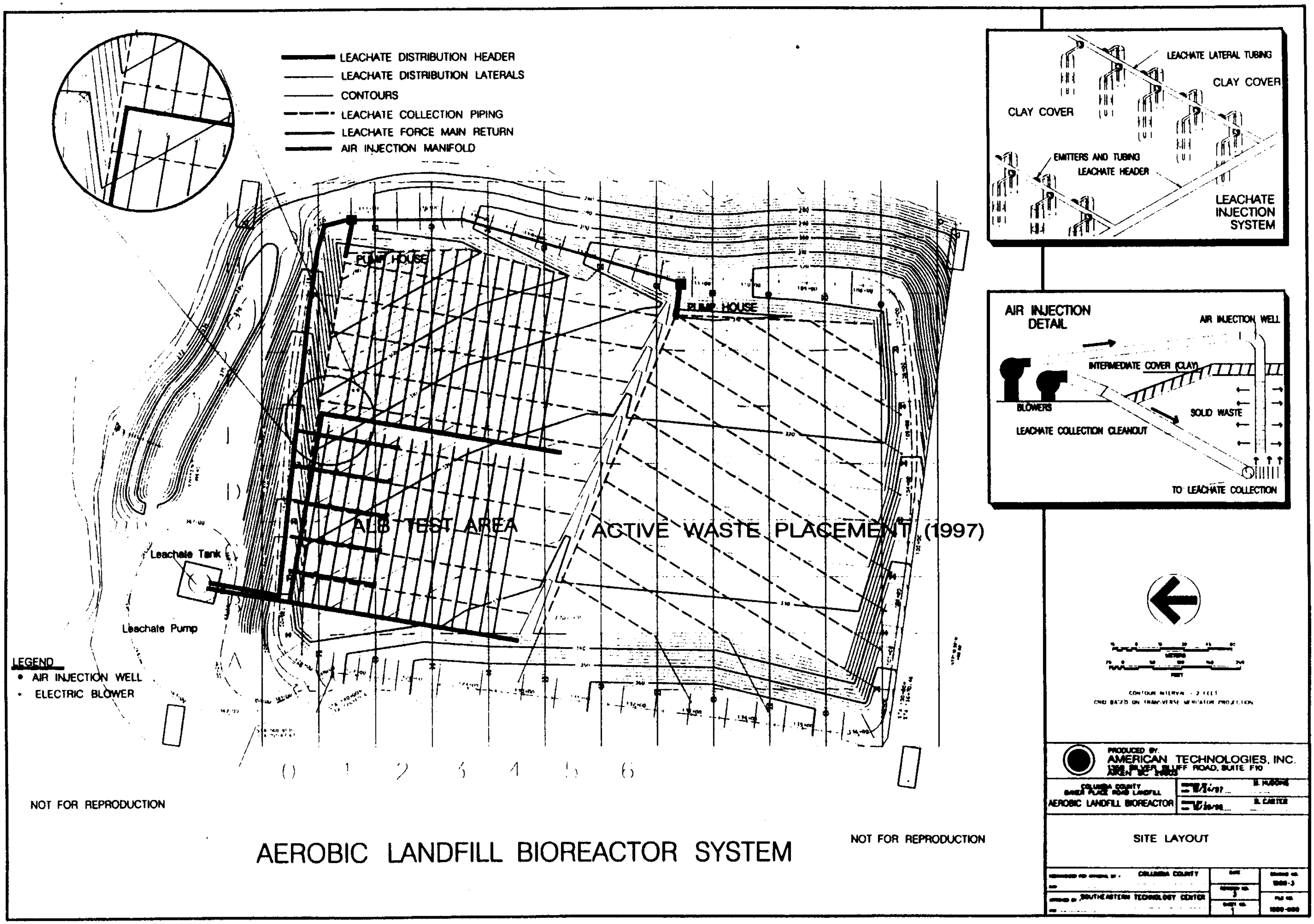


Figure 1: Typical ALS Construction

The ALS was divided into three areas, as shown in Figure 2: 1) air injection and leachate recirculation, 2) leachate recirculation only, and 3) active waste placement (no air or leachate injection). LFG data and waste samples were collected in these areas for comparisons.



AEROBIC LANDFILL BIOREACTOR SYSTEM

Aerobic conditions were balanced in the landfill by properly adjusting leachate flow and air delivery into the waste mass to keep the waste mass moisturized and aerated. Improper balancing of air and leachate can lead to poor ALS performance and, possibly, elevated waste mass temperatures. Technicians closely monitored the ALS during the startup period (2 to 5 months) to ensure safe, effective operating conditions were established. Adjustments to the system were made based on key data, as described below. Afterwards, monitoring of the system was readily accomplished by site personnel. Automation of system components can be implemented to further minimize the time requirements for landfill operators.

During ALS operation, waste mass moisture content, temperature and off-gas concentrations (VOCs, CO_2, O_2, and CH_4) were measured in the field to ensure safe, efficient aerobic operations. Using moisture probes, thermocouples, and vapor points that were installed directly into the waste, key operational data were collected from portable monitoring instruments. Leachate analyses includes, at a minimum, pH, TKN, TSS, specific conductivity, BOD, COD, metals, and VOCs. Other data includes an inventory of leachate production/use for mass balance calculations, and measurement of the moisture content of the landfill gas.

The primary goal of the ALS is to achieve optimum waste stabilization. This is defined in terms of decreased concentrations of leachate constituents, reduced methane production, and waste mass subsidence. Laboratory analyses provided the data needed to determine the ALS's effectiveness on the leachate. Direct measurements of landfill gases were used to determine the amounts of methane production. The subsidence of the landfill waste mass was monitored by physical survey. Although, the biodegradation rate of this process can be determined in various manners, for this application, the biodegradation rate was determined based on oxygen uptake rates, and waste mass temperature measurements. The results of the CCBPRL ALS are provided below.

Upon complete stabilization of the waste, the ALS will be removed, the temporary soil cover stripped back and stockpiled, and replaced on a new lift of waste, thereby minimizing material costs.

II. Bioreactor System Results

Overall, the ALS demonstrated that aerobic decomposition of MSW *in-situ* could safely and successfully be accomplished. The analyses of vapor samples, leachate chemistry, biological activity, and inspection of waste samples confirmed that the ALS was extremely effective at stabilizing the waste. Moreover, the ALS can functions as an *in-situ* leachate treatment system, whereby leachate volumes as well as toxic contaminant concentrations are reduced.

Specifically, the ALS demonstrated: 1) a significant increase in the biodegradation rate of the MSW over anaerobic processes, 2) a reduction in the volume of leachate as well as organic concentrations in leachate, and 3) significantly reduced methane generation. In addition, waste settlement was observed as the ALS stabilized the organic portions of the waste mass. These benefits were obtained while maintaining an optimum moisture content of the waste mass and stabilized waste mass temperatures. Table 1 provides a summary of the results:

Parameter	**Results (11/97)**	**Notes**
Biodegradation Rate	**Increased > 50%** (1)	(1) Based on CO_2 production, O_2 uptake, and waste mass temperatures
Leachate BOD_5	**Reduced by 70%**	
Metals & VOC concentration in leachate	**Reduced by 75 - 99%** (2), (3)	(2) Iron reduced by 75% to 90%; Lead was reduced to BDL. (3) e.g. MEK, toluene, acetone
Leachate Volume	**Reduced by 86%**	
MSW Settlement (ft/ft)	**Greatest: 12%** (4) **Average: 4.5%**	(4) Based on physical survey, future overburden not considered
Methane Generation	**Reduced by 50 - 90%** (5)	(5) Methane reduced by 50 to 90% for 80% of the points: 70 to 90% for the row of points closest to air injection.

Table 1 Summary of Results

A. Landfill Gas Measurements

At system startup, O_2 initially increased in many of the vapor points inserted in the waste mass. In conjuncture with this, CO_2 fell initially and then rose in close correlation with O_2 consumption. When observed with the methane levels, these gas readings indicated a transformation from anaerobic to at least partial aerobic metabolism: CO_2 rises as O_2 is consumed and CH_4 production falls off. Based on direct measurements from thermocouples inserted in the waste, waste mass temperatures remained stable between 40° C and 60° C after aerobic conditions had been reached. Waste mass moisture was above 50% (w/w) in the most active areas. Overall, these data indicated that aerobic conditions within the waste were attained. Typical landfill gas and waste mass temperature data is presented in Figure 3.

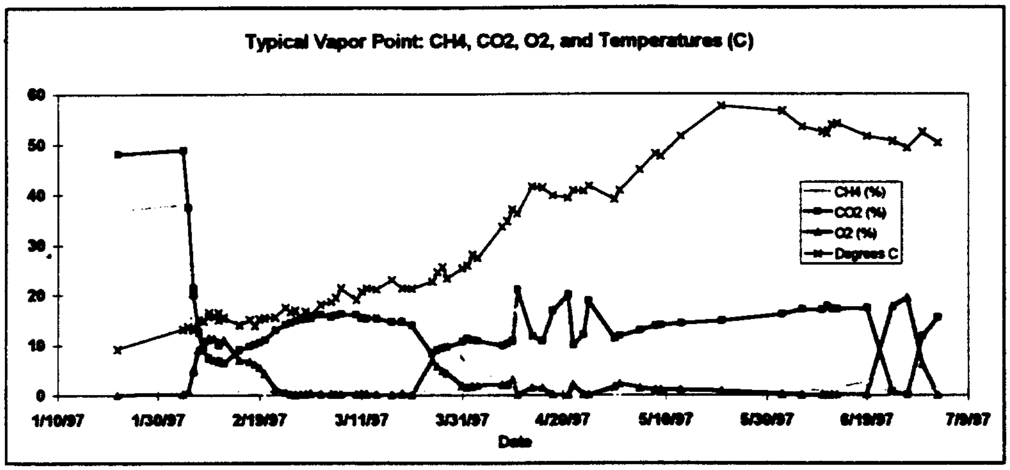


Figure 3: Typical Vapor Point/Thermocouple Measurements

B. Leachate Quality

Laboratory analyses of Biochemical Oxygen Demand (BOD) and Volatile Organic Compound (VOC) concentrations in the leachate indicated significant reduction by the aerobic process, as shown in Figures 4 and 5. BOD in the "Sump One" samples were reduced by at least 70%. Organics such as methyl-ethyl ketone (MEK) and acetone were reduced significantly; also fecal coliform was eliminated from the leachate. Total VOC concentrations in the many of the vapor samples collected were less than 1 ppm.

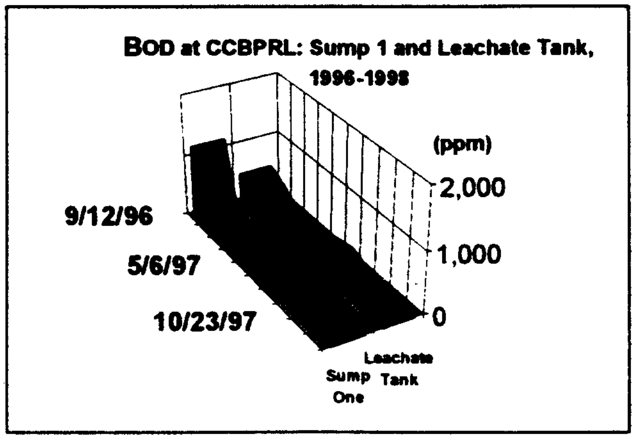


Figure 4. BOD Analyses

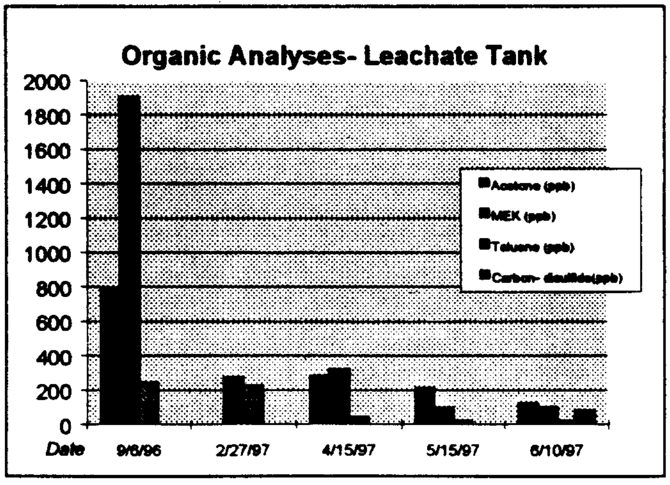


Figure 5. VOC Analyses

C. Leachate Volume Reduction

Prior to ASL startup in January 1997, the CCBPRL sent approximately 120,000 gallons of leachate each month to the local treatment plant. This leachate was pumped through the landfill's new lift station (a capital investment of approximately $100,000) with no pre-treatment.

During the first six months after ALS startup, the County did not pump any leachate to the treatment plant. As of March, 1998 (14 months since startup), the County has only pumped a total of 250,000 gallons to the treatment plant. If a leachate production rate of 120,000 gallons per month were maintained, approximately 1.68 million gallons (120,000 gallons x 14 months) would have required treatment. As a result, the County's leachate treatment needs were reduced by over 85%.

It is estimated that this reduction of leachate is caused, in part, by the evaporative effects of the higher waste mass temperatures and the effects of air drying out the waste. Additional studies associated to this effect are ongoing, including evaluations of waste mass field capacity.

D. Waste Excavation Results

In November, 1997, "aerobic" and "anaerobic" areas of the landfill were excavated to examine the results of the ALS. In most of the areas excavated, the waste appeared to be MSW typical of this region of the country, bagged and unbagged food, paper, plastic, and miscellaneous wastes. However, an abundant percentage of large, inert and recalcitrant materials such as C&D wastes, treated lumber, wood wastes, and thick plastics were observed in the waste excavations. This had not been anticipated, for waste surveys conducted prior to this project, reported that the CCBPRL had been accepting MSW with a high organic content (over 60%). Despite the presence of these recalcitrant materials, however, inspection of the various types of organic wastes collected the "aerobic" areas confirmed that the ALS rapidly degraded these organic fractions of MSW (see photos below), similar to other aerobic composting operations.

The waste inspections indicated that the readily degradable materials, such as food wastes, vegetation, and paper products, had been significantly composted to a brown, rich humic material. In comparison, inspection of the waste samples collected from the excavations in the "anaerobic" areas confirmed little to no degradation of the organic wastes present. Also, odors from the excavations in the "anaerobic" areas had significant ammonia and sulfur components. MSW examined in these two areas had been placed into the landfill at approximately the same time.

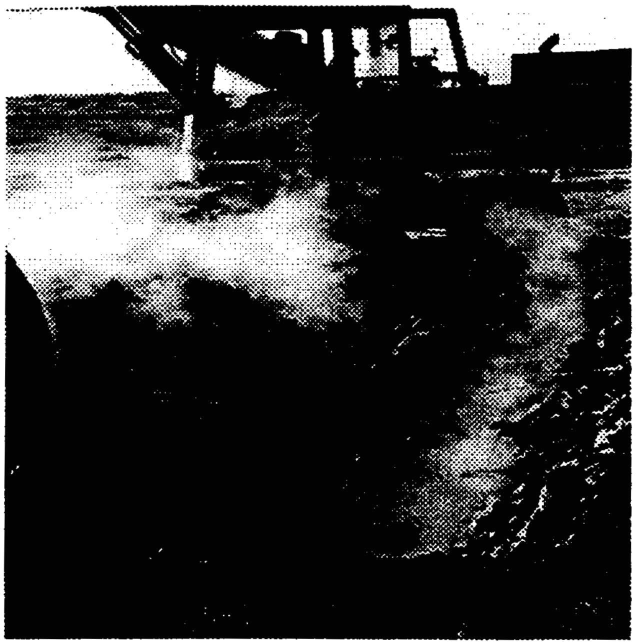
In addition, it was noted during the excavations that the large, recalcitrant landfill materials were arranged in a matrix, containing large void spaces that were filled with organic materials, as described above. It is likely that although the aerobic process did little to reduce the structural strength of the matrix materials (attributable to the minor settlement of intermediate clay cap), this matrix still allowed the injected air and leachate to be introduced to the more easily degradable organic matter.

As a result, the ALS data presented indicates the composting of, mostly, the readily degradable materials. Over a longer period, however, it is estimated that the ASL will ultimately degrade much of these recalcitrant woody materials, further reducing their structural strength.

E. Waste Settlement

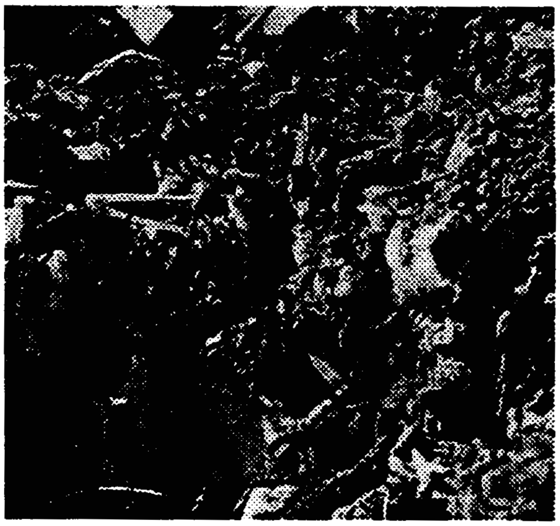
Waste settlement is a function of waste types, compaction density, moisture, landfill heights, and time. Despite the "bridging" effect described above, the 11 months of operation, the types of recalcitrant waste encountered, and that the waste was, on average, only 10 feet deep (approx.), physical waste surveys, taken before and during the project, indicated cover settlement at several locations in the aerobic test area. (Table 1) Although it is apparent that the ALS can compost readily degradable landfill wastes despite these limitations, it is recommended that inert and recalcitrant materials such as treated lumber, concrete, wood wastes, and thick plastics be placed into C&D-type landfills or recycled, where appropriate. This would allow the ALS to compost a larger percentage of landfill materials in a more efficient manner.

Based on other composting studies, it is estimated that the ALS will increase the predicted landfill waste settlement as a result of the overburden from future waste lifts. Meanwhile, the ALS continues to aerobically degrade and reduce the strength of the waste, as shown below:



Waste Excavation w/ Water Vapor Release (120°F)

Stockpile of Aerobically Composted MSW (120° F)



Close-Up of Aerobically Composted MSW

III. Benefits of the ALS

While the ALS depends upon complex biological mechanisms, this technology can easily be incorporated into new and existing landfills in such a manner as to minimize its impact on the landfill operations. Since the degraded waste at CCBPRL is similar in nature to the waste in many other landfills, the benefits realized by Columbia County using the ALS can repeated worldwide. As this technology develops, additional system data can be evaluated to optimize performance of future ALS systems .

The potential cost benefits of the ALS include: 1) increased revenues through airspace recovery, 2) reduction in leachate contaminants and volumes, 3) reduction in methane gas generation, 4) reduced closure and post-closure costs, and 5) reduced environmental liabilities. In addition, this design incorporates a practical, cost-effective approach to providing air and moisture to the waste mass.

A. Projected Cost Benefits Using the ALS

1. *Recapturing of Air Space/ Extension of Landfill Life*

In previous laboratory and bench-scale studies, MSW settlement by aerobic degradation has been observed to be 30% and greater[2]. Assuming a waste mass settlement of 15% is achieved at the CCBPRL, the remaining fill capacity of 720,000 cubic yards could potentially be extended by 107,000 cubic yards. Using a net tipping fee of $24.50 per ton ($32.50/ton gross fee minus $8/ton O&M costs) and a compacted waste density of 0.65 tons per cubic yard, additional revenues to the landfill could be up to $1.7 million. This amount does not account for future value of the revenues which could yield a much higher net value. Additionally, this 15% increase in air space could extend the life of this landfill by almost a year. Waste is accepted at the CCBPRL at a rate of approximately 250 tons per day.

2. *Reduced Landfill Leachate Management Costs*

With an ALS in place, concentrations of organic compounds typically found in aging leachate streams, such as toluene, methylene chloride, and methyl-ethyl ketone (MEK), as well as BOD (a measurement of leachate strength), can be more rapidly reduced (as compared to under anaerobic conditions) as the result of the ALS.

In addition, the overall volume of landfill leachate can be reduced. As presented earlier, the ALS at the CCBPRL reduced approximately 120,000 gallons of leachate from the entire landfill each month. Based on this benefit, a landfill with leachate generation of 120,000 gallons per month and a treatment cost of 3 cents per gallon could save at least $21,600 per year (1997 dollars) assuming the ALS reduced leachate by only 50%. At a 6% interest rate, future value savings would be over $222,000 over 40 years (10 years of landfill operations plus 30 years of post-closure leachate treatment).

3. *Methane Gas Management Cost Savings*

There has been much focus on the earth's environment since the 1980's, including extensive studies on its atmosphere. Fueled by discussions on "global warming" and the possible effects of "greenhouse gases" on the earth and human population, many governments are setting reduction goals, and encouraging the development of new methods for reducing these gases. In the U.S., recent changes to the Clean Air Act (CAA) regulations require specific controls and monitoring provisions be implemented for methane production from landfills, also a "greenhouse-gas."

One methane management approach is landfill gas (LFG) for energy recovery, otherwise known as "waste-to-energy" (WTE). At several landfills, the LFG is produced under mostly anaerobic conditions and the methane captured, cleaned, and used for combustion and/or supplemental fuel. However, although WTE is feasible, this methane management approach does not offer attractive economic advantages for many other landfills. The EPA's Methane Outreach Program (1997) estimates that of the approximately 3,700 landfills in the nation, only 750 are considered candidate WTE landfills. This leaves approximately 3,000 non-candidate landfills, many of which may face methane gas compliance with few low-cost LFG management options. This assessment is based on factors such as the size of U.S. landfills, their location and proximity to a potential LFG user, and potential market conditions.

In an attempt to increase the production of LFG to make WTE possibly more economically attractive, a number of studies have been conducted using leachate recirculation technologies under anaerobic conditions to increase the production of methane and other gases. In these cases, increased LFG is produced, captured, cleaned, and used for combustion and/or supplemental fuel.

Despite the limited success of WTE projects as well as demonstrations that optimize LFG production, there are several issues of potential concern.

- Increased production of methane could increase, if not create, new CAA regulatory compliance requirements for certain landfills. Not only would capital and O&M costs increase but regulatory compliance cost may as well;
- The size of the landfill, its location, and proximity to a potential LFG user, and market conditions could still not offer an attractive economic advantages even with an increase in electricity/usable gas production;
- At many landfills, there can be significant gas recovery inefficiencies with respect to the capture of landfill methane landfill (i.e. fugitive methane emissions). If there is an increased methane gas production via enhanced-WTE with no improvements in gas recovery efficiency, there would most likely be a high potential for increases in fugitive methane emissions from the landfill. This could have significant regulatory impacts and/or increase gas collection/recovery capital costs; and,
- WTE and enhanced-WTE projects still operate under anaerobic conditions. Although certain organic compounds can be degraded under anaerobic conditions, there remains the potential, over the long term, to increase the overall toxicity of landfill leachate under anaerobic conditions. As a result, the costs, environmental risks, and liabilities associated with anaerobic waste conditions within a landfill, as described earlier, could be issues for WTE landfills.

In contrast, by minimizing the production of methane gas from landfills, the ALS provides an alternative, natural, approach to reducing "greenhouse gases" that may be more cost-effective. As presented above, the ALS at the CCBPRL demonstrated that methane gas was reduced up to 90% in many of the "aerobic" areas. At many landfills, one of the short-term cost savings associated with this benefit could be the costs that would, otherwise, be directed to methane gas collection, treatment, and management options. (This is provided that carbon dioxide recovery is not required.)

The long-term cost savings of reduced methane production (where WTE is not economical) may be significant where reductions in regulatory monitoring and compliance efforts are allowed. This would lower methane management costs and associated methane-related risks. Columbia County, for example, plans to seek regulatory relief of certain landfill monitoring requirements, based on this benefit.

In this light, the EPA has recognized the ALS as an emerging Tier II methane control technology and that this approach "is expected to become a prime candidate technology for landfills in the U.S. and elsewhere that can not generate LFG in sufficient quality or quantity to economically recover the associated energy."[3] As this technology develops further, additional performance data will be available to measure the impact of the ALS on reducing "greenhouse" gases. Discussions are continuing with other state and federal regulatory agencies on possible relief under the CAA using the ALS. Other cost benefits are being evaluated with respect to: 1) possible impacts to landfill insurance premiums, 2) relief of certain financial responsibility requirements, 3) emission "shares", and 4) the impact of meeting "greenhouse gas" reduction goals. Overall, this natural approach to methane control could be very beneficial to landfills.

4. *The ALS As A Remediation Option*

There are many landfills world-wide that pose threats to local groundwater and surface water resources. At many landfills, it is predicted that toxic compounds typically found in aging leachate streams will ultimately leak through cracks that will develop in the landfill's protective liner systems and be released into nearby water resources at elevated concentrations. Once released, these contaminants can migrate through the subsurface and into groundwater and surface water, causing severe health effects. This is evident due to the increasing number of landfills that have (and are planning) to initiate remediation activities associated with landfill leachate releases. Of the numerous groundwater remediation technologies available, many leaking landfills with related groundwater problems look toward conventional "pump-and-treat" or *ex-situ* systems as a solution. These type systems recover the contaminated ground and/or surface water through a series of pumping wells or surface intakes, and treat the influent using a variety of physical, chemical, and/or biological systems.

However, these type of treatment approaches are initiated only *after* the release has been identified. In addition, they can be expensive, and require extensive laboratory analyses, monitoring, and regulatory compliance. Furthermore, using only a "pump-and-treat" approach for groundwater remediation can add years to a landfill cleanup. These type systems, once installed, rely on subsurface hydrogeology to transport impacted groundwater to well intakes. Assuming there is a high-efficiency recovery of impacted groundwater, this approach still could take many years to meet groundwater quality standards. Overall, this is an indirect response to leaking landfills that will inevitably extend the cost of site remediation. A more pro-active approach is needed, one that not only addresses present groundwater impacts at landfills, but one that also address the landfill waste mass, *before* it becomes a source of groundwater contamination.

By treating the waste aerobically with an ALS, the leachate is *directly* treated, before it can be released through any cracks in the landfill liner. At landfills undergoing (or preparing for) groundwater remediation, this method of directly treating the waste (and leachate) would lessen the toxicity of the escaping leachate, thereby lessen the toxicity of the impacted groundwater and reduce "downstream" groundwater remediation efforts, saving potentially significant system operating and monitoring costs.

Furthermore, the ALS was shown to reduce vapor-phase VOCs. Since many of these compounds can migrate through the subsurface and impact groundwater, early deployment of ALSs at landfills that could potentially impact the environment (e.g. off-site VOC migration) would minimize the production of these gases, thereby reducing risks and associated remediation costs.

5. *Odor Control*

In the "aerobic areas" of the CCBPRL, strong NH_3- and H_2S odors associated with conventional landfill operations were minimal throughout ALS operations. Instead, less pungent, organic odors indicative of composted waste were detected. From a public acceptance perspective, this benefit can be important to solid waste planners during the siting of new landfills or to address odor complaints at existing ones.

6. *Reduced Closure and Post-Closure Costs*

Potential cost savings could also be realized with respect to site closure. A recent study conducted by the University of Ohio found that the mean cost of closing a sanitary landfill (in Ohio) was $67,112 per acre. Post-closure care for landfills include, at a minimum, groundwater, surface water and methane monitoring, as well as maintenance of the landfill cap. For many landfills, closure and post-closure costs are in the millions of dollars.

Upon waste stabilization and reaching full landfill capacity, the ALS provides the opportunity for landfills to seek regulatory relief of closure and post-closure monitoring requirements. Since the a portion of waste at the CCBPRL has been stabilized and leachate quality improved via the ALS, the potential for groundwater impact by the leachate as well as the production of VOCs and methane has been reduced. As the system is to be expanded, operated, and monitored, the potential to stabilize more of the waste will exists. There is now an opportunity to demonstrate further reductions in risks to the environment based on future LFG, leachate, and groundwater analyses. In this light, ATI has begun discussions with the Georgia EPD regarding regulatory relief with respect to the County's closure and post-closure requirements, starting with a request for a reduced monitoring program.

Additionally, landfills can consider the option of landfill mining as part of an ALS strategy. In these cases, the waste is rapidly stabilized in a more timely manner and the humis removed, analyzed, and possibly used for agricultural purposes or as landfill daily cover. The remaining non-degraded matter (plastics, glass, and metal) could have some market value, providing additional income for the landfill and reducing "up-front" recycling efforts (costs). This approach lends itself to a continuous landfill, precluding the need for a costly permanent cap and the siting of new landfills, altogether saving millions of dollars. It is cautioned, however, that markets should be first established and that the composted materials could be sold or re-used at a cost less than the efforts to mine and process the stabilized waste.

Moreover, a less-expensive, temporary cap would be used instead to cover the waste while it degrades, then removed to allow mining activities. New waste would be placed back into the landfill and the previously mined humis reused as a cover, prior to re-starting of the aerobic process. Under this option, a significant portion of the costs associated with the cover, closure and post-closure, as described earlier, as well as siting new landfills could be avoided.

B. ALS Costs

Overall costs for an ALS can be significantly lower than the costs owners and operators will face during the operation and maintenance of a landfill. Although, there are many landfill design and operational factors to consider as part of the implementation of an ALS at a particular landfill, it is estimated that an ALS would provide an attractive return on investment for many landfills. The design of an ALS should, at a minimum, consider the landfill's current design and waste operations, waste height and placement, environmental regulations, and site conditions. As presented in this paper, three possible ALS approaches have been identified: 1) ALS applications on successive lifts of waste landfills (landfills under construction); 2) ALS applications on existing landfills; and 3) ALS applications with cell mining.

The approximate capital cost for an ALS in these cases would be similar to the costs for a methane gas collection system ($25,000 to $30,000 per acre). Since the ALS may preclude the need for gas collection system (due to reduce methane production) and that the ALS could re-use much of its original air and lecjate injection equipment (less buried PVC piping and plastic hoses), the net increased capital cost would be minimal. Gas monitoring system(s) would still be required in with or without the ALS. Any capital investment in gas filter/combustion would be significantly reduced.

An ALS application in a cell approach whereby the waste is mined could provide significant savings. Once the waste is degraded and stabilized, the ALS equipment is then moved to an adjacent cell and this process repeated. The previously degraded wastes are then mined and recovered for market or for re-use. It is estimated that only a few cell areas would be required to perform this cycle of waste placement, aerobic degradation, mining, and cell re-use, rather than an entire landfill. This approach could significantly reduce landfill construction/capital costs.

In each of the three cases (or modifications thereof), operational and monitoring costs would be moderate for each ALS cell start-up (2 to 6 months) and would include monthly leachate and landfill gas analyses as well as daily system monitoring by a technician. After the start-up period, monitoring requirements (and costs) would be reduced, and the system possibly turned over to landfill personnel. Depending on the type of landfills (under construction, existing), its construction, and regulatory requirements, O&M costs would most likely vary from site to site.

However, compared to the costs of expensive site cleanups, methane gas and leachate management, closure and post-closure O&M, and the risks associated with landfill operations, it is estimated that the ALS approach provides potentially significant savings for many landfills. For example, based on waste settlement alone, the CCBPRL stands to benefit from an estimated two-year return on investment. Additional cost savings could be realized as the leachate and methane gas management costs are reduced, as discussed above.

IV. Summary

For landfills worldwide, the ALS promotes a change in the overall management of solid waste disposal. In many cases, the ALS serves as means to operate landfills more efficiently. Additionally, the ALS serves as a cost-effective, aerobic remediation solution for landfills which are adversely impacting the environment. Through the continued development of this technology, the ALS will foster a new perspective on landfilling waste, and, at the same time, reduce the cost burdens of landfill operations and/or site remediation. In addition, the long-term liability and costs associated with landfill operation and closure will be greatly reduced.

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Mr. Hudgins serves as the Project Manager for the ALS Project and all of ATI's landfill biotechnology programs. Mr. Hudgins' professional career has primarily been involved with assessment and remediation of hazardous wastes, specifically the development and implementation of biotreatment systems. He is a 1985 graduate of the Citadel, holds a Bachelor of Science in Civil Engineering. Mr. Hudgins has led numerous treatment system design programs, including hazardous waste remediation systems, bioremediation, and biofiltration and odor control systems, as well as groundwater assessment and treatment programs.

Mr. March, a Biological Engineering Degree graduate from The University of Georgia, is the ALS project's field engineer. Mr. March's work experience includes an extensive research background, including work with treatment of landfill wastes, treating hazardous waste with plants (phytoremediation), and enzyme studies. He has also served as an investigator for a state funded fire ant research program and helped develop a hypothesis for fire ant control. Mr. March has also designed experiments and wrote software modeling phytoremediation of heavy metals. He is also pursing a Master's Degree in Biological Engineering at The University of Georgia.