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OPERATIONAL CHARACTERISTICS OF TWO AEROBIC LANDFILL SYSTEMS

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SUMMARY: Solid waste landfills worldwide are experiencing the consequences of conventional landfilling techniques, whereby the anaerobic conditions created within the landfill, promotes slow stabilization of the waste, methane gas production (a "greenhouse" gas), and generation of harmful leachate over long periods of time. As a solution, it has been demonstrated at two U.S. landfills that the aerobic degradation of waste within a landfill can rapidly increase the rate of waste decomposition and settlement, decrease the production of methane gas, improve leachate quality, and decrease the quantity of leachate that needs treatment. As a result of this increased "stabilization," not only can environment risks be reduced, but more waste can be placed in the airspace gained, thus extending the life of the landfill. In other cases, the landfills could instead be redeveloped for commercial activities, or mined to recover composted materials, undegraded plastics, metals, and glass. This approach of rapidly reducing risks followed by landfill reuse once mined, could lead to the development of “sustainable landfill” strategies for many countries.

1 INTRODUCTION

Many of the world’s landfills have become significant risks to the environment. As conventional landfilling promotes the anaerobic decomposition of sanitary wastes within a landfill, two major environmental and health concerns develop: 1) the chronic production of toxic leachate, which can contain high concentrations of organic compounds as well as pathogens; and, 2) slow degradation of the waste mass, thereby preserving long-term risks to the landfill.

In attempts to reduce the production of this leachate and to minimize the release of this leachate to the environment, "impermeable" soil caps are installed over the waste to reduce moisture infiltration from the surface, while composite liner and leachate collection systems are installed beneath the waste to collect the leachate that is generated.

Referred to as the “dry-tomb” method, this conventional design approach actually increases environmental risk. First, despite the effectiveness of most landfill capping systems, moisture can still infiltrate into the landfill, thus contributing to the leachate production described above. Second, according to the US EPA, “liner and leachate collection [systems] ultimately fail due to natural decomposition…” (Lee, 1996). Since landfills can produce this leachate over long periods of time, organic compounds, impact to local water resources can continue for generations or until remediation is performed.

In addition, anaerobic conditions within a landfill promote the production of methane, an explosive, odorless gas, which is also considered a "greenhouse gas" by Global Climate Change Initiatives. Methane generated in landfills is typically in excess of 45% of the total landfill gases (LFG) and over 20 times more harmful than carbon dioxide, the other predominate LFG. Also, non-methane organic compounds (NMOCs) such as those derived from solvents and pesticides, for example, can be released from their solid or liquid state and be emitted as a fraction of LFG. According to the US EPA, NMOCs can contribute to ground-level ozone and can be been a source of groundwater contamination as they migrate through landfill cap systems and the subsurface.

As a result, LFG has become a significant concern. As such, a large number of landfills are required to monitor, collect, and control (e.g. flaring) LFG in attempts to comply with increasingly stringent air and environmental regulations. In the many cases where LFG-to-energy is not economical, LFG management not only contains inherent risks, but can be costly, as well.

Unfortunately, there are few options to the "dry-tomb" landfilling approach. As a result, landfill owners find themselves facing significant environmental issues, increasing landfill costs, and long-term liabilities. Thus, the need to develop low-risk, sustainable MSW management strategies is warranted.

2 THE PROCESS OF COMPOSTING

2.1 Reduction of solid waste organic matter by composting

Aerobic biodegradation processes, such as composting, have demonstrated that many of the organic compounds found in MSW can be degraded in significantly short time frames by the introduction of air and moisture in the proper proportions (Murphy, 1992). In most all aerobic composting environments, respiring bacteria present in the waste convert the biodegradable mass of the waste and other organic compounds to mostly carbon dioxide and water, with a "stabilized" humus remaining. As this aerobic metabolism occurs, the structural integrity of the organic waste decreases and the overall matrix begins to settle (as seen in "shrinking" compost piles) due to the force of gravity. Additionally, composting stochiometry illustrates that methane gas production decreases.

Because composting increases microbial populations and diversity within the soil or waste matrix, the degradation of the organic compounds is accelerated (Cole, 1994). Lastly, in most composted materials, the combination of high organic content and a variety of minerals make the compost an excellent adsorbent for many organic and inorganic chemicals.

2.2 Reduction of aqueous organic compounds by aeration

Aerobic treatment processes can also reduce many organic compounds typically found in industrial 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.

At the University of South Florida, it was demonstrated that by recirculating MSW leachate through the landfill waste mass while at the same time adding oxygen, aqueous concentrations of organic compounds could also be reduced in a similar manner (Stessel, 1992). The waste matrix served as an efficient "trickling media", allowing the effective recycling of leachate and introduction of air. This process continually provided the respiring microorganisms the moisture, nutrients, and oxygen needed to degrade the solid and aqueous organic compounds.

2.3 Exothermic nature of composting

During the initial stages of most composting operations, high microbial activity cause temperatures within the compostable material to rise rapidly into the thermophillic range (50 ^{o}C and higher). This temperature range is maintained by periodic turning or the use of controlled air flow (Viel, 1987). After the rapidly degradable components are consumed, temperatures decline during the curing stage. At the end of this stage, the material is no longer self-heating, and a "finished" compost can be ready for use.

In a landfill environment, it was shown that the addition of air caused waste mass temperatures to rise to above 80 ^{o}C, which, in this cases, ignited the waste (Merz, 1970) However, it was proposed that these elevated waste mass temperatures could be controlled by the addition of moisture during composting (Murphy, 1992). Furthermore, if the waste mass temperatures could be kept within the mesophilic range of 15 to 40 ^{o}C, these temperatures would not only most likely be well below waste ignition temperatures, but also in the range that would promote the most rapid organic waste degradation. In addition, this temperature range would also tend to evaporate moisture from the waste, thus reducing landfill leachate production.

2.4 Basis for Experimental Study

In many landfills, the waste mass can comprise of over 50 % humic and organic fractions, containing food wastes, fatty acids, and lignins, as well as concentrations of toxic organic compounds, such as toluene and MEK, and medium to high molecular weight acid materials. In addition, acidic leachate (typically 5 to 7 pH units) can be generated, containing high concentrations of toxic organic compounds and Biochemical Oxygen Demand (BOD) values of over 50,000 mg/l.

With the ideas that: 1) most all organic composting methods share similar characteristics and processes, 2) many landfill wastes contain a high degree of degradable organic fractions, and 3) that a landfill could serve as a large aerobic composting vessel to control an aerobic degradation process, two separate aerobic landfill systems were demonstrated at MSW landfills in Georgia (USA) to determine whether composting could successful degrade and stabilize organic fractions in the waste and leachate.

3 EXPERIMENTAL STUDY

The two aerobic landfill systems were installed and operated within set-aside Subtitle D portions of the 1) Columbia County Baker Place Road Landfill (Columbia County landfill) near Augusta, Georgia (USA) and 2) a private landfill in Atlanta, Georgia. Both systems were installed and operated by different companies but similar protocols.

Both landfills were constructed under EPA Subtitle D regulations, whereby each Cell was constructed with a composite plastic liner and leachate collection system. The waste in each study Cell was overlain by a 0.5 m intermediate clay cover. Leachate that was generated in each Cell or not utilized during the aerobic process after re-injection, drained back into the respective leachate collection system. For each aerobic landfill system, the air injection mechanism comprised of electric blowers or an air compressor and piping, all connected to vertical air injection wells that were installed directly into the waste. Leachate, collected in holding tanks at each site, was pumped into each aerobic system through a leachate recirculation system installed on top of the intermediate cap. This part of the system, consisting of either 5.1-cm diameter PVC vertical wells or drip irrigation hoses, injected leachate through the intermediate clay cap and into the waste mass. The leachate then percolated downward through the waste mass and mixed with the air that was forced into the waste. Leachate that was not utilized during aerobic decomposition migrated downward to the leachate collection system was pumped back to the tank, to be recirculated again.

The capital and operating costs (per acre) of these systems were similar to the costs of the gas collection and management system that would be installed at these sites in the future. Details on each landfill cell and aerobic system are summarized in Table I.

Table I - Summary of Landfill Study Cells and Aerobic Landfill System Design Parameters

Design Parameter	Columbia County Landfill	Atlanta Landfill
Cell Size (hectares)	1.6-active, 1.6-control	1.0
Average Waste Depth (m)	3	10
Total Waste Volume (m^3)	45.200	49.000
Age of Waste at Startup (months)	18	36
Leachate Injection Rate (L/day)	13.608	25.230
Total Leachate Injection (L)	Over 7 million	6.676.200
Air Injection Rate (m^3/min)	56	100
Duration of Study	Jan 97 - June 98 (18 mo)	Jan 97 - Sept 98 (9 mo)
Annual Rainfall (cm/yr)	137	114

3.1 Experimental Procedure

The primary goal of each aerobic landfill system was to achieve rapid waste stabilization through aerobic degradation. At both sites, visual inspection of the wastes as well as direct measurements of key landfill gases (VOCs, CO_2, O_2, and CH_4) and waste mass temperatures were the primary means used to determine aerobic/anaerobic conditions within the waste. Secondary data included the measurement of landfill cover subsidence, leachate analyses, and leachate production. At the Columbia County landfill, leachate analyses included pH, BOD, COD, metals, and VOCs (Hudgins, 1998). Real-time data were collected using moisture probes, thermocouples, and/or vapor points that were installed directly into the waste.

Prior to startup of the air injection system at both sites, leachate was injected into the waste to achieve waste mass moisture contents of above 60%. Once these levels were reached, air injection commenced. As anaerobic conditions within the waste converted to aerobic, waste mass temperatures increased while moisture levels decreased, in some cases to below 40%. As such, leachate flow and air delivery rates were adjusted based on the field data to keep the waste mass adequately moisturized and aerated. Improper balancing of air and leachate could have led to poor aerobic landfill performance and, possibly, elevated waste mass temperatures. After the initial start-up phases (3 to 4 months), aerobic conditions tended to "stabilize," whereby adjustments in air and leachate rates were minor and infrequent.

In November, 1997, "aerobic" and "anaerobic" areas of the Columbia County landfill were excavated for comparative results. The waste excavated from each area was approximately the same age. At the Atlanta landfill, approximately 4.275 kg of MSW was excavated and separated with trommels after the waste had degraded (Smith, 1998). Waste characterizations were also performed.

4 RESULTS AND DISCUSSION

Although there were minor differences in data collection methodologies, the aerobic degradation data were almost similar, with respect to methane gas and odor reduction, leachate volume reduction, and increased waste settlement. Table II below provides a summary of the results:

Table II - Summary of Final Results, Aerobic Leachate Recirculation

Parameter	Columbia County Baker Place Road Landfill	Atlanta Landfill
MSW Settlement (ft/ft)	Greatest: 9% Average: 4.5%	Greatest: 10%
Methane Generation	Reduced 50 - 90%	Reduced 50 – 90%
Leachate BOD_5	Reduced from 1,100 to 300 ppm in 3 months	N/A
Leachate VOCs	Reduced by 75 - 99%	N/A
Leachate Volume	Reduced by 86%	Reduced 50% (est)

4.1 Reduction of Organic Solid Waste

Based on direct measurements from thermocouples inserted into the waste at both sites, waste mass temperatures remained stable between 40^o C and 60^o C after aerobic conditions had been reached. Waste mass moisture was maintained above 50% (w/w) in most areas of each Cell. When compared to the landfill gas data, presented in the next section, these data indicate that aerobic conditions within the waste were attained at both study sites.

The operation of each system was a dynamic process. It was observed in some areas that the decay process would revert back to anaerobic once temperatures decreased and that the air would make its way to other nearby areas, thereby repeating the process. Also, if too much leachate was applied in the "aerobic" areas, there would be an insufficient amount of oxygen to the bacteria, thereby reverting the decay process back to anaerobic. Conversely, if too little leachate was applied, waste mass temperatures would tend to rise into the thermophillic range (40 to 70 ^{0}C). In several cases, it was also observed that air could provide a "cooling" effect on the waste mass temperatures above 60^{0}C or increase temperatures that were below 20 ^{0}C (Hudgins, 1998), provided sufficient moisture was applied.

During waste excavation at the Columbia County landfill, visual inspection of the various types of organic wastes collected after 11 months of composting confirmed that the aerobic landfill system rapidly degraded much of the organic fractions of MSW, and the final compost appeared similar to the compost that would be observed at most other composting operations. Readily degradable materials, such as food wastes, vegetation, and paper products, had been significantly composted to a brown-to-black, rich humic material with minimal odors. In comparison, inspection of the waste samples collected from the excavations in the control, or “anaerobic” areas (with the same age waste as "aerobic areas"), confirmed little to no degradation of the organic wastes present. Also, odors from the excavations in the “aerobic” areas had significantly lower ammonia and sulfur components than from the control waste. (Hudgins, 1998).

At the Columbia County landfill, aerobic activity occurred despite the high percentage of recalcitrant and inert materials observed in the waste, including C&D wastes, treated lumber, wood wastes, and thick plastics. Although the aerobic process did little to reduce the structural strength of the inert materials, the matrix of large voids apparently allowed the injected air and leachate to be introduced to the more easily degradable organic matter. Despite this, surveys indicated cap settlement at several locations of up to 27 cm over 3 meters. (Hudgins, 1998)

After five months of operation at the Atlanta landfill, samples of waste were collected from boreholes that were installed in the waste. Results showed that the water content increased with depth, as well as the degree of composted materials. Lastly, observations during drilling operations showed that the drier materials were the least composted; the wetter areas had the most degradation. (Smith, 1998).

Laboratory analysis showed that soluble salts, metals, and pH were within safe ranges. Also, no pathogens were detected in the materials. With respect to the degree of compost activity, oxygen uptakes ranging from 0.167 to 0.351 mg per gram of volatile solid per hour (VSPH) were measured. Respiratory measurements of this type performed on compost have determined that oxygen uptake rates of less than 0.5 mg of oxygen per gram of VSPH indicate stable compost (Smith, 1998).

During waste excavation and separation at the end of the study, the largest fraction of the waste (over 50%) appeared as a suitable soil/compost material with a sufficient moisture content (30%). The compost, which passed through a 1- to 2-cm screen, was stable, with little odor. This material was re-used on site as daily cover, as part of Atlanta landfill operations. (Johnson, 1998) Plastic products, metals, and glass occupied over 30% of the remaining materials, with inert materials as the balance (Smith, 1998). Lignin-containing materials (e.g. wood and paper) degraded slightly. Lastly, the physical survey at the Atlanta landfill cell measured over 10% of settlement in several areas of the Cell, based on initial cell height of 10 meters. (Johnson, 1998)

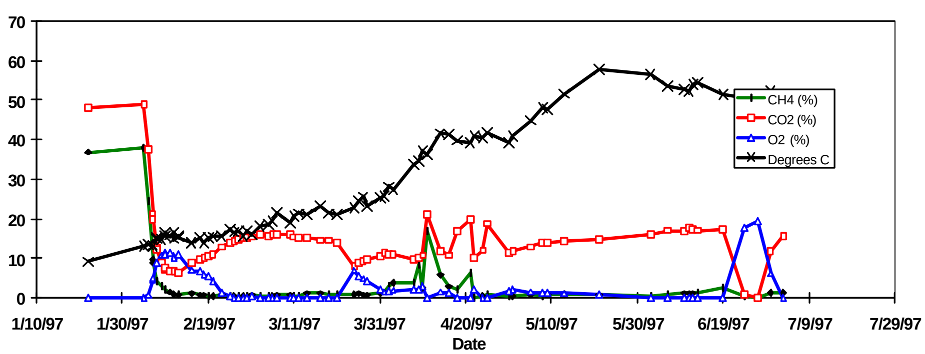

Figure 1 - Typical LFG/ Temperature Measurements, Columbia County Landfill

Analyses of landfill gas samples from both aerobic landfill systems, showed that O_2 initially increased in many of the vapor points and wells, at system startup. 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. With respect to the temperature data presented earlier, these data indicated that aerobic conditions within the waste were attained at both study sites. Typical landfill gas and waste mass temperature data observed at the Columbia County landfill site are presented in Figure 1. Overall, methane concentrations decreased by at least 80% in three weeks after system startup in many areas and remained consistently below 5% (v/v) during each project.

4.2 Leachate Quality

Laboratory analyses of VOC concentrations in the leachate at the Columbia County landfill suggest a positive influence by the aerobic process. Within 5 months, acetone was reduced from 750 ppm to less than 250ppm; MEK was reduced from 1,800 ppm to 300 ppm, and toluene was reduced from 250 to 50 ppm. Also, fecal coliform, initially detected, was eliminated from the leachate in three months. BOD was reduced from 1,100 to 300 ppm in three months (Hudgins, 1998). At the Atlanta landfill, iron concentrations in the leachate at the indicated significant reduction by the aerobic process, from 61 ppm to 23.03 ppm. No VOC analyses were conducted at the Atlanta landfill (Smith, 1998)

4.3 Leachate Volume Reduction

Prior to system startup, the Columbia County landfill collected and sent approximately 453.600 L of leachate each month to the local treatment plant. During the first six months of aerobic landfill operations, the leachate produced by the entire landfill (16 acres) was utilized by the aerobic system, whereby, no leachate was sent offsite for treatment. Fourteen months later, just over 945.000 L had been sent offsite for treatment, a reduction of 86% if leachate production would have continued at the same rate during that time (6,35 million L). At the Atlanta landfill, it was estimated that an average of 124 liters of moisture were added per cubic meter of fill (Smith, 1998) Even with these additions, there was no noticeable increase in the quantity of the leachate produced by the cell.

For both of these sites, it is estimated that 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. In addition, it is believed that the water may have contributed to raising the moisture content of the fill without exceeding the waste mass field capacity. In both cases, there were not sufficient quantities of leachate available to keep the waste mass at target moisture content levels; other sources of moisture (stormwater, pond water) were required.

5 CONCLUSIONS

Each study illustrated that aerobic decomposition of MSW *in-situ* can rapidly and safely degrade organic matter in MSW. Despite the uniqueness of each landfill, the aerobic system, and waste characteristics, LFG and odor reduction as well as increased waste settlement was also achieved.

The key to the aerobic landfill's effectiveness is the proper control of aerobic conditions, whereby waste mass temperatures and moisture are maintained within optimal ranges. While the aerobic landfill depends upon complex biological mechanisms, this technology is a natural process that can be effectively controlled.

Either for addressing environmental concerns or for use to gain additional airspace to extend landfill life, the potential benefits of this approach include: 1) reduction in leachate contaminants and volumes,

2) reduction in methane gas and "anaerobic" odors, 3) increased revenues through airspace recovery, 4) reduced closure and post-closure costs, and 5) reduced environmental liabilities. As additional full-scale studies are conducted, for example the 12-acre New River Landfill near Gainesville, Florida (USA), additional data will be available to optimize aerobic landfill designs and/or redesign certain landfill into more efficient waste "processing" cells.

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