Analytical Methods of Testing Solid Waste and Leachate to Determine Landfill Stability and Landfill Biodegradation Enhancement

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Thesis submitted to the Faculty of Virginia Polytechnic Institute and State University
in partial fulfillment for the degree of

Master of Science

In

Environmental Science and Engineering

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September 10, 2009

Blacksburg, VA

Keywords: Landfill, Methane, Bioreactor, Leachate, Stability

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ABSTRACT

This was a study undertaken to investigate municipal solid waste (MSW) landfill stability parameters and landfill leachate properties to determine how solid waste and leachate characteristics can be used to describe stability. The primary objective was to determine if leachate properties could be used to determine stability of the overlying refuse. All landfills studied were engineered landfill bioreactors giving insight to how leachate recirculation affects stability.

This study investigated the correlation between cellulose, lignin, volatile solids, and biochemical methane production (BMP). These parameters can been used to characterize landfill stability. The BMP tests indicate that a saturated waste can produce methane. Cellulose is an indicator of landfill stability. Wastes high in cellulose content were found to have high BMP. Paper samples studied indicated gas production from high-cellulose paper was higher compared to low-cellulose samples. Lignin has been found to correlate fairly well with BMP. Increasing cellulose to lignin ratios correlate well with increasing BMP levels, further supporting the use of the BMP test to indicate solid waste stability.

In the BMP test for leachate, a mixture of the standard growth medium (less 80% distilled water) and 80% v/v leachate incubated for 15 days produced the most consistent BMP results. Leachate cellulose and BMP correlated well. The chemical oxygen demand (COD) and biochemical oxygen demand (BOD) also had some correlation to BMP tests. Leachate COD was found to decrease over time in landfill bioreactors. The use of leachate rather than MSW to determine stability would be more efficient.

ACKNOWLEDGEMENTS

First I would like to thank Dr. John Novak and the University of Virginia Tech for providing me with the tools to conduct my research and the opportunity to do so. I would also like to thank my committee members Doug Goldsmith and Clifford Randall as well as Waste Management for supporting my research.

I would like to thank Julie Petruska, Jody Smiley, and Betty Wingate for providing me with their specialized support. I thank all of the students that did not give me dirty looks in the halls of the labs for the malodorous samples. I thank Raj and Ryan for showing me how to work with the samples, explaining the methods, and having patience.

I thank my Father for showing me that science and imagination can create wonderful things, especially with a D.I.Y. approach. I thank my Mother and Grandparents for having faith in me and listening to all of my wild ideas while continually pushing me to work smarter. I thank my Stepfather for always having great advice and being a great mediator. I thank my Sister for providing me with all of the best college survival tips you could ever have. I thank Owen and Bryan for being there as great friends and Jessica for helping me get over my writers block. There are truly too many people to list whom I owe thanks; so, a thank you goes out to them as well.

Lastly I would like to say that I am thankful that we all have such a wonderful place to conduct our research, whatever it may be.

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CHAPTER 1

Introduction

The population of the earth is increasing and with this increase comes an increased need for food and material goods and an associated increase in wastes from their production and use. These wastes have been labeled as municipal solid waste (MSW) and encompass a large range of materials. Landfills are used to help store and degrade solid wastes, and with this, enhancement techniques to try to improve the effectiveness of the landfills have been proposed. These enhancement techniques mainly focus on the natural biodegradation in the landfill and the acceleration or control of biological activity.

One of the most effective methods of improving the degradation of material in landfills is the landfill bioreactor (LFB), which uses leachate recirculation and water addition, along with monitoring to achieve control. Even though there are additional enhancement techniques, more research is needed to fully understand their effects and how to improve on them. Improvements in the testing methods used to investigate landfills will improve the ability to manage the landfill gas and leachate produced by the landfills and allow for improved predictability of performance. Landfill gas modeling, settlement calculations, and biological enhancement technique effectiveness are just a few areas of interest that would benefit from more research.

The first part of this study is a literature review using material obtained from the library at Virginia Tech, the Internet, online documents of the EPA, and other sources. The purpose was to understand the current state of landfills throughout the United States. Enhancement techniques and testing methods already being employed in these landfills along costs and benefits of the landfill and its enhancement were also investigated.

The second part of this study was an analysis of the methods used to determine MSW stability in a landfill. Among the constituents that are commonly tested in a landfill are volatile solids, cellulose, lignin, pH, and Biochemical Methane Potential (BMP). All of the samples were from bioreactor landfills involved in the EPA's Project XL. Samples of solid waste were shipped in large iced coolers. Once the samples were received, they were tested for these various components. The results were then compared graphically to see if there were any relationships between them, and what these relationships mean in terms of landfill waste stability.

The third part of this research was a study on landfill leachate, the liquid that is recirculated over a landfill to accelerate degradation. Leachate recirculation is a direct method of leachate containment and landfill degradation enhancement. Moisture and temperature are the main variables that determine successful biodegradation in a landfill.

All of the leachate tests were conducted using samples from the Outer Loop Landfill of Louisville, Kentucky. The focus of this research was on the BMP and chemical oxygen demand (COD) of leachate. Data for the MSW samples, which correspond to these leachate samples, were also obtained. These were compared to the BMP and COD results for the leachate for correlations that might exist.

The overall purpose of this study was to show the possibility of using leachate to evaluate landfill stability, and to determine the applicability of the biochemical methane potential test for leachate. The cost of assessing landfill stability could be greatly reduced if leachate could be used to test for stability instead of drilled MSW samples.

CHAPTER 2

Literature Review

Current State of Landfills

As the world's population has increased, we have a greater need to properly treat and dispose of municipal solid waste. Classical methods of tomb land filling have become obsolete because engineered landfill bioreactors have been developed. Typical landfills take too much time to reach a state of closure, eliminating the possibility to use the land for other purposes and causing many problems with post closure site monitoring and pollution of surrounding lands.

Landfills often require large plots of land, which have limited value for future development. This can affect the land for 20-30 years after the landfill is closed and monitored. Because of the positive relationship between moisture content and biodegradation of MSW, the dry tomb approach to land filling actually extends the time it takes to degrade the waste (Wall & Zeiss, 1995).

Landfills are still being designed with dry tomb methodology. It has been shown in the past, however, that this convention provides a risk of uncontrolled leachate and biogas leaks and surrounding contamination. Moisture is important to the initial steps of biodegradation, and continual moisture content provides the proper environment for microbes to receive nutrients and degrade wastes (Yuen et al., 2001).

Municipalities around the world have encountered problems with their management of wastes. The city of Istanbul is expected to see an increase in solid wastes generated per capita of as much as 25% (Šan & Onay, 2001). In the United States, almost half of the MSW produced has been sent to traditional landfills, where degradation takes place under less than optimum conditions (Mehta et al., 2002).

In Florida, it has been discovered that from waste such as batteries, electrical switches, fluorescent light bulbs, and others, methylated mercury compounds can be formed under these methanogenic conditions. These monomethyl and dimethyl mercury compounds are very toxic to humans and other species (Lindberg et al., 2001).

It has been determined that almost half of the greenhouse gasses produced from paper in Australia came from paper that had been landfilled. This paper makes up about 10%

of their total MSW volume. Reducing the amount of paper that makes it to the landfills by way of recycling or waste-to-energy recovery has proven to be effective method to reduce these emissions (Pickin et al., 2001).

The classical method of using a landfill as a storage site typically means that the leachate infiltration and migration is reduced. With this comes the problem of decreased rates of degradation. Leachate recirculation allows the landfill to operate as a landfill bioreactor, providing an environment suitable to increased degradation rates as well as providing control of side effects (Townsend et al., 1996).

Because research has told us much about the behavior of landfills, there has been an increased interest in the development of landfill bioreactors. They have been engineered to reduce leachate migration into the subsurface, increase degradation rates, and increase landfill gas production. Another goal of the bioreactor landfill is increased subsidence during the active operating period to provide more space for land filling. Waste shredding, moisture and temperature control, and addition of nutrient rich leachate are a few of the successful methods already used to achieve these goals (Warith, 2001).

By adding moisture, buffers, and microbe sources such as wastewater treatment plant sludge, a degradation rich environment is achieved. Leachate recirculation not only provides the moisture and nutrient transport required for microbe development, it provides the microbes a way to rid themselves of fermentative products that are detrimental to their development (Nopharatana et al., 1998).

To consider a landfill for closure methane production should be minimal, maximum settlement of the MSW should be observed, as well as the absence of adjacent contamination from leachate. Using a bioreactor landfill approach, reduced cost of post-closure monitoring and land reclamation are among the biggest advantages (Lee et al., 2001).

Landfill Bioreactors

One of the most effective ways to reduce the side effects of land filling and increase the rate of degradation of MSW is the engineered landfill bioreactor. Landfill bioreactors are the alternative to dry-tomb land filling. A landfill bioreactor can provide up to a 10-fold decrease in closure time for a landfill site, when compared to the dry-tomb approach. There is also a greater range of control in a landfill bioreactor, which allows engineers to minimize the environmental hazard from the landfill.

A basic description of a landfill bioreactor is a landfill where additional air and liquids are introduced to the waste mass to enhance the microbial activity and increase the rate of degradation and stabilization of the waste mass. There are three main types of bioreactor landfills, aerobic, anaerobic, and hybrid designs. In an aerobic landfill bioreactor, air is injected into wells throughout the MSW to enhance the aerobic processes, while the addition of recirculated leachate from the bottom of the landfill is added in a controlled manner to enhance the nutrient availability of the aerobes. In an anaerobic landfill bioreactor, degradation takes place in the absence of oxygen, allowing methanogenic anaerobes to break down the wastes while producing methane or natural gas. Optimal moisture levels are obtained by again recirculating leachate and nutrients in a controlled manner. In a hybrid designed landfill bioreactor, both aerobic and anaerobic processes take place. In this design, the upper sections are operated as aerobic systems, allowing for faster degradation and faster onset of methanogenesis in the lower levels. As the methanogens are cultured, they produce methane, which is collected from these lower levels. In the latter two designs, the methane or natural gas that is produced can be collected for onsite energy needs or sold offsite for other uses, adding to the efficiency of the landfill (U.S. EPA, 2003).

Moisture content is the number one environmental condition for success in a landfill bioreactor, though there are many other factors involved. Through the rapid stabilization of landfill wastes, less risk of future environmental contamination and post closure costs are sooner achieved, as well as reclamation of the landfill site property (Townsend et al., 1996).

Leachate recirculation rates must be chosen wisely, where too much or too little can both be detrimental to the effectiveness of a landfill bioreactor setup. With too much moisture, problems such as highly acidic conditions as well as ponding and saturation exist. If flow rates are too high, removal of the methanogens and buffering problems will disable the methanogenic processes, where too little flow will allow a buildup of inhibitory products (Šan & Onay, 2001).

With the proper residence time, methanogens are able to maximize the conversion of MSW to methane, including the conversion of recalcitrant compounds. Increased conversion of complex compounds along with increase in initial biomass growth is found with the increase in leachate recirculation (Chen et al., 2000).

Benefits found in bioreactor landfills are present other than just faster degradation. Damaging effects of settlement on the final cover of a landfill are reduced by the increased settlement found in bioreactor landfills, where this increase in waste density also adds to the overall volume available for filling. In addition, the costs of offsite treatment of leachate are reduced because the leachate is partially stabilized during the process of continuous recirculation. Natural gas recovery also becomes a more realistic task when there is an increased rate of gas production (Mehta et al., 2002).

Landfill Bioreactor Chemistry

Landfill bioreactors are noted to go through different phases. There are five main phases of degradation, which are the initial adjustment phase, the transition phase, the acid formation phase, the fermentation phase, and the maturation phase. Each of these phases is characterized by different chemical changes and properties. The initial adjustment phase is where land filling begins, and there is ample moisture to support aerobic decomposition. The second or transition phase is where the moisture content begins to reach field capacity and anaerobic conditions prevail. In the acid formation phase, the volatile organic acids formed by hydrolysis of organics and other wastes cause a drop in pH. Following this is the fermentation phase, where the available acids are then converted into methane by the anaerobic microbes. In the last maturation phase, activity slows down and stability is found in the landfill and its leachate (Kelly, 2002).

During the first three phases, the pH can drop to around 6.5-6.0, and it is during these phases that the methanogens begin to become more active. During the fermentation phase, the pH can increase from 6.8-8.0 due to the degradation of volatile fatty acids.

Leachate is found to contain chloride concentrations anywhere from 1000mg/L and above. Over the course of landfill life, the BOD/COD ratio decreases, indicating an increase in microbial activity and a decrease in biodegradable organic compounds (Warith, 2001). In young leachate, high amounts of volatile fatty acids account for most of the COD, and this causes the BOD/COD ratio to be high.

Biogas produced in the landfills typically contains about 50-65% methane, and the remaining fraction is mostly carbon dioxide. Methane production is also normally related directly to the reduction of COD. For these reasons the COD removal rate and methane production rates are some of the important operating parameters. A larger loading rate of COD also causes a larger volumetric production rate of methane. For approximately 2.86g of COD decomposition, there is 11g of methane production in a typical landfill bioreactor setting. In addition, the production of methane increases linearly with COD loading at a slope of 0.57g CH_4 –COD/g COD loaded, indicating that about 57% of the COD is converted to methane where the rest is converted to biomass (Özturk, I., and Timur, H., 1999).

As opposed to control areas of experimental setups, leachate recirculation areas were found to have decreasing methane productions over time where the controls remained mostly constant. Also it has been noted that the methane yield of samples in control areas did not correlate well with age, where the opposite was found in leachate recycle areas (Townsend et al., 1996).

CHAPTER 3

Testing MSW and Relationships Which Predict Landfill Stability

Abstract

To properly operate a Landfill Bioreactor, continued analysis of the landfill is critical for optimal performance, before and after closure of the site. This study's focus was to determine for Municipal Solid Waste (MSW) the parameters that can be used to measure solid waste composition and stability.

MSW borings were all taken from a group of landfills across the United States, which were conventional landfills, Landfill Bioreactors (LFBs) that are involved in the EPA's Project XL or CRADA (Cooperative Research and Development Agreement) between the US EPA and Waste Management, Inc. and those independently operated by Waste Management as recirculating or bioreactor landfills. The landfills were all of different ages and sizes, and since they were from different parts of the country, there was considerable variation in the composition in each MSW sample.

The measured parameters were compared to each other to determine the relationship between various parameters. Using these comparisons, the samples were compared to determine the best parameters to characterize relative stability. The best trends were found when comparing BMP to cellulose (%) and to volatile solids (%). To a lesser extent, the cellulose/lignin ratio and BMP provided a reasonable correlation.

A study was also conducted to determine the best way to conduct the BMP test with regard to the amount of waste used and the amount of sludge used to seed the bottles. It was also found that using less MSW (0.5g) at a higher cellulose concentration produced the highest BMP, and using more MSW (2.0g) at the same or a lower cellulose concentration produced lower BMPs.

The broth concentration and the strength of wastewater treatment plant sludge used in making the broth both influenced the outcome of the BMP test. As a result, comparison of BMP values from one landfill to another may be problematic. However, within a landfill, BMP values can be compared to determine the effects of depth, moisture content and age of the waste.

Introduction

In major cities around the world, problems exist with the management of increasing amounts of municipal solid waste (Šan & Onay, 2001). Many laboratory scale and full size landfill studies have been conducted to learn how to more efficiently operate landfills.

It has been repeatedly shown that the addition of moisture, sludge from wastewater treatment plants, and buffering agents will accelerate the biological degradation of MSW (Nopharatana et al., 1998). A 10-fold increase in the decomposition of COD in MSW was observed when wastewater treatment plant sludge was present in a landfill (Kouzeli-Latsiri et al., 1999).

This engineered approach to disposing of MSW is called the landfill bioreactor. Waste shredding, leachate recirculation, sludge addition, and nutrient spiking are a few methods found to be effective in operating a bioreactor landfill. The operation of a bioreactor landfill can stabilize MSW within 5-8 years of processing. This controlled environment also reduces the possibility of long-term risks (Warith, 2001).

By using leachate recirculation, it is possible to operate a landfill as a bioreactor for MSW. The traditional method was to limit leachate production by using a closed cell approach, which inhibits the stabilization of MSW (Townsend et al., 1996). This method is very inefficient, and can cause the stabilization to require decades before it is complete. Leachate recirculation was suggested almost 20 years before full scale systems were implemented (Mehta et al., 2002).

A large lag time in the decomposition of MSW is associated with traditional landfills. The rapid development of an adapted anaerobic community and the maximization of its ability to produce methane can be obtained through proper leachate recirculation. In addition, through this increase of methane production, internal landfill temperatures are found to be higher (Chen et al., 2000).

Methane is 23 times more potent than carbon dioxide as a greenhouse gas. Bioreactor landfills provide a better environment to control the emission of greenhouse gasses as well as the odor and migration of these gasses (Warith, 2001). Landfill gas is unpleasant to the senses, is explosive, and has other potential environmental risks associated with it.

It has been determined that almost half of the greenhouse gasses produced from paper in Australia came from paper that had been disposed of in landfills (Pickin et al., 2001).

It has been found that from waste such as batteries, electrical switches, fluorescent light bulbs, and others, methylated mercury compounds can be formed in these methanogenic conditions. These monomethyl and dimethyl mercury compounds are very toxic to humans and other species (Lindberg et al., 2001).

The major organic components of MSW are paper and yard wastes, which are mostly composed of cellulose and lignocelluloses and these degrade well under methanogenic conditions (Kim et al., 1997). The degradation of municipal solid waste takes place in a number of different phases. In the active degradation phase, energy rich methane production is at its highest. The final phase is where proper maintenance of the landfill and collection systems must be maintained to reduce the risk of atmospheric pollution. This phase takes the longest time and is the source of much of the uncollected gases that are discharged to the atmosphere.

Volatile solids are commonly used to estimate organic content of MSW (Townsend et al., 1996). Cellulose is considered the largest biodegradable fraction of MSW (Mehta et al., 2002). Cellulose also correlates well with volatile solids (Kelly, 2002) and provides an excellent estimate of the readily degradable organic content. Since lignin is very resistant to decomposition under methanogenic conditions (Mehta et al., 2002), the ratio of cellulose to lignin can be used as an indicator of stability in a landfill.

The BMP can also be used to evaluate the relative stability in a sample of MSW. The BMP test has not yet been standardized, as it is still being studied. For the purpose of this study, it has shown to be a difficult task to produce similar results from repetitive BMP tests. BMP is a measure of how much readily degradable organic content is available for methanogens to use. It correlates well to cellulose and volatile solids, but not very well with the ratio of cellulose to lignin. Volatile solids and the cellulose to lignin ratio are also found to have low correlation (Kelly, 2002).

Purpose

The purpose of this study was to determine the correlations that exist between laboratory-tested components for a wide range of MSW samples. BMP, pH, moisture, volatile solids, cellulose, and lignin were all tested and compared. Another purpose of this study was to determine the best way to conduct the BMP tests.

Methods and Materials

Samples

Dr. Douglas Goldsmith of Alternative Natural Technologies, Inc. and his associates shipped MSW samples to the laboratory at Virginia Tech while serving as research consultants for Waste Management, Inc. Dr. Goldsmith also provided data for samples that were sent to other testing facilities. The samples were taken from a large group of bioreactor landfills across the United States and were shipped in large coolers with ice packs.

Shortly after receiving the coolers, they were opened, the ice packs removed, and the samples were placed in the walk in refrigerator for future analysis. The samples were prepared within the first two weeks after receiving them. Initially pH and moisture tests were performed. The samples were then ground and milled in a blender and a 10 mesh Willey Mill. The samples were then tested for volatile solids. The remaining MSW was moisture free and stored for further analysis (cellulose, lignin, and BMP).

pH

The pH was measured by preparing a mixture of MWS and deionized water. The preparations were roughly a 50/50 mixture by volume, and were prepared in Nalgene 1 L beakers. After approximately 5 hours, the measurements were taken with a silver/silver chloride reference pH probe. These readings are usually taken quickly in the field due to changes after standing in water.

Moisture

The moisture tests were performed using modified Standard Method 2540-B (APHA, 1992). In this test, 500-1000g of fresh MSW are measured out into an aluminum pan, and dried to a constant weight at 105^0C. This constant weight was achieved in no more than two days. The results were recorded as a percent weight loss from the original sample.

Final Sample Preparation

After the samples were oven dried to a constant weight (105^0C), materials such as glass and large pieces of metal that are unable to be ground were removed, and the remaining material was ground to a manageable size using a stainless steel blender. After this, each sample was then passed through a 10 mesh Wiley Mill. The final product was a finely chopped, dusty soil type substance.

Volatile Solids

A modified Standard Method APHA Method 2440-E (APHA, 1992) was used to measure volatile solids. Approximately 100-300mg of dried sample was measured into small aluminum pans which were then placed into a muffle furnace at 550^0C. After 20 minutes, the samples were removed and cooled in desiccators to a constant temperature and weight. The samples were then weighed and the volatile solids contents were reported as a percentage weight loss from the dried samples.

Lignin and Cellulose

Lignin and Cellulose were analyzed by using the ASTM E $1758\text{-}95^{el}$ (ASTM, 2001) modified method. Using the milled and dried samples, the first step was to hydrolyze the cellulose into glucose monomers. This was done by placing 300mg of each sample into vials along with three milliliters 72% sulfuric acid. The mixture was then heated in a 45^0C water bath for two hours.

After this, the samples were washed into 300ml brown septa bottles using 84ml of nanopure water and placed into the autoclave at 121^0C and 15 psi for one hour. After filtering the solutions using standard TSS glass fiber filters, the volatile suspended solids determined by combustion at 550^0C in the muffle furnace were considered to be lignin and were reported as % lignin w/w.

The remaining filtrate was neutralized to a pH of 5-6. This was accomplished using $CaCO_3$ directly placed into each of the filtrate samples. By slowly adding the $CaCO_3$ and testing with a silver chloride reference pH probe, the fastest and most consistent results were produced. The neutralized filtrates were then placed into 1 ml vials and measured using a HPLC carbohydrate column HPX-87C with a refractive index detector to determine the glucose content. The results were reported as percentage cellulose w/w.

Biochemical Methane Potential

The method used to analyze the BMP was a modified version of a procedure described by Kelly (2002) and Vaidya (2002). In this study, 0.5g to 2.0g of each sample of MSW was added to a 250mL septa seal bottle. Next, 100mL of anaerobic growth media was added.

The anaerobic growth media consisted of phosphate, M3 (Na, Ca, Mg, and NH_4 salts), trace nutrient, and vitamin solutions. In addition there were also 10% by volume anaerobic digester biosolids. The source of the biosolids was the anaerobic digester at the Peppers Ferry Treatment Plant in Fairlawn, VA. The growth medium is seeded with the sludge to promote the growth of anaerobic microbes.

After the samples were prepared, they were sealed and well mixed by shaking. Then they were placed in an incubator regulated at 35^0C. The standard test method called for 45 days of incubation.

After the incubation, one liter Teflon gas-sampling bags were attached to the bottle with a short piece of plastic tubing connected to a syringe needle tip. This was pushed through the septa seal, and then the bags were opened which allowed flow of pressurized gasses into the sampling bags. The total gas was recorded as the headspace in the bottle (165mL) added to the volume of gas collected in the sampling bags.

Before the sample bags were detached, another gas sampling syringe was used to pull out a 100 micro liter sample. Each sample was then run through a Gas Chromatograph utilizing a carbosieve packed column and a flame ionization detector (FID). Using blanks, the overall methane potential was reported as milliliters of methane (STP) per gram of dried MSW (mL CH_4/g).

Results and Discussion

The major components of municipal solid waste were measured to determine if there was a correlation between the stability parameters, BMP, VS, cellulose, and lignin. There was also interest in determining which would provide the most consistent data. These data and correlations can give insight to the composition of the MSW, as well as help describe the stability or residence time needed for stability of MSW in bioreactor landfills.

The use of volatile solids is one method used to quantify the concentration of organic content in a sample of municipal solid waste (Townsend et al., 1996). Kelly, et al. (2002) also found that VS was a reasonable indicator of stability and correlated well with cellulose. In this project, samples from several landfills were collected and stability indicators measured to determine the variability between specific landfills. The data from the Kelly, et al. study included data from 11 landfills and numerous measurements. While the correlation between some parameters was good, there was a considerable scatter amongst the 11 landfills. For this reason it was important to determine how individual landfills might fit the data.

The major readily biodegradable fractions of municipal solid waste are cellulose and hemicelluloses. Lignin is quite resistant to degradation under anaerobic conditions. As cellulose is degraded, most of the lignin remains and its percentage in the MSW increases (Mehta et al., 2002). For this reason, the cellulose to lignin ratio has been proposed as an indicator of the level of decomposition in a sample. Lignin concentrations may also be a good way to determine the time it will take a sample to be fully digested under anaerobic conditions.

Since anaerobic biological decomposition of MSW produces methane as an end product, the biological methane potential (BMP) has been used as an indicator of landfill stability. As decomposition proceeds, the BMP decreases; however, BMP measurements have been found to be highly variable at lower levels of BMP (Mehta et al., 2002). This is probably due to the heterogeneous nature of municipal solid waste.

To see how BMP could be affected by using different weights of MSW, as well as solid waste of different degrees of decomposition, a pilot study was conducted to determine the most appropriate amount of ground solid waste to be used in the BMP test. Sample weights tested were 0.5g, 1.0g, 1.5g, and 2.0g of ground solid waste in a BMP bottle. The strength (BMP) of the sample was estimated by looking at the relative concentrations of volatile solids and cellulose in waste samples. The three samples ranging in relative strength from strong, medium, and weak, were all from the Plantation Oaks LFB in Natchez, Mississippi and were collected on August 22, 2002.

As seen in Figure 3.1, the strength of the trash was an important factor in determining the value of total BMP. The strong sample had the highest volatile solids, highest cellulose, and also the highest BMP, while the lowest cellulose and VS were associated with the lowest BMP. These values can be found in Table 5.2 and Table 5.3. This suggests that any of the three measures, BMP, cellulose or VS, could be used to indicate stability.

The sample size of MSW had an important effect on the BMP value. For weights of 0.5 and 1.0 grams, the BMP was relatively constant at 180 to 200 mL/g for the strong waste and 90 to 100 mL/g for the medium waste. However, when the sample weight was increased to 1.5 g and above, the BMP declined, indicating that all the degradable material was not being converted to gas. This was probably due to at least one of three things; limiting headspace, limiting nutrient supply, or limiting number of microbes in the inoculums. Another observation with regard to BMP was at higher BMP values, there was considerable scatter among repeat measurements. This suggests that BMP measurements are less reliable than cellulose or VS measurements.

One of the main problems with the BMP test run during this study was occasional leakage of the septa seals, lowering the accuracy of the tests. A constant head collection system should be utilized since some of the samples can produce significantly more gas due to sample heterogeneity. Because of this, 1.0g was selected as the sample size for measurement of BMP.

It was also found that as BMP increases, higher levels of volatile solids, cellulose, and lignin were observed. This is illustrated in Figure 3.2, where these three constituents were plotted versus BMP. For this set of data, the slope of the line for cellulose is the steepest, suggesting that cellulose has the largest impact on BMP.

Lignin does not usually correlate well with BMP; however, as seen in Figure 3.3 the correlation between lignin and BMP is fair. The data for Figure 3.3 was from the pilot study and only sampled a small sample set. When using a larger sample size, the variability increases. Greater variability is also seen in samples with higher BMP.

Lignin, as found by Kelly (Kelly, 2002), does not seem to decompose until the level of cellulose is below 25%. This is shown in Figure 3.4 where the relationship between cellulose and lignin are plotted for the entire Virginia Tech data set. For the majority of the samples, the level of lignin is constant above 20% cellulose and then decreases as the cellulose decreases.

Figure 3.5 and 3.6 show the cellulose and volatile solids concentrations plotted against BMP, respectively for the entire Virginia Tech data set. The low correlation between cellulose and BMP (r^2 less than 0.5), as well as between volatile solids and BMP are likely due to several reasons. One would be that these plots are of heterogeneous mixtures of municipal solid waste, consisting of anything thrown into household and business trashcans as well as dumpsters. Also to collect these data, the tests were conducted over several years and the source of sludge most likely varied over time as well as the anaerobic microbe culture. Finally, it appears as was noted earlier, that the BMP test is also highly variable.

The ratio of cellulose to lignin has been thought to be a good indicator of MSW stability. In Figure 3.7, the cellulose and lignin values for different samples from one landfill are shown. The cellulose values are all below 40%, making it difficult to compare the data in Figure 3.4 with the data for the Maplewood landfill shown in Figure 3.7. However, this graph does show the strong correlation between lignin and cellulose, especially the data below 20% cellulose.

Figures 3.8-3.10 for three individual landfills show that the cellulose to lignin ratio increases with BMP. These graphs represent one sampling event from three different landfills. However, the correlations are only moderately strong. There is considerable scatter between the separate landfill data sets. This indicates that either the BMP or the C/L ratio may not be a good predictor of landfill stability. Kelly, et al. (2002) found that both VS and cellulose were good indicators of stability. Therefore, plots of cellulose and VS versus BMP were prepared.

Figure 3.11 and Figure 3.12 show the trend of increasing BMP with increasing cellulose and volatile solids. The data for Plantation Oaks shows a better correlation than the data for Maplewood. This may be, in part, due to the data point for a BMP of 300 mL/g in the Maplewood data that does not fit the remaining data set. If that point is eliminated, the data correlate much better. The high variability in both data sets suggests that BMP may not be a good indicator of stability. One other observation noted from these data is that when the VS is less than 15%, there is no measurable methane generation and when the cellulose is less than 10%, there is little BMP. This suggests that a value of 15-20% VS and 10-12% cellulose are good ranges to depict stability of landfill waste.

The strength of the correlation between cellulose and volatile solids is shown Figure 3.13, where a large group of multiple landfills data have been collected and plotted against each other. With increasing volatile solids, you see increasing levels of cellulose. Volatile solids are a good measure of organic content where cellulose is a good measure of how much of this is readily available to landfill microbes.

An additional study was conducted to investigate the effects of different types of paper on BMP and to compare that to the cellulose content. Gary Hater of Waste Management Inc. sent the samples and they were to be tested as normal MSW. The types of paper used were cardboard, newspaper, office paper, phone book pages, and magazines.

These samples were prepared by cutting them and then grinding them in a 10-mesh screen Wiley Mill. The data from this study are shown in Figure 3.14 and Table 5.4. The material with the highest cellulose content corresponded to the paper that produced the highest BMP. Office paper and Cardboard had the highest values, indicating they are the most readily biodegradable. These were followed by Magazines, Newspapers, and Phone Book pages.

The data indicates that the best stability indicators are cellulose and volatile solids. While BMP seems like it would be a good indicator of stability, the high variation in the results make it problematic for assessing landfill stability. Because the BMP test is the most complicated and requires the longest time to complete, it is much better to use cellulose in order to get rapid and reliable results. If equipment is not available to conduct a cellulose test, the volatile solids analysis will provide reliable results.

It should be noted that the volatile solids do not need to be reduced to zero for a solid waste sample to be considered stable. If the value is less than 20%, the waste will generate little methane as indicated by the data in Figures 3.11 and 3.12. For cellulose, a value of less than 12% also indicates a stable waste.

Summary and Conclusion

Of the tests performed, volatile solids, cellulose, and lignin seemed to provide the best data for predicting stability of a landfill sample. BMP could be a better indicator of stability given two things. These are a more standardized formula for broth and inoculums, and a more accurate system of gas collection and analysis. Some of the samples were found to produce much more gas than the bottle could contain, causing the septa seals to leak. On the other hand, some of the samples seemed to be “dead with little gas production. Overall conclusions from this study are the following:

- Volatile solids, cellulose, and lignin provide the best data for predicting stability of a landfill sample.
- Lignin decomposes little until cellulose falls below 20%.
- Lignin correlates fairly well with BMP
- Greater variability when comparing BMP in larger sample sets and samples with higher BMP.
- The ratio of cellulose to lignin increases with BMP, indicating that the C/L ratio can be used as a stability indicator.
- A waste sample size of 0.5 to 1.0 g provides best BMP results
- Office paper and cardboard have higher BMP than magazines, newspaper, and phone book pages due to the higher cellulose content of the office paper and cardboard.
- The heterogeneous nature of the landfill can lead to variability in test results of all parameters.

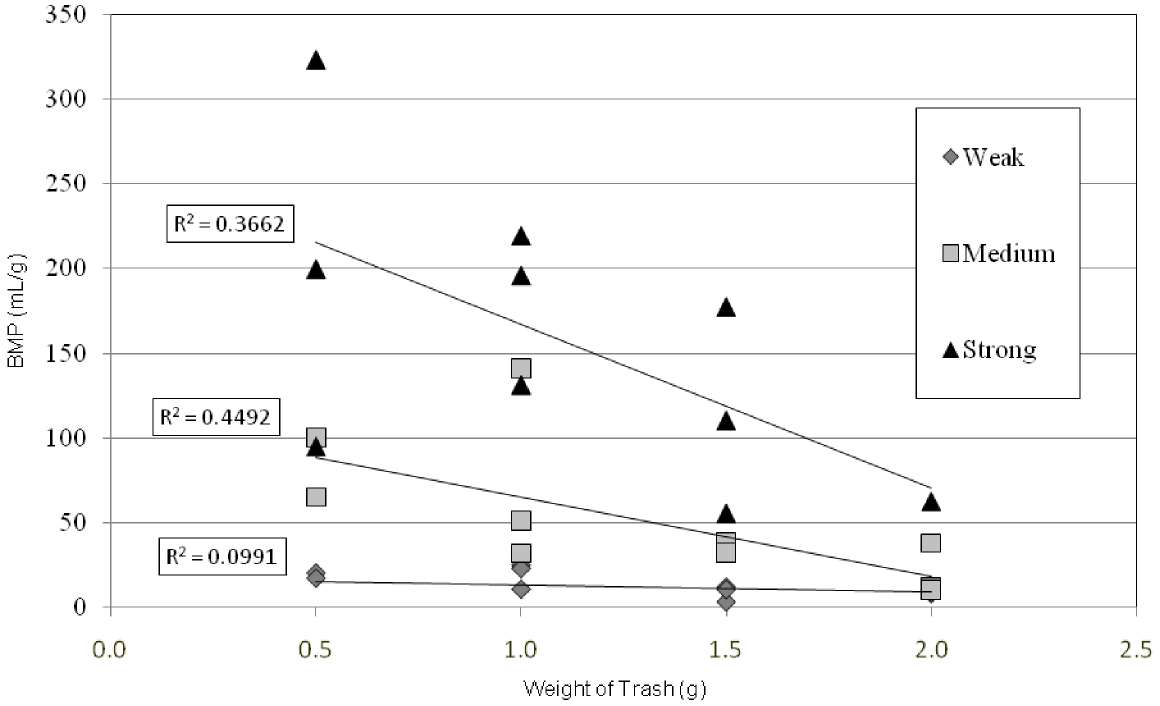

Figure 3.1 - BMP versus weight of MSW Using Different Strengths and Weights of MSW

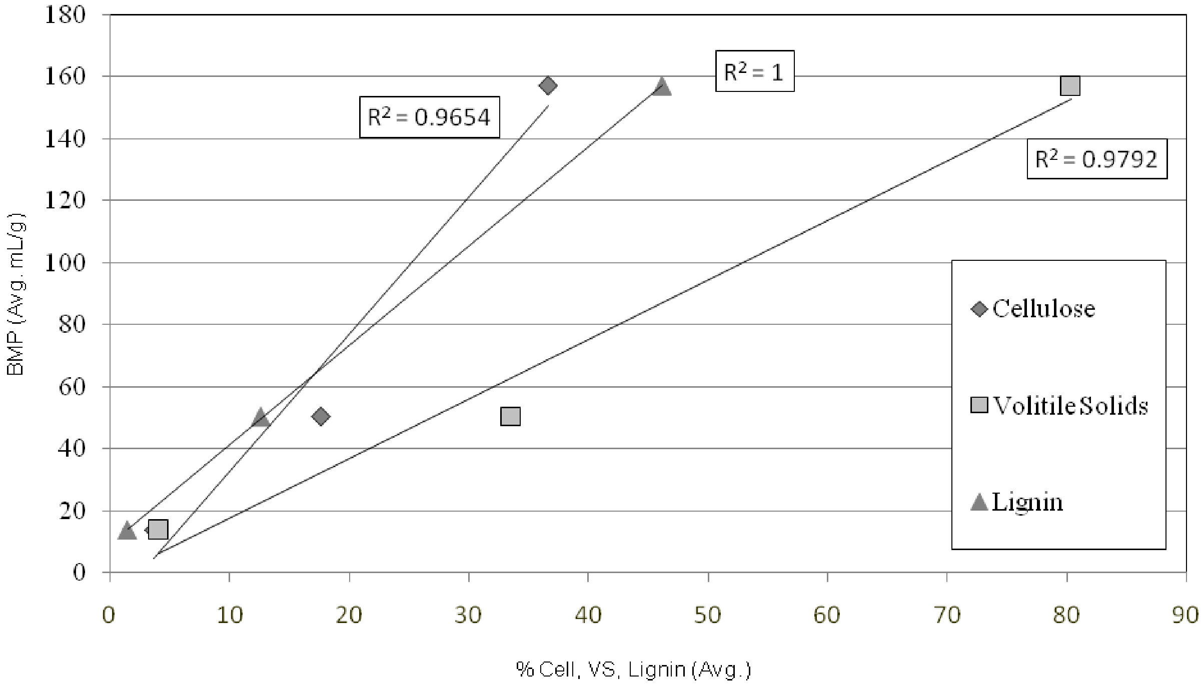

Figure 3.2 - BMP vs. Lignin, Volatile Solids, and Cellulose for Three MSW Samples

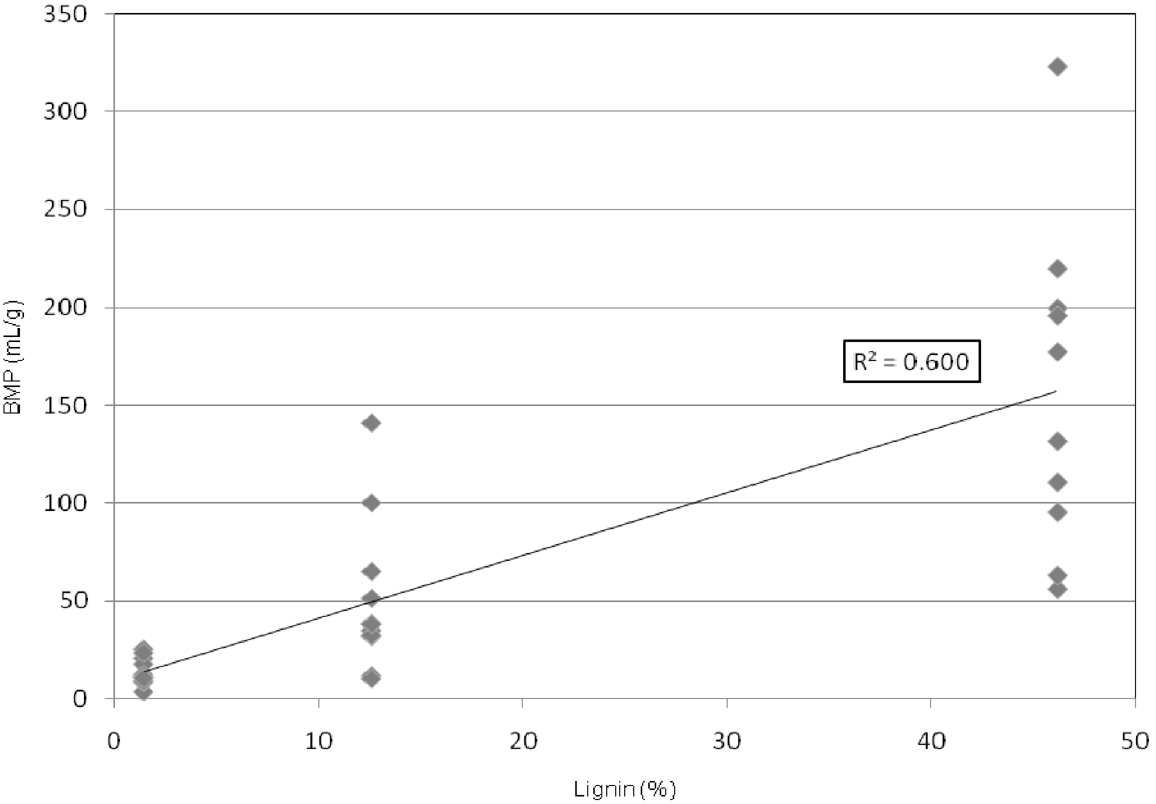

Figure 3.3 - Lignin vs. BMP for MSW Pilot Study Data

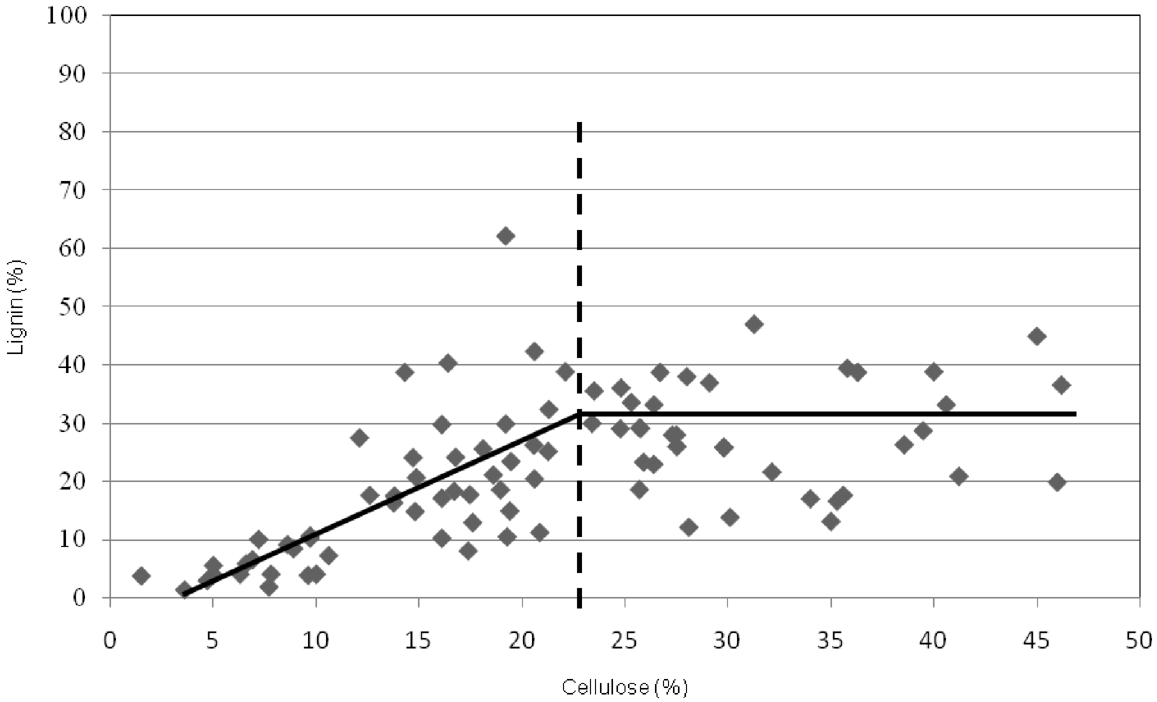

Figure 3.4 - Cellulose vs. Lignin for All Landfill Data

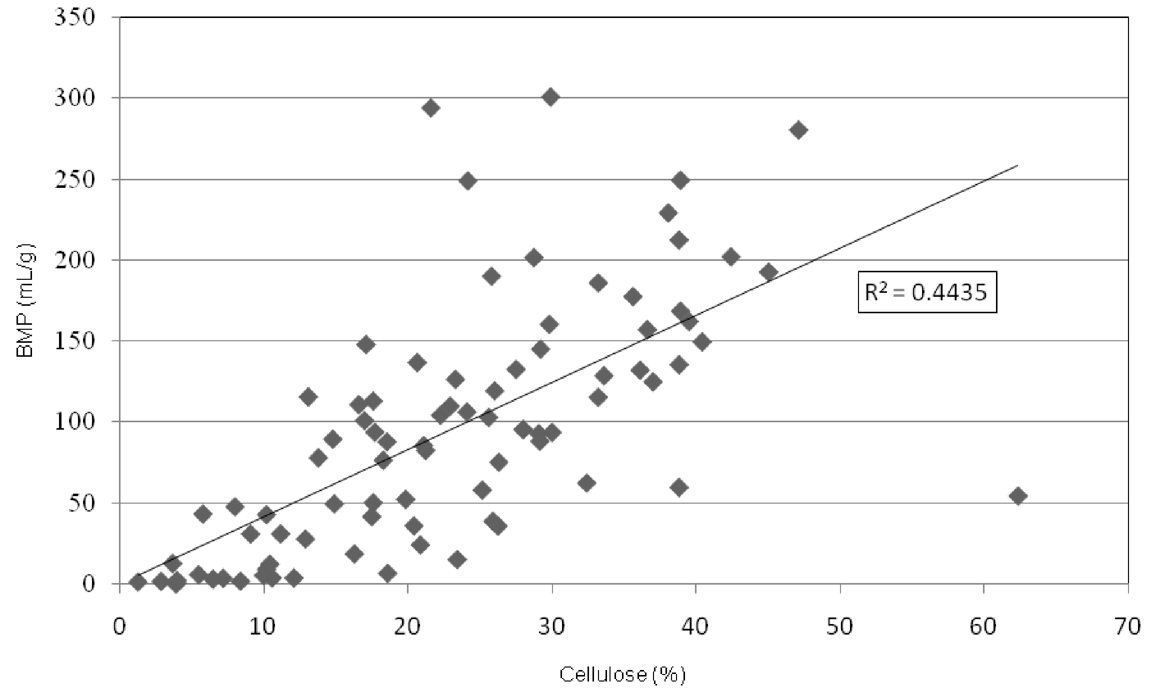

Figure 3.5 - Cellulose vs. BMP for all landfill data

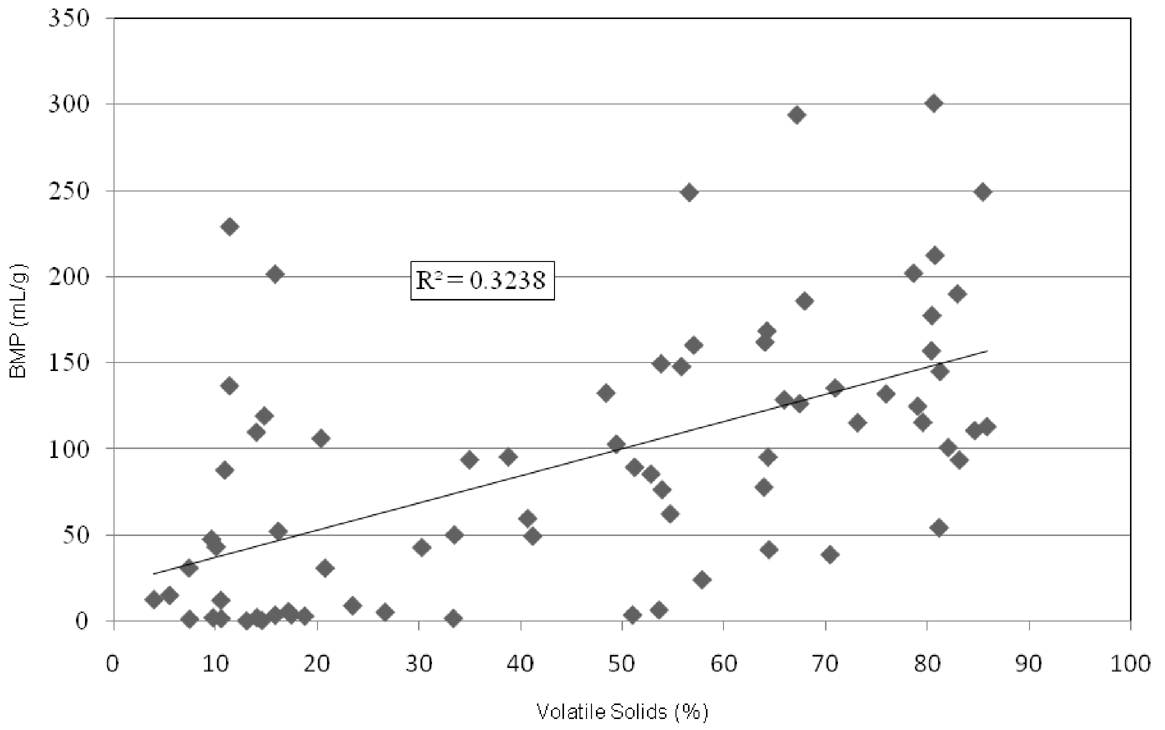

Figure 3.6 - Volatile Solids vs. BMP for all landfill data

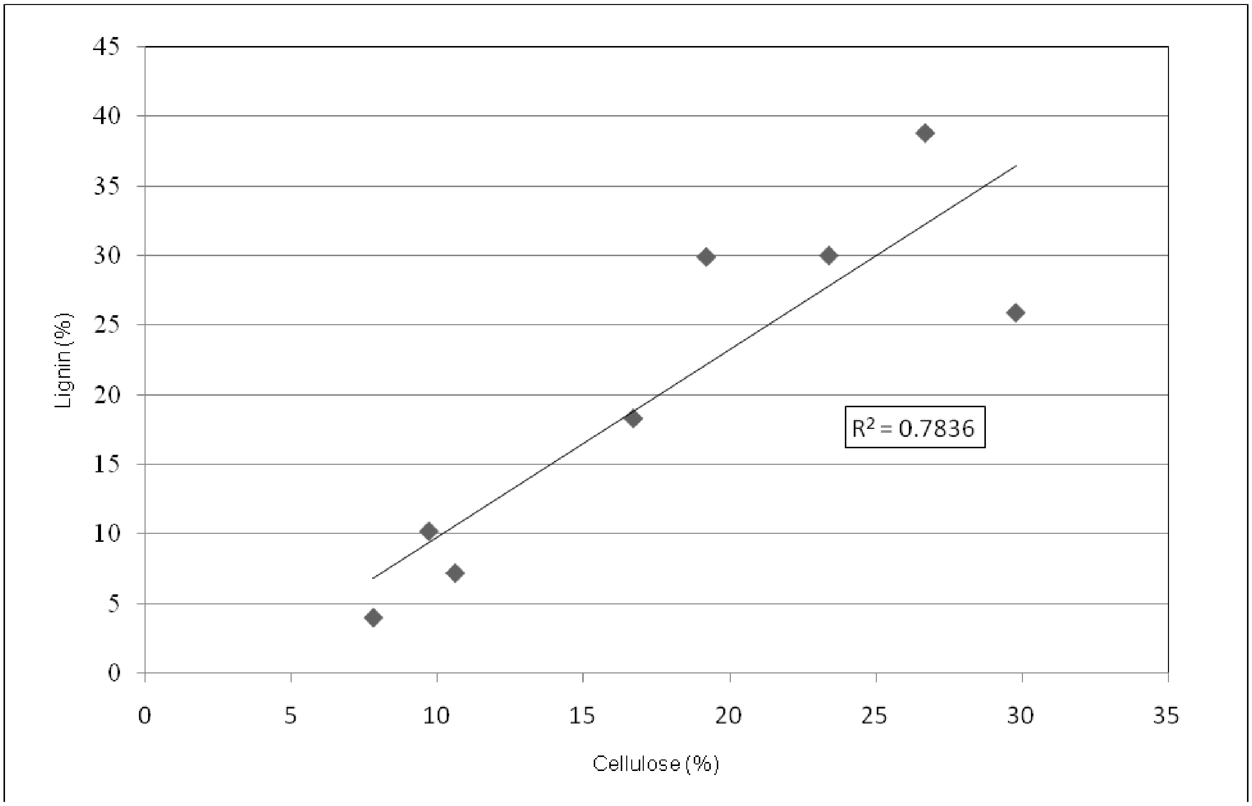

Figure 3.7 - Lignin vs. Cellulose in Maplewood Landfill

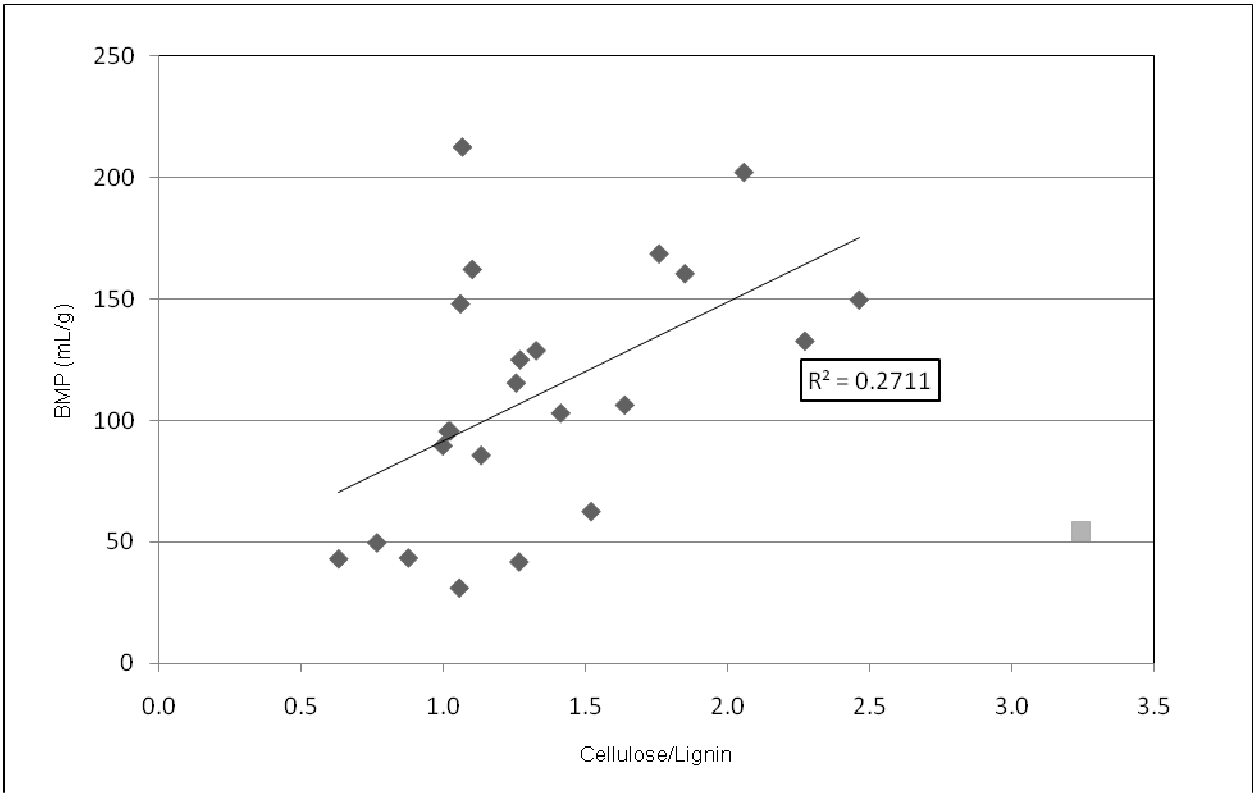

Figure 3.8 - Cellulose/Lignin Ratio vs. BMP for Lake Mills Landfill (outlier removed from trend line)

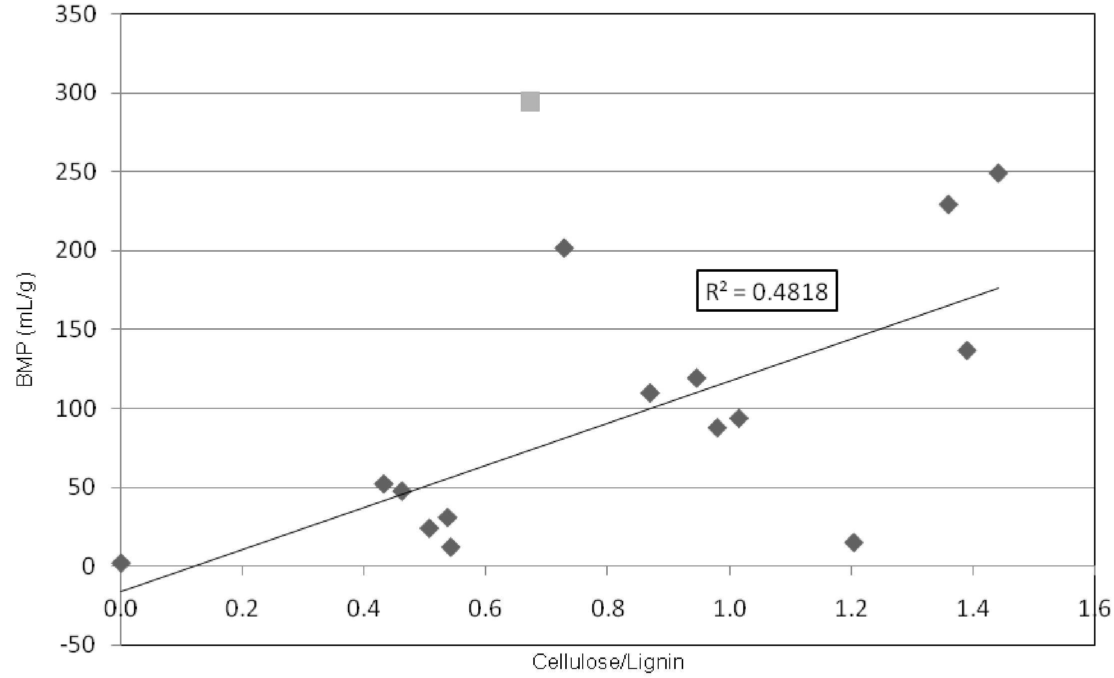

Figure 3.9 - Cellulose/Lignin Ratio vs. BMP for King George Landfill (outlier removed from trend line)

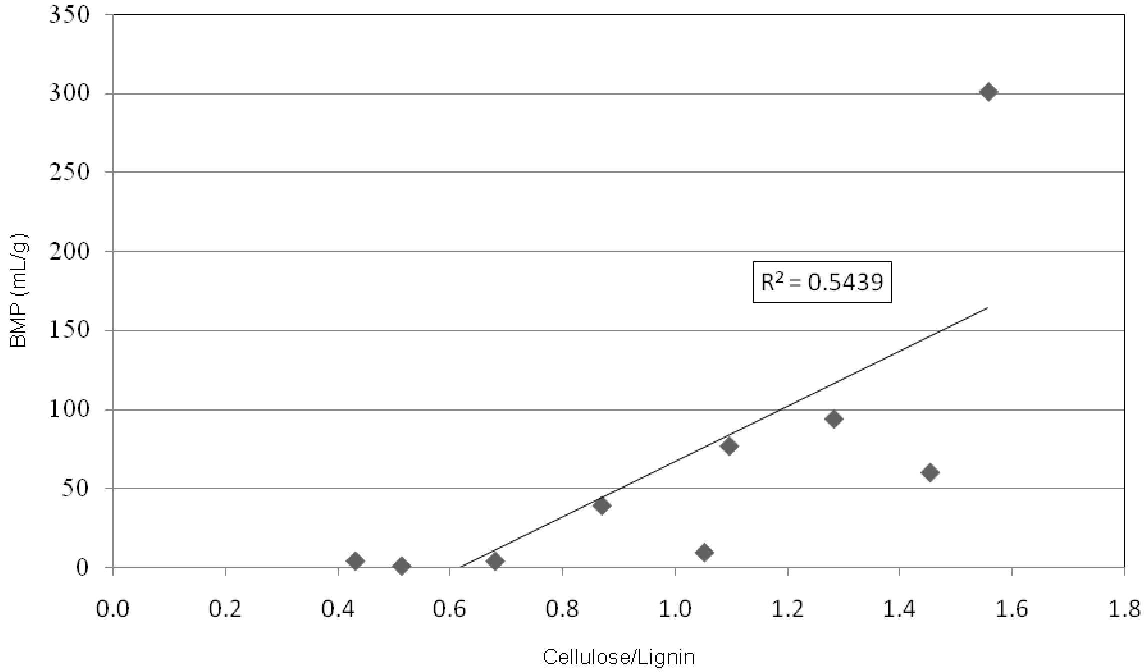

Figure 3.10 - Cellulose/Lignin Ratio vs. BMP for MSW Samples from the Maplewood Landfill

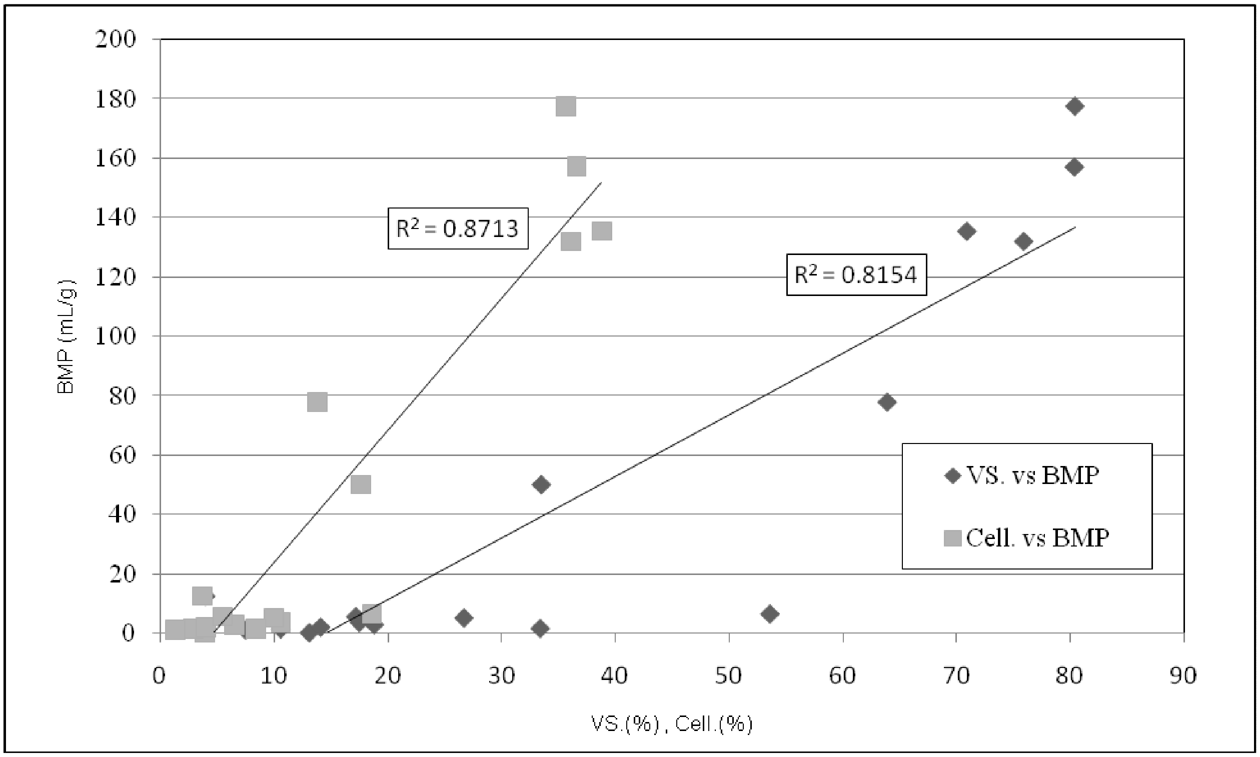

Figure 3.11 - Volatile Solids and Cellulose vs. BMP for MSW Samples from the Plantation Oaks landfill

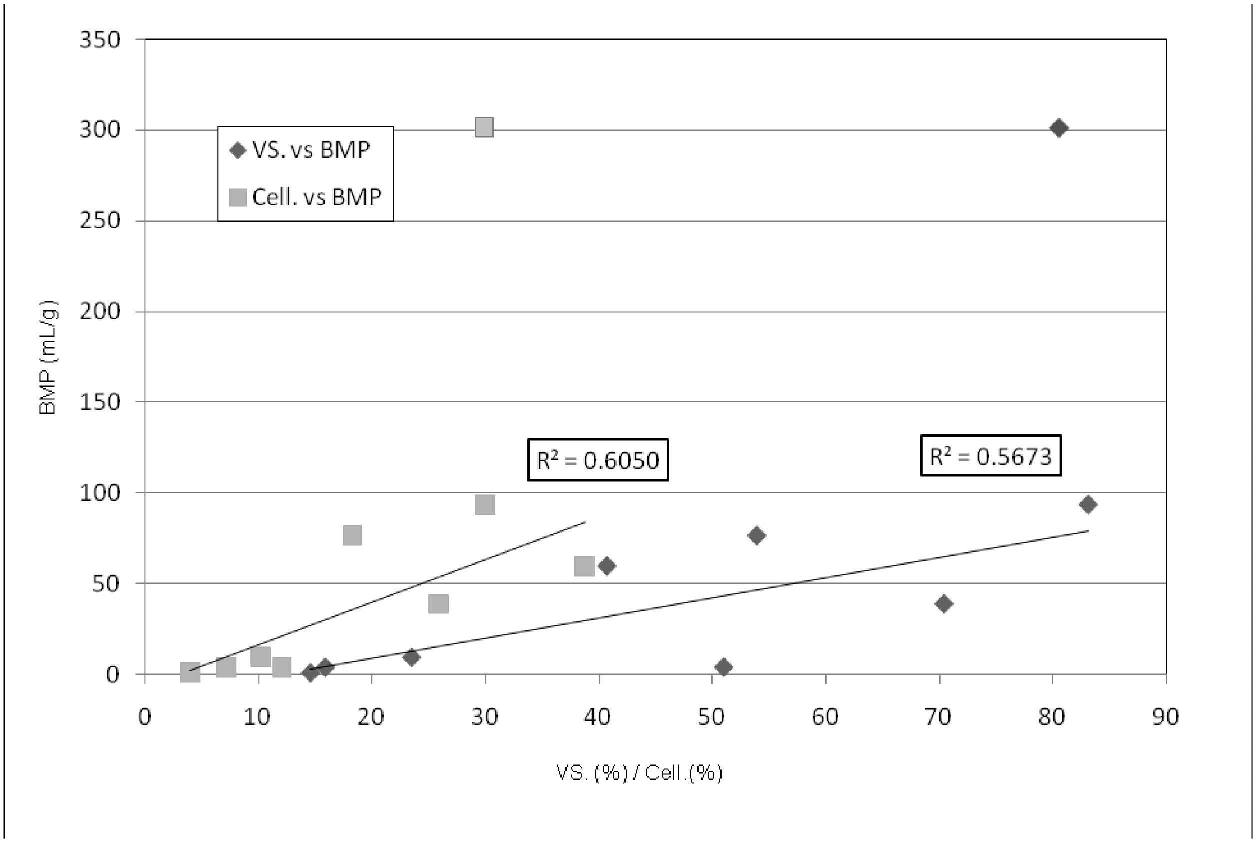

Figure 3.12 - Volatile Solids and Cellulose vs. BMP for MSW Samples from Maplewood Landfill (outliers removed from trend line)

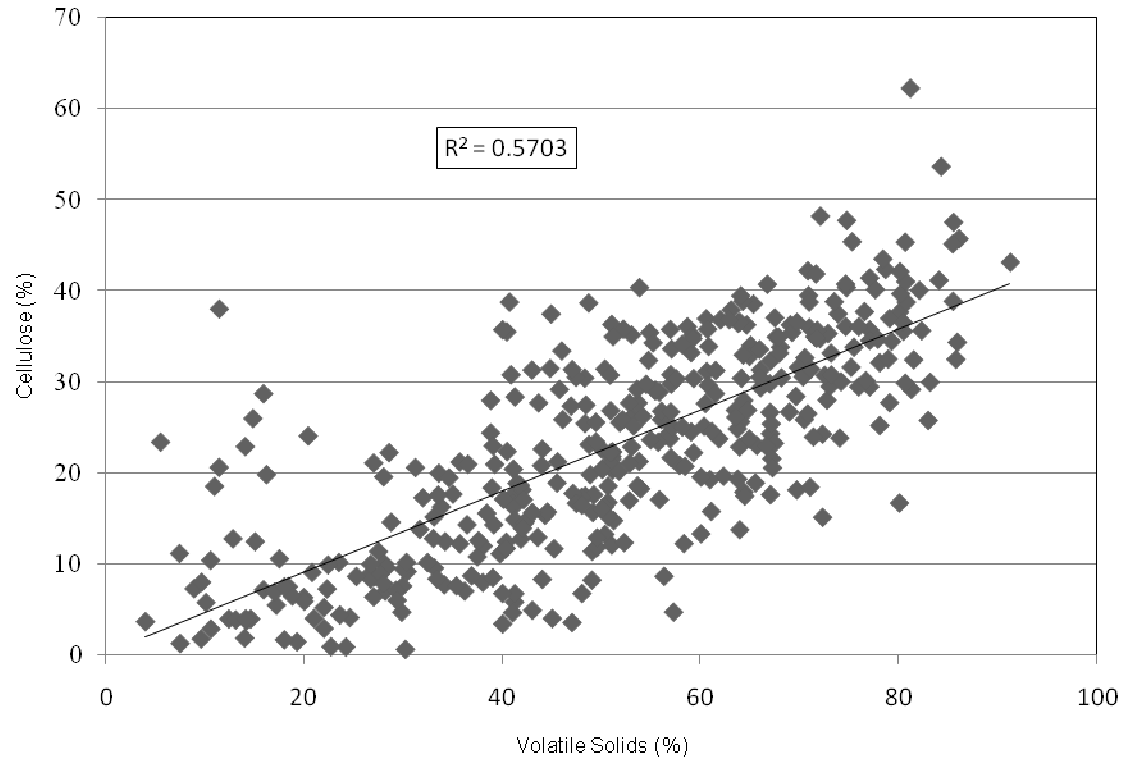

Figure 3.13 - Volatile Solids vs. Cellulose for All Landfill Data

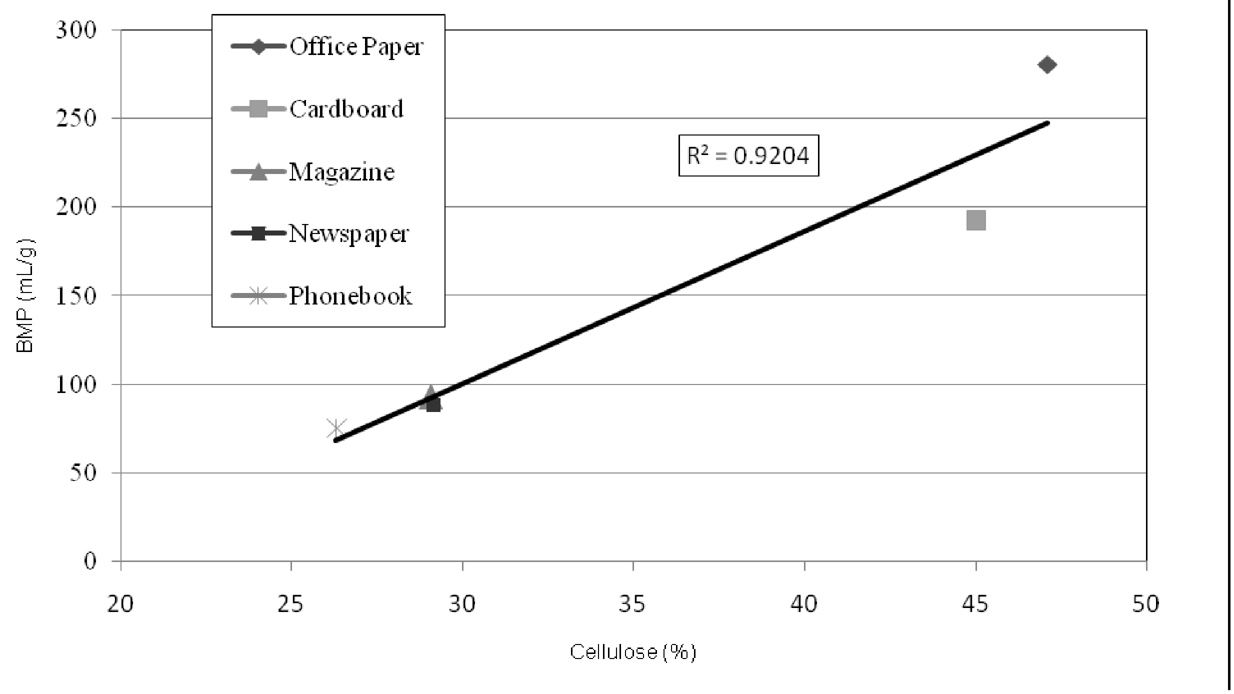

Figure 3.14 - Five Types of Paper Tested for Cellulose and BMP

CHAPTER 4

Testing Landfill Leachate and Predicting Landfill Stability

Abstract

Landfill Bioreactor is a term used to describe a method of land filling. Instead of operating the site as a containment unit, the landfill is run as a biological waste decomposition reactor. To properly operate a Landfill Bioreactor, frequent analysis of the landfill and its leachate are critical to optimize performance, before and after closure of the site. During the operation of these landfills, nutrient rich leachate is recycled to control the moisture content and to provide a nutrient rich environment for microbes to decompose the waste.

This study's focus was to determine if leachate characteristics could be used to determine the stability of a landfill. Leachate biological methane production (BMP) and a variety of stability parameters were measured to determine landfill composition and stability. The standard stability parameters, volatile solids, cellulose, and cellulose to lignin ratio, were tested and compared to the leachate BMP. BMP testing for leachate has not been carried out as a common practice. However, it was the aim of this study to see if it could be done and how useful this information could be.

BMP in essence is not only a measure of stability in MSW; it may also help estimate how much methane could potentially be produced by the landfill as a whole. Being able to estimate the methane potential in leachate as well as MSW could be useful in determining what level of gas collection will be possible. This methane is natural gas and can be used for onsite energy needs or could be sold to offsite customers.

Fresh leachate from a recently filled site tends to be high in COD and BOD. These concentrations decrease over time as decomposition proceeds. With the BMP test developed during this study, some correlations between BMP and COD as well as BOD were found. Some of the COD and BOD data were provided by Gary Hater of Waste Management Inc., while all of the leachate samples shipped to Virginia Tech were also tested for COD and BMP in the laboratory.

One of the problems with the Leachate BMP test was that a large amount of gas was produced. This gas created pressure in the incubation bottle and resulted in the loss of gas so the measured amounts of gas were incorrect for samples that contained a large

amount of biodegradable organics. The use of diluted samples or a more effective gas collection system for the test would solve this problem.

Also, as seen with MSW BMP tests, considerable variability was present. Although the method developed for Leachate BMP may have some variability, it could be further developed to provide a worthwhile test for leachate strength.

Introduction

In major cities around the world, problems exist with the management of increasing amounts of municipal solid waste. Many laboratory scale and full size landfill studies have been performed to learn how to more efficiently operate landfills.

It has been repeatedly shown that the addition of moisture, sludge from water treatment plants, and buffering agents will accelerate the biological degradation of MSW (Nopharatana et al., 1998). A 10-fold increase in the decomposition of COD in MSW is observed when wastewater treatment plant sludge is present in a landfill (Kouzeli-Latsiri et al., 1999).

This engineered approach to disposing of MSW is called the landfill bioreactor. Waste shredding, leachate recirculation, sludge addition, and nutrient spiking are a few methods found to be effective in operating a bioreactor landfill. The operation of a bioreactor landfill can stabilize MSW within 5-8 years of processing. This controlled environment also reduces the possibility of long-term risks (Warith, 2001).

By using leachate recirculation, it is possible to operate a landfill as a bioreactor for MSW. The traditional method was to limit leachate production by using a closed cell approach, which inhibits the stabilization of MSW (Townsend et al., 1996). This method is very inefficient, and can cause the stabilization to require decades before it is complete. Leachate recirculation was suggested almost 20 years before full scale experiments would be implemented (Mehta et al., 2002).

This second part of this landfill study was performed using municipal solid waste from a group of landfill cells, which have similar MSW in the cells, yet are run in different modes to provide comparison between these different methods. The two experimental modes studied were a Facultative Landfill Bioreactor (FLB) and an Aerobic-Anaerobic Landfill Bioreactor (AALB). Both of these are processes based on patents held by Waste Management, Inc. (Waste Management, 2000).

The single most important operation of a landfill is the addition and management of liquid to the matrix. By using leachate recirculation, not only is offsite leachate treatment costs reduced, an additional landfill space of up to 25% can be recovered for more land filling due to the settlement of the MSW in as little as an 8 year period. The amount of leachate required to have bioreactor landfill operation is to provide enough to maintain recirculation is present (Warith, 2001).

The FLB is operated in such a way that the ammonia in the landfill leachate is nitrified in the on-site leachate treatment plant (SBR), and then recirculated back into the landfill. The leachate is denitrified, providing a net loss of nitrogen. In this case, the landfill leachate nitrogen is essentially converted to nitrogen gas inside the landfill reducing the need to treat leachate after it leaves the landfill (Waste Management, 2000).

In an AALB, there is a layered structure, where lower levels are run in an anaerobic mode, and upper layers are provided with air injection. Leachate collection is from the bottom of the lowest layer (Waste Management, 2000). This mode of operation produces leachate that is stronger in organic content, suggesting that more organics are removed from the landfill and are transferred into the leachate. Regarding collection of methane produced by the breakdown of MSW, this would be a more logical way to run the landfill simply because it is easier to control gas production from a liquid bioreactor than from a typical landfill. However, increased cost of operations must also be considered to arrive at the best decision.

Leachate methane production outside the bioreactor landfill in an anaerobic sequencing batch reactor is highly efficient. The methane concentration in biogas has been found to be in the range of 58-75% methane. When this methane is released into the biogas, there is a reduction in the carbonaceous mater in the leachate itself. The production of 11g of methane results from the breakdown of 2.86g of COD in the leachate (Özturk, I., and Timur, H., 1999). This would suggest that a correlation between BMP and COD should exist. Higher COD values in leachate should provide a higher BMP.

With an increase in leachate recirculation, an increased production of methane is seen. This can cause problems such as the greenhouse effect on our atmosphere, as well as the need for increased odor management. This acceleration in biodegradation also increases the lifespan of the landfill and lowers post closure monitoring costs (Warith, 2001).

This increase in gas production does, however, suggest a faster biodegradation of the landfills MSW through rapid degradation of COD in the leachate. An increase in COD loading to a landfill leads to a higher volumetric methane production rate (VMPR). Natural gas production from the anaerobic digestion of leachate is a valuable resource (Özturk, I., and Timur, H., 1999).

A 10-fold increase in methane production is seen where sludge from wastewater treatment plants is added to leachate (Kouzeli-Latsiri et al., 1999). It has been determined that almost half of the greenhouse gasses produced from paper in Australia came from paper that had been placed in landfills (Pickin et al., 2001). It has been found that from waste such as batteries, electrical switches, fluorescent light bulbs, and others, methylated mercury compounds can be formed in these methanogenic conditions. These monomethyl and dimethyl mercury compounds are very toxic to humans and other species (Lindberg et al., 2001).

Bioreactors are more efficient when leachate added has been enhanced with the addition of storm water runoff, wastewater, and water treatment plant sludge. Operating a landfill simply by recirculation of plain leachate may not always lead to the development of a landfill bioreactor. The optimal moisture content is near field capacity (35-65% moisture) is required to operate a bioreactor landfill. If 50% of all the MSW produced in the U.S. were placed in bioreactor landfill settings, 270 billion cubic feet of methane per year could be produced. According to the U.S. Department of Energy, this would account for about 1% of our energy needs (U.S. EPA, 2003).

When examining leachate as an indicator of stability in the landfill, addition of new MSW should be accounted for (Townsend et al., 1996). In addition, pre-buffering of leachate seemed to further enhance the biodegradation rate (Šan & Onay, 2001). A pH value of 6.5 or less has been found to inhibit the anaerobic microbes and its ability to break down the MSW. The microbes are most active at a neutral pH (Mehta et al., 2002).

Enhanced degradation was also seen when leachate was repeatedly passed through the landfill instead of just once. The frequency of this leachate addition further increased efficiency. In a single pass reactor, the COD in the leachate converted to methane is only around 3.5%. On the other hand, a recycle reactor can convert as much as 71% of the COD to methane (Šan & Onay, 2001).

These common findings of COD reduction with BMP production in leachate suggest that BMP and COD are both important in monitoring leachate as well as its respective landfill. Containment and collection of biogas produced in any bioreactor landfill is essential for two reasons. One, it reduces the ability of the methane and other toxic methylated species to pollute the environment. Secondly, the gas collected could be used to provide a significant amount of energy. This is important in this time of energy crisis.

Methods and Materials

Samples and Data

All of the samples came from the Outer Loop Landfill Facility in Louisville, KY. The leachate samples were sent in 1L plastic bottles, and were packaged in iced coolers. Once they were received, the bottles were removed from the coolers and placed in the 4^0C cooler until they were processed. Data for COD and BOD that were measured at the time of sampling were also sent.

Chemical Oxygen Demand (COD)

The method used to measure COD is an USEPA approved method, which was developed by the HACH Corporation. It was Reactor Digestion Method #8000 utilizing prefabricated 3-150mg/L COD digestion vials, the HACH DR2500 COD reactor, and the HACH photo spectrometer (HACH Company, 2003). This method was used to reduce waste and time.

In this method, 2mL of each leachate sample was added to a COD digestion vial, with the proper reagents already in them. Then the vials were capped securely and wiped clean with a lint free paper towel. Next, they were placed into the HACH reactor, which was preheated to 150^0C, for a period of two hours.

After allowing the vials to cool to room temperature and entering the proper program, the blank is used to zero the photo spectrometer. Then each sample was placed into the photo spectrometer, and its COD concentration is displayed as mg/L.

Due to the amount of COD in the samples, a few trials were run, and the samples were finally diluted to 1:20 and 1:32. In some of the samples, a crystalline precipitate was formed. This was probably due to the chloride levels in the sample, since landfill leachate tends to be very high in chloride.

Biochemical Methane Potential

The method used to analyze the BMP was a modified version of a procedure described by Kelly (2002) and Vaidya (2002). In this study, instead of using MSW, landfill leachate was used. The leachate was used as the main portion of the growth media, instead of distilled water.

The anaerobic media consisted of phosphate, M3, trace nutrient, and vitamin solutions. In addition there was also 10% by volume anaerobic digester biosolids. The source of the biosolids was the anaerobic digester at the Peppers Ferry Treatment Plant in

Fairlawn, VA. These biosolids are added as a seed to the media to help promote the growth of proper species of anaerobic microbes.

In each inoculated bottle of the BMP test for MSW, 100mL of broth was added to each bottle. In order to keep the volume the same and use leachate as the main liquid portion of the broth, a stronger broth was used. To run a BMP test where leachate was to make up 50mL (50% concentration) of the total broth, a broth had to be prepared with 50% less distilled water. For example, to prepare the broth for 10 leachate BMP test bottles to be run with 80% leachate, 80% less water is used in preparing the broth.

After the samples were prepared, they were sealed and mixed by shaking. Then they were placed in an incubator regulated at 35^0C. The standard test method called for 45 days of incubation. In this case, 15, 20, 30, 33, 42, and 55-day incubation times were used. In addition, concentrations of leachate were varied between 50% and 80%.

After incubation, one liter Teflon gas-sampling bags were attached to the bottle with a short piece of plastic tubing connected to a syringe needle tip. This was pushed through the septa seal, and then the bags were opened which allowed flow of pressurized gasses into the sampling bags for testing.

The total gas was recorded as the headspace in the bottle (165mL) added to the volume of gas collected in the sampling bags. Before the sample bags were detached, another gas sampling syringe was used to pull out a 100 micro liter sample.

Each sample was then run through a gas chromatograph utilizing a carbosieve packed column and a flame ionization detector. Using blanks, the overall methane potential was reported as milliliters of methane (STP) per liter of leachate (mL CH_4/L).

Results and Discussion

This study on leachate was undertaken to determine if the leachate BMP was a useful indicator of the stability of the solid waste overlying the leachate collection point. Different lengths of incubation time and concentration of leachate in the microcosm were the test variables, along with solid waste samples and solid waste from various locations throughout the landfill.

A shorter incubation time resulted in a smaller BMP as shown in Figure 4.1. The samples were run for 15 and 30 days at a concentration of 80% leachate. At 15 days, the results are precise, but do not indicate ultimate BMP. At longer times the BMP was greater, suggesting that the incubation time should be at least 30 days. The BMP for the tests run in Figure 4.1 were from a relatively weak leachate so it was expected that for stronger samples, the results would be even more time sensitive.

Figure 4.2 gives an indication of the reproducibility of duplicate samples. Four samples were from different locations in the landfill and the fifth sample was a composite of the four samples added in equal volumes. These samples were run for 55 days at a concentration of 50% leachate. The reproducibility of the results can be seen. The variability of BMP appears to be greater for the stronger samples than in weaker samples.

As indicated in Figure 4.2, lower levels of leachate BMP for these samples were found to be around 100-200 mL/L, whereas the highest values were around 1400+ mL/L. One of the samples run in this study was a mixture of the other four samples. As expected, the results for the mixture reflected the combined BMP values.

Overall, in samples run at 50% leachate concentration, the highest BMPs found were in upwards of 2600 mL/L. The samples that consistently had the highest value of BMP were from cell 7.4B. The concentrations of COD and BOD in the leachate from this cell, and the BMP of the municipal solid waste samples were also the highest of all the cells.

In Figure 4.3, a fair correlation between BOD and BMP was found. As the BOD increased, BMP also increased. These samples were run for 15 days at a concentration of 80% leachate. It is possible that a more dilute sample with a longer incubation time would have provided better correlations. However, when these samples were run, the procedure was still being developed. The COD did not correlate with leachate BMP.

The reason for the lack of correlation between COD and BMP for this data set is not known. It could be the result of variability in the sludge used to inoculate the samples or to the high level of chloride usually found in leachate. High levels of chloride have a negative effect on the outcome of a COD digestion process. In addition, leakage of the septa seals in the leachate study of BMP may have impacted the results.

Figures 4.4, 4.5, and 4.6 are plots BMP, BOD, and COD over time, respectively for 7 locations in the landfill. As shown by the graphs, there is a similar trend of increasing to decreasing concentrations of all three constituents over this period. These data suggest that the leachate BOD and COD was highest for the late September sample. There is no reason for this result. The data may reflect dry conditions where the strength of the leachate might have been impacted by evaporation.

For all of these samples, the COD increases, and then decreases. A lack of decrease in BMP was found only in samples from cells 5.2B and 7.3B. A lack of decrease in BOD was only found in cells 5.2B and 7.4B.

The data in Figure 4.7 shows a correlation between BOD and BMP for these cells. Although there is considerable scatter at the higher BMP and BOD concentrations, when the BOD is low, the BMP is also low. This would be expected.

Investigation into Measurement Errors

These results from the cells suggest a lack of correlation between BMP and COD. However, the BMP measurement could be erroneous. Since there were potential errors in the containment and collection of gas volume, the concentration of methane in the microcosm itself was investigated. BMP is a measurement made up of the concentration of CH_4 in a sample bottle, as well as the volume in the bottles headspace and the volume of pressurized gas released into the collection bags.

Leakage of the septa seals lowers the amount of pressure in the microcosm, leading to errors in the volume of the gas produced. This causes lower readings for the BMP. For this reason a plot of the concentration of gas in the headspace injected into the Gas Chromatograph vs. COD was constructed. Figure 4.8 is a plot of all of the samples run for 42 days incubation at a concentration of 50% leachate. This graph shows increasing concentrations of methane with increasing COD. However, there is considerable scatter in the COD values for GC values around 100. It is likely that the problem is with the measurement of COD. For fresh leachate, much of the COD would be biodegradable and lead to high values of BMP. However, for older leachate, the COD might be high but the BMP and BOD could be low. Therefore, the better correlation between BOD and BMP is expected while the lack of correlation between COD and BMP is also not unreasonable.

Figure 4.9 is a plot of the same data set, with the values of gas volume collected included, giving BMP. The correlation (R^2 value) is poor, suggesting that COD provides little information about the degradability of organic matter in leachate.

In figure 4.10, COD concentrations for one of the FLB cells, 5.2B, are observed to decrease over time. A closer look at the plot reveals that over a period of a few months, the values increase and decrease. This suggests that the level of COD in a cell is quite variable over these short periods. This could be due to overall moisture in the cell. If COD is to be observed as an indicator of stability, it has to be observed over a longer period, such as a year or a few years.

When looking at COD over a period of a few years, a decrease in leachate COD suggests decomposition. Since the data for MSW BMP and COD were also found to decrease with time, long term trends in leachate COD can be studied to get an idea of MSW COD and BMP trends.

Figure 4.11 shows a moderate correlation between MSW cellulose and total gas collected from leachate for Outer Loop Landfill. The lack of correlation between BMP and cellulose for these samples is due to the low levels of cellulose. Gas is still being produced, but the strength of this gas is highly variable, further suggesting that levels of cellulose levels near 12% in MWS indicate the approach of stability. With more development of leachate test protocol, monitoring of closed sites could gain accuracy while reducing testing costs.

The volume of gas produced by the leachate BMP tests was comparable to that of the solid waste BMP tests. The reason for this may be that even though the weight of leachate used in the test is much greater, the solid waste contains more gas producing components per weight.

Better results would probably be obtained by using a much lower concentration of leachate, around 5-10%, since the lower level BMPs provide a much more precise measurement. This is important, showing that the organic matter in a landfill can be removed from processes inside the landfill, as well as outside the landfill. Leachate can be treated and gas produced could be collected with more ease, such as in an Anaerobic Sequencing Batch Reactor. From an engineering standpoint, collecting gas produced in the landfill can be a costly and complicated process.

Summary and Conclusions

- As a landfill is stabilized, COD decreases because of Methane Production. Increased methane concentrations are produced in samples with higher COD.

- Proper containment and collection of methane produced in the microcosm is required for accurate and precise BMP tests.

- Eighty percent concentration of leachate incubated at fifteen days produced the most consistent results for the BMP test. This test is not long enough to provide ultimate BMP.

- A more diluted sample should be used to reduce the amount of gas production in the microcosm to reduce potential septa leakage in a leachate BMP.

- The BMP of leachate varies on average in the range of 0-1400+ mL/L of leachate.

- BMP increases as BOD increases in a leachate sample.

- Samples producing more gas have more scattered data for multiple BMP trials of the same sample and when BMP was compared to other parameters.

- Plotting BMP over incubation time in a pilot study provides a fitted line and slope. With further study, the slope of this line may provide information about the stability of the leachate.

- The AALB landfill has stronger leachate (BMP) than the FLB, where the FLB is supposed to denitrify the nitrate containing leachate inside the landfill.

- Gas volume produced by leachate has a moderate correlation with the amount of cellulose in overlying MSW samples.

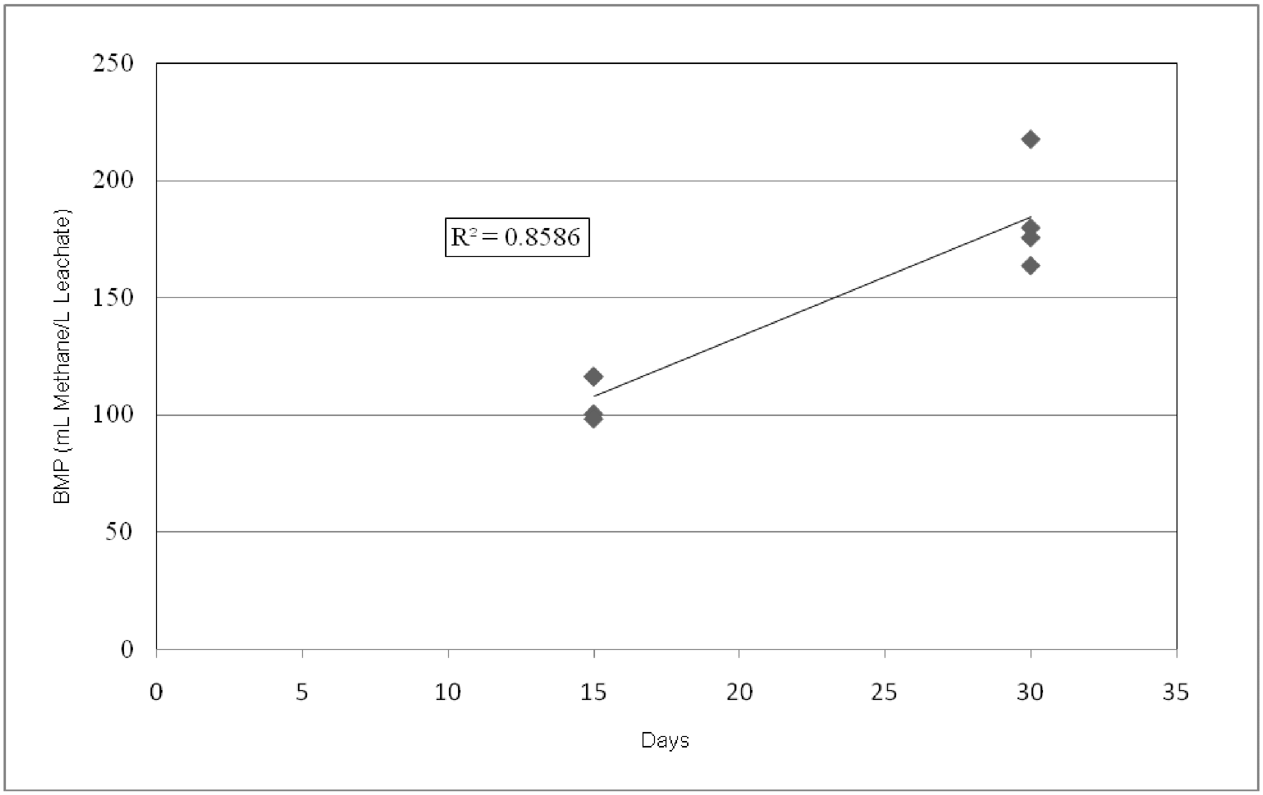

Figure 4.1 – Incubation Time vs. BMP in One Outer Loop Leachate Sample Pilot Study

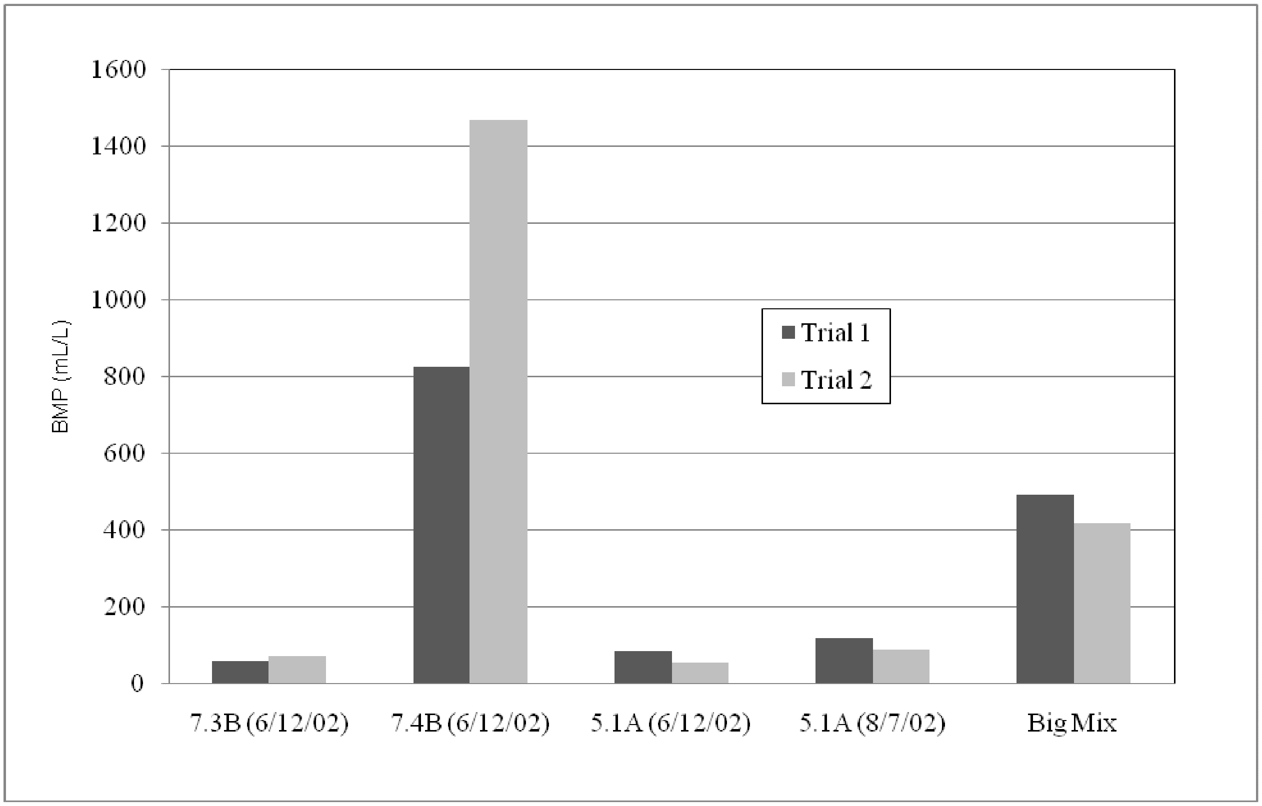

Figure 4.2 – Leachate BMP (mL/L) Using a 55 Day Incubation Time Showing the Reproducibility of BMP in Leachate.

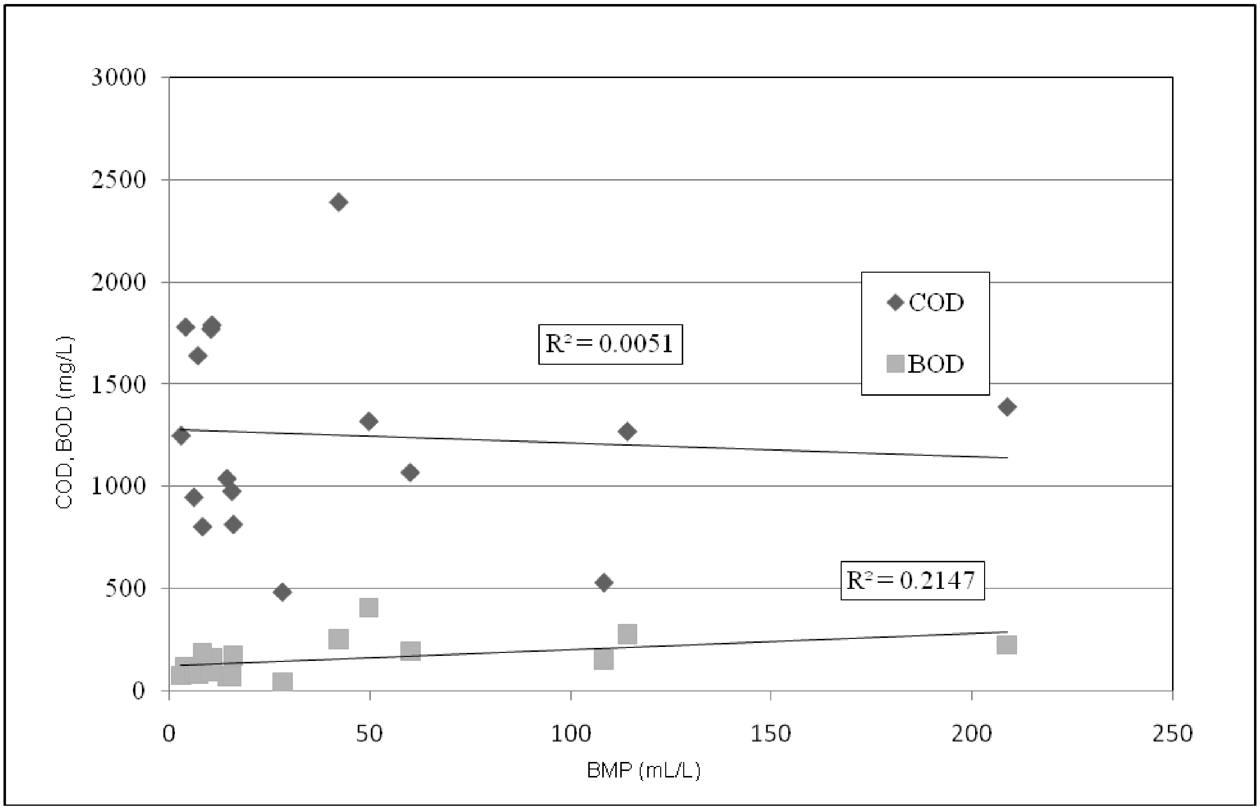

Figure 4.3 – BMP vs. COD and BOD for Outer Loop Leachate 15 Day Incubation 80% Concentration

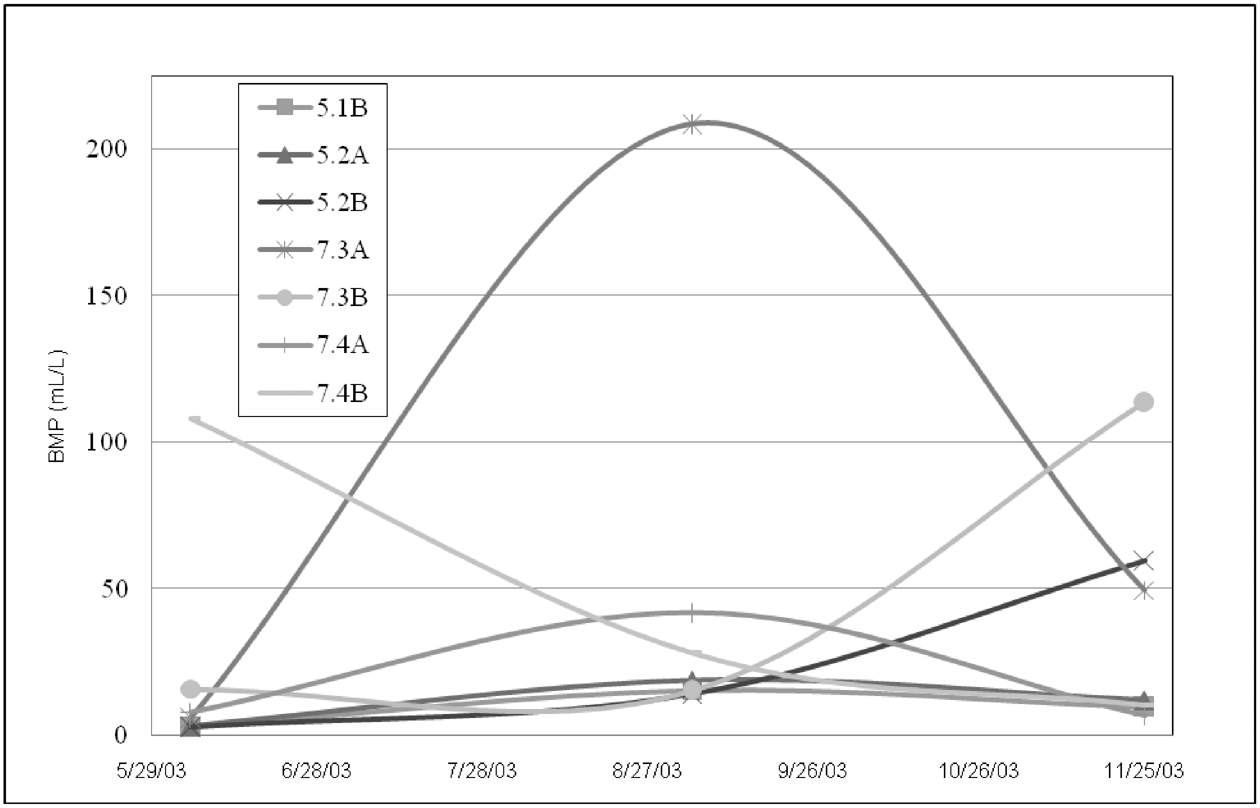

Figure 4.4 – BMP vs. Time for Different Leachate Samples

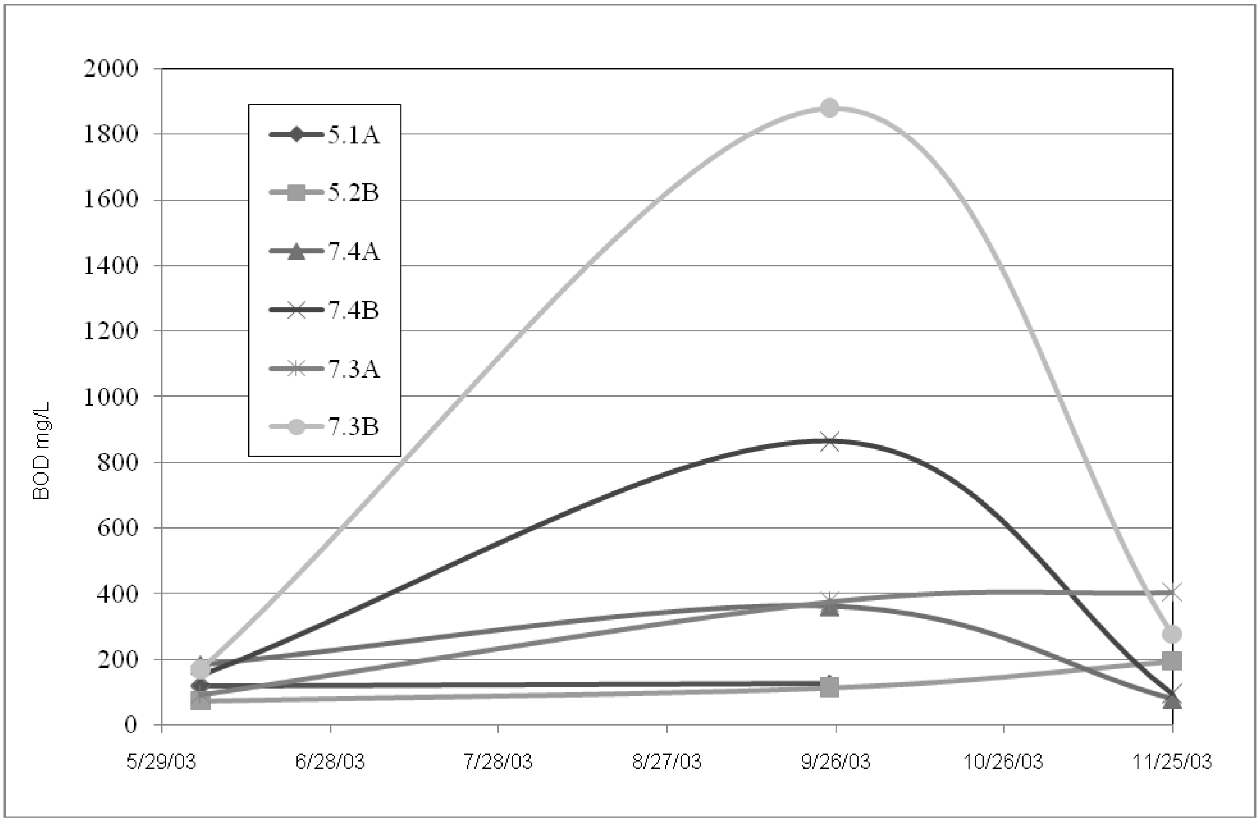

Figure 4.5 – BOD vs. Time for Different Leachate Samples

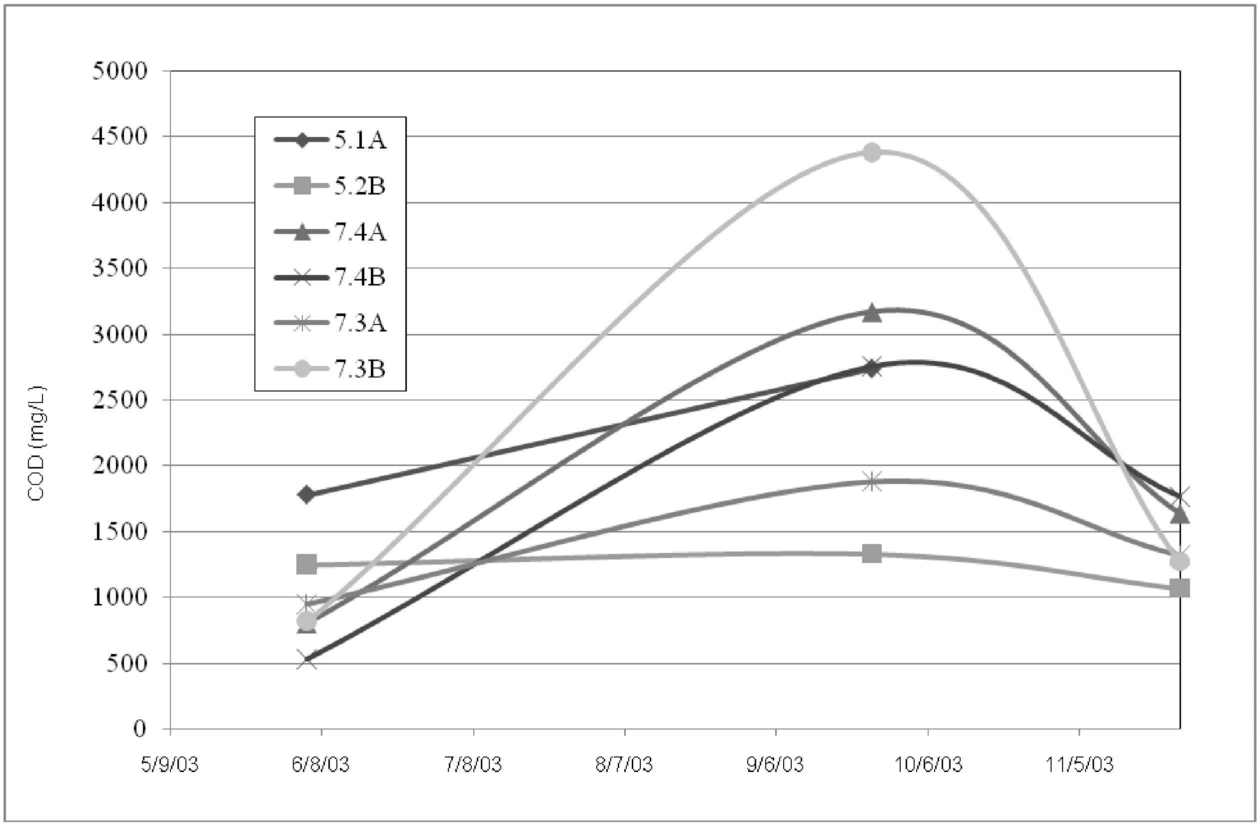

Figure 4.6 – COD vs. Time for Different Leachate Samples

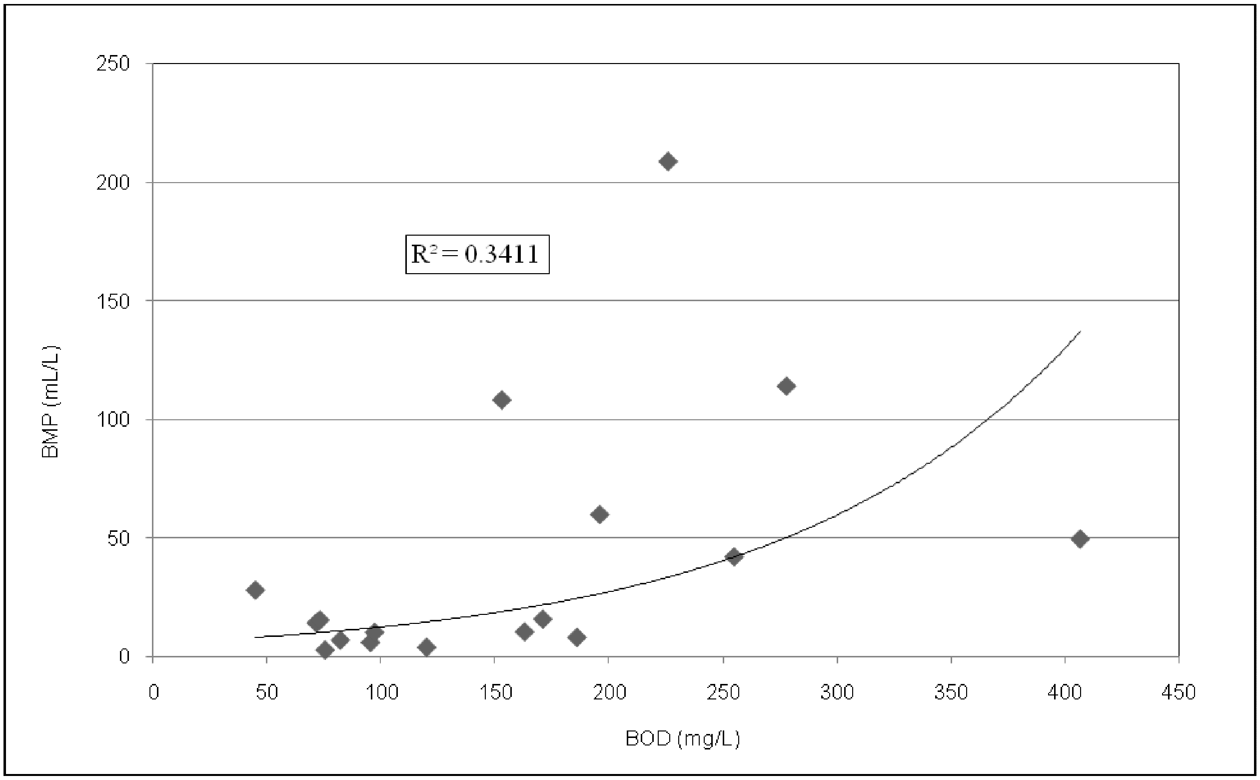

Figure 4.7 – BOD vs. BMP for BMPs Run at 80% Concentration for 15-Day Incubation

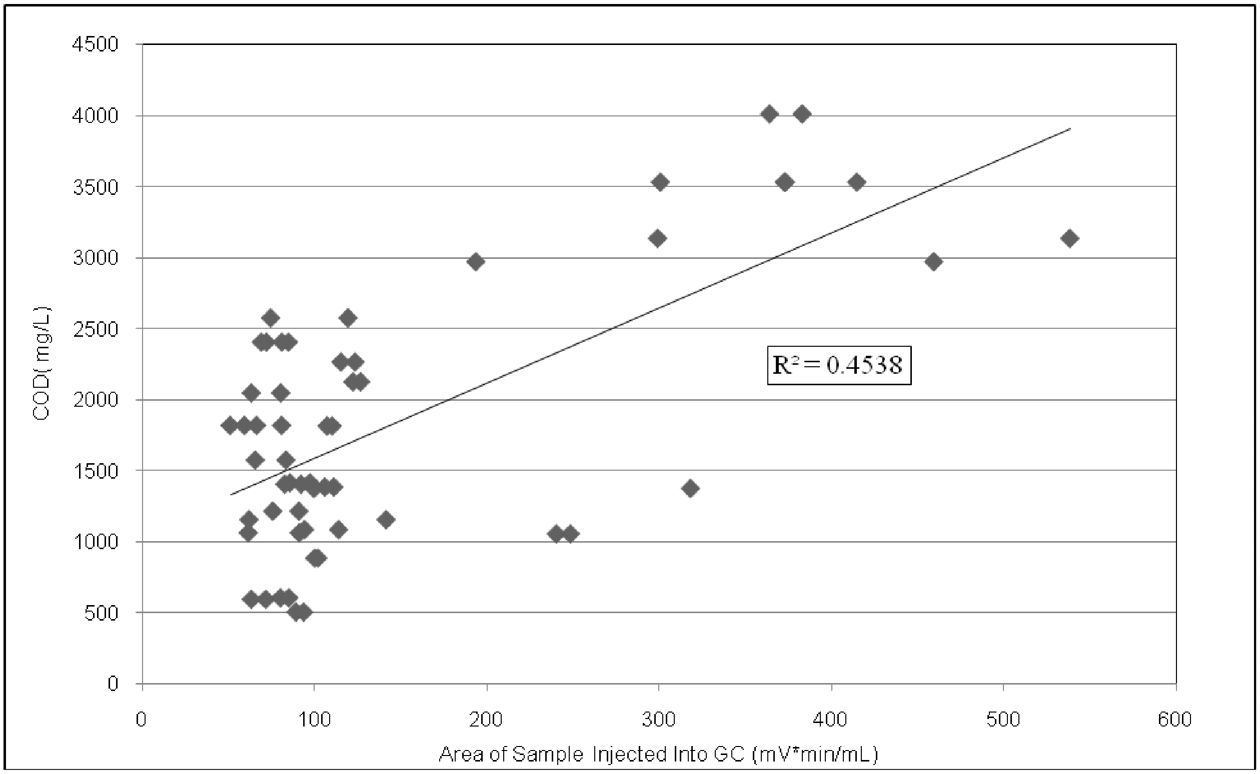

Figure 4.8 – Area of Injection (concentration) of Methane in Incubated Samples vs. COD

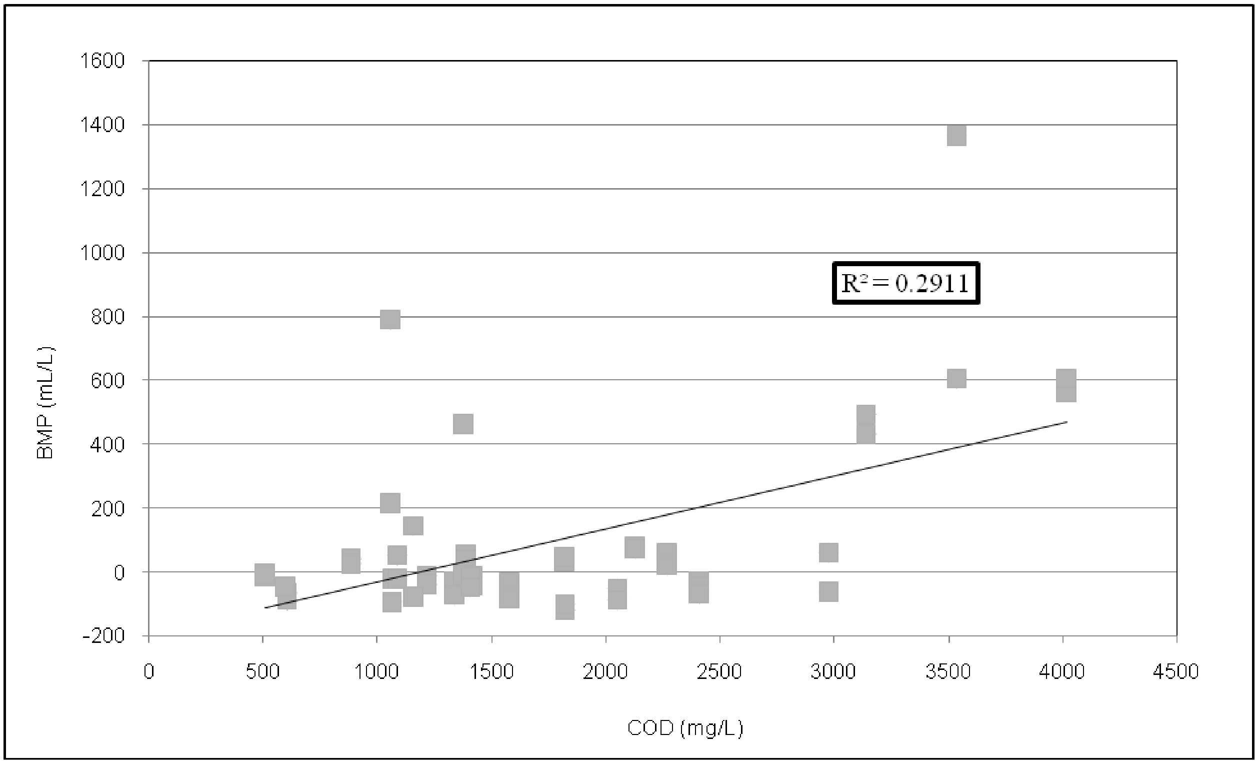

Figure 4.9 – BMP vs. COD for Samples Tested at 50% Concentration for 42 Days (same samples as in figure 4.8)

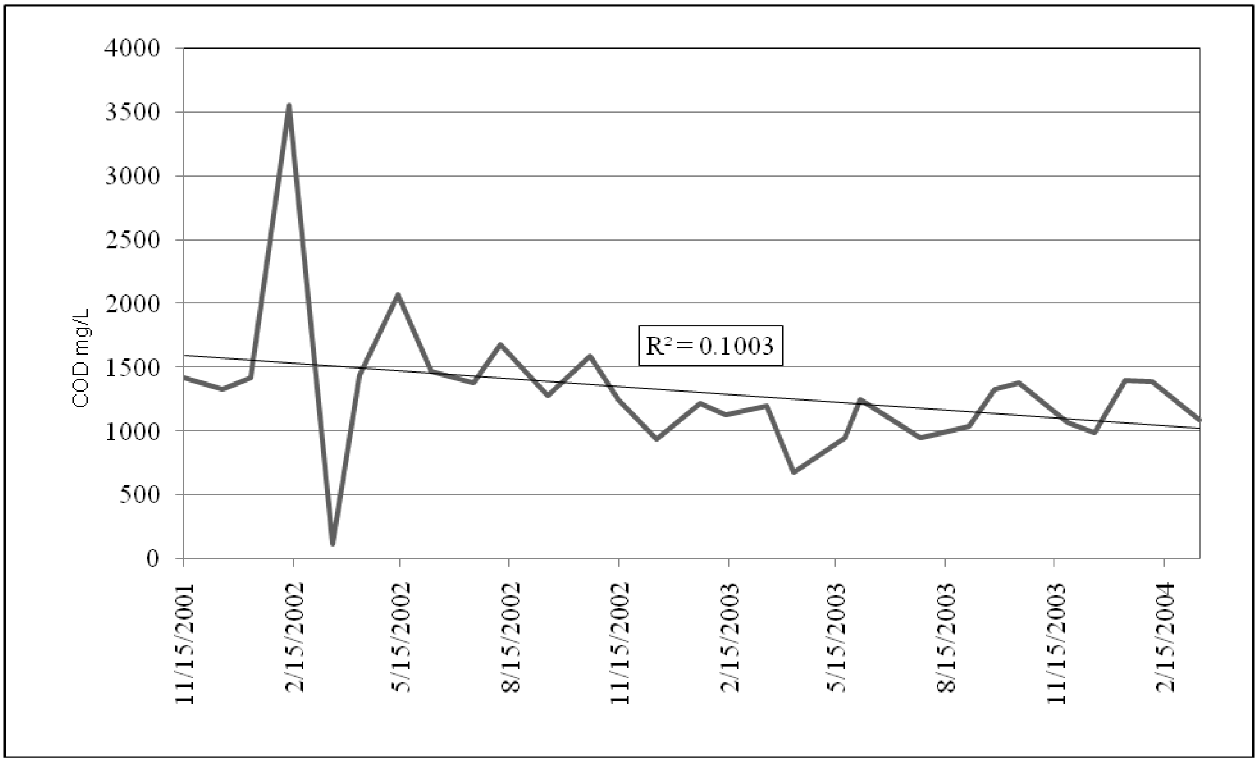

Figure 4.10 – COD of Leachate vs. Time for Cell 5.2B in Outer Loop Landfill, KY

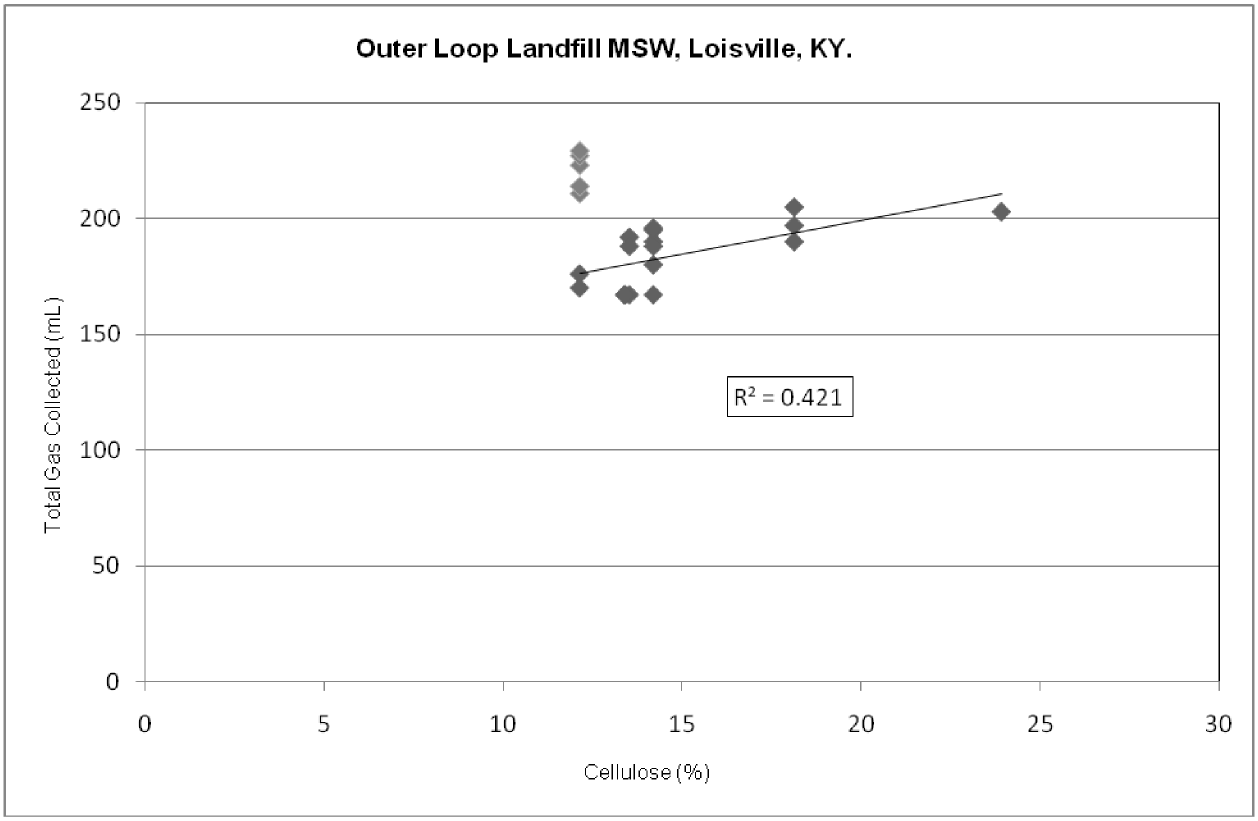

Figure 4.11 – MSW Cellulose vs. Total Leachate Gas Collected for Outer Loop Landfills MSW

CHAPTER 5

Appendix

Table 5.1 – MSW Laboratory Test Results for All Samples Sent to VPI

Landfill	Sample Date	Location	Depth (ft)	Moisture (%)	VS (%)	Cellulose (%)	Lignin (%)	Cell/Lig. Ratio	pH	BMP (mL/g)
Lake Mills	4/22/2002	east gas well 200'MH	5-15	54.5	54.1	26.3	20.6	1.3	6.1	35.97
Lake Mills	4/22/2002	east gas well 200'MH	15-25	31.5	50.1	20.4	20.6	1.0	6.0	36.05
Lake Mills	4/22/2002	east gas well 200'MH	25-35	31.6	49.5	12.9	17.6	0.7	6.4	27.94
Lake Mills	4/22/2002	east gas well 200'MH	35-45	52.2	41.1	16.3	13.8	1.2	6.6	18.74
Lake Mills	4/22/2002	east gas well 200'MH	45-55	52.8	60.3	25.2	21.3	1.2	7.0	58.14
Lake Mills	4/22/2002	east gas well 200'MH	55-65	52.5	35.7	21.2			6.7	82.62
Lake Mills	4/22/2002	east gas well 200'MH	65-75	35.7	28.6	22.3			7.0	104.36
Mohawk Valley	5/22/2002	LFB 6	28-36	26.6	14.2	3.8	9.6	0.4	6.9	
Mohawk Valley	5/22/2002	LFB 6	36-39	26.2	9.6	1.8	7.7	0.2	6.9	
Mohawk Valley	5/22/2002	LFB 6	51-53	24.6	12.4	4.0	10.0	0.4	6.9	
Maplewood	8/12/2002	S1T1	--	35.6	14.6	4.0	7.8	0.5	6.5	0.68
Maplewood	8/12/2002	S1T2	--	33.8	40.7	38.8	26.7	1.5	7.9	59.82
Maplewood	8/12/2002	S1T3	--	42.2	23.5	10.2	9.7	1.1	6.4	9.23
Maplewood	8/13/2002	S2T1	--	20.7	15.9	7.2	10.6	0.7	7.0	3.70
Maplewood	8/13/2002	S2T2	--	45.5	83.1	30.0	23.4	1.3	5.7	93.80
Maplewood	8/13/2002	S2T3	--	33.0	53.9	18.3	16.7	1.1	6.0	76.59
Maplewood	8/14/2002	S3T1	--	33.0	70.4	25.9	29.8	0.9	6.2	38.88
Maplewood	8/14/2002	S3T2	--	43.0	80.6	29.9	19.2	1.6	5.6	301.02
Maplewood	8/14/2002	S3T3	--	59.4	51.0	12.1	28.1	0.4	8.6	3.82
Plantation Oaks	8/22/2002	5-4-1	0-10	32.2	17.5	10.6	9.7	1.1	6.1	3.93
Plantation Oaks	8/22/2002	5-5-1	0-10	28.5	33.4	8.4	8.9	0.9	6.6	1.87
Plantation Oaks	8/22/2002	5-2-1	0-10	23.8	13.1	3.9	5.0	0.8	6.7	0.43
Plantation Oaks	8/22/2002	5-4-2	10-20	29.4	26.7	10.0	7.2	1.4	6.8	5.44
Plantation Oaks	8/22/2002	5-5-2	10-20	15.7	7.5	1.3	3.6	0.4	7.6	1.39
Plantation Oaks	8/22/2002	5-2-2	10-20	25.0	10.6	2.9	4.7	0.6	7.6	1.71
Plantation Oaks	8/22/2002	5-4-3	20-30	30.7	63.9	13.8	30.1	0.5	6.6	78.08
Plantation Oaks	8/22/2002	5-5-3	20-30	19.3	18.8	6.5	6.9	0.9	5.7	3.18
Plantation Oaks	8/22/2002	5-2-3	20-30	40.3	33.5	17.6	12.6	1.4		50.31
Plantation Oaks	8/22/2002	5-4-4	30-40	34.7	80.4	35.6	23.5	1.5	5.8	177.72
Plantation Oaks	8/22/2002	5-5-4	30-40	16.0	17.2	5.5	5.0	1.1	5.7	5.86
Plantation Oaks	8/22/2002	5-2-4	30-40	36.7	70.9	38.8	14.3	2.7	7.0	135.59
Plantation Oaks	8/22/2002	5-4-5	40-50	31.2	80.4	36.6	46.2	0.8	7.0	157.25
Plantation Oaks	8/22/2002	5-5-5	40-50	31.8	53.6	18.6	25.7	0.7	7.0	6.75
Plantation Oaks	8/22/2002	5-2-5	40-50	27.6	75.9	36.1	24.8	1.5	6.0	132.21
Plantation Oaks	8/22/2002	5-4-6	50-60	26.0	4.0	3.7	1.5	2.5	6.3	12.77
Plantation Oaks	8/22/2002	5-2-6	50-60	25.6	14.1	4.0	6.3	0.6	5.9	2.32
King George	11/26/2002	1A	--	17.8	9.8		5.0	0.0	8.1	2.23
King George	11/26/2002	2A	--	48.2	57.8	20.9	41.2	0.5	7.2	24.30
King George	11/26/2002	3A	--	47.1	56.6	24.2	16.8	1.4	7.1	249.19
King George	11/26/2002	4A	--	40.7	67.1	21.6	32.1	0.7	7.1	294.24
King George	11/26/2002	1B	--	39.9	35.0	17.7	17.5	1.0	7.5	93.95
King George	11/26/2002	2B	--	47.5	14.8	26.0	27.5	0.9	7.0	119.47
King George	11/26/2002	3B	--	69.6	16.2	19.9	46.0	0.4	8.6	52.42
King George	11/26/2002	4B	--	31.6	5.5	23.4	19.5	1.2	7.3	15.26

Table 5.1 – MSW Laboratory Test Results for All Samples Sent to VPI (cont.)

Landfill	Sample Date	Location	Depth (ft)	Moisture (%)	VS (%)	Cellulose (%)	Lignin (%)	Cell/Lig Ratio	pH	BMP (mL/g)
King George	11/26/2002	3C	--	47.5	11.4	20.7	14.9	1.4	7.4	136.92
King George	11/26/2002	4C	--	34.1	7.4	11.2	20.9	0.5	8.1	31.09
King George	11/26/2002	1D	--	40.4	14.1	22.9	26.4	0.9	7.2	109.98
King George	11/26/2002	2D	--	51.1	9.7	8.0	17.4	0.5	8.5	47.85
King George	11/26/2002	3D	--	39.5	10.6	10.4	19.3	0.5	7.6	12.38
King George	11/26/2002	4D	--	50.0	15.9	28.7	39.5	0.7	6.2	201.79
Columbia Ridge	3/28/2003	1	0	56.2	81.2	29.2	25.7	1.1	6.8	145.25
Columbia Ridge	3/28/2003	2	0	29.1	82.9	25.8	29.8	0.9	5.0	190.27
Columbia Ridge	3/28/2003	3	0	48.1	67.9	33.2	40.6	0.8	5.2	186.15
Columbia Ridge	3/28/2003	4	0	42.9	67.4	23.3	25.9	0.9	5.5	126.55
Columbia Ridge	3/28/2003	5	0	45.9	85.4	38.9	40.0	1.0	4.9	249.53
Lake Mills	3/27/2003	TLG1	30	33.0	57.0	29.8	16.1	1.9	6.0	160.52
Lake Mills	3/27/2003	TLG1	65	23.3	49.4	25.6	18.1	1.4	5.0	103.04
Lake Mills	3/27/2003	TLG1	90	43.0	73.1	33.2	26.4	1.3	5.8	115.48
Lake Mills	3/27/2003	TLG3	30	37.7	81.1	62.3	19.2	3.2	6.0	54.51
Lake Mills	3/27/2003	TLG3	50	32.5	64.2	38.9	22.1	1.8	6.7	168.73
Lake Mills	3/27/2003	TLG4	40	35.9	65.9	33.6	25.3	1.3	5.8	128.82
Lake Mills	3/27/2003	TLG4	70	60.7	53.8	40.4	16.4	2.5	5.9	149.69
Lake Mills	3/27/2003	TLG4	92	38.0	48.4	27.5	12.1	2.3	6.0	132.74
Lake Mills	3/27/2003	TLG10	27	28.3	54.7	32.4	21.3	1.5	6.1	62.51
Lake Mills	3/27/2003	TLG10	33	55.7	80.7	38.8	36.3	1.1	8.5	212.67
Lake Mills	3/27/2003	TLG10	55	49.7	51.2	14.8	14.8	1.0	6.7	89.61
Lake Mills	3/27/2003	TLG11	30	93.3	55.8	17.1	16.1	1.1	6.9	148.08
Lake Mills	3/27/2003	TLG11	60	32.3	20.4	24.1	14.7	1.6	5.6	106.38
Lake Mills	3/27/2003	TLG11	65	40.0	41.2	14.9	19.4	0.8	8.4	49.65
Lake Mills	3/27/2003	TLG11	78	51.5	64.3	28.0	27.5	1.0	5.5	95.54
Lake Mills	3/27/2003	TLG12	35	42.1	79.0	37.0	29.1	1.3	6.4	125.02
Lake Mills	3/27/2003	TLG12	50	34.4	20.8	9.1	8.6	1.1	6.9	31.03
Lake Mills	3/27/2003	TLG12	71	62.3	52.8	21.1	18.6	1.1	6.2	85.65
Lake Mills	3/27/2003	TLG13	25	29.6	38.8	28.0	27.3	1.0	6.3	95.65
Lake Mills	3/27/2003	TLG13	47	47.7	30.3	10.2	16.1	0.6	7.7	43.01
Lake Mills	3/27/2003	TLG14	18	28.8	64.0	39.5	35.8	1.1	5.1	162.28
Lake Mills	3/27/2003	TLG14	50	57.2	64.4	17.5	13.8	1.3	8.1	41.76
Lake Mills	3/27/2003	TLG15	20	19.0	10.1	5.8	6.6	0.9	6.9	43.38
Lake Mills	3/27/2003	TLG15	35	57.5	78.6	42.4	20.6	2.1	5.8	202.29
Daily Cover	6/5/2003	1	--	54.3	79.5	13.1	35.0	0.4	5.0	115.71
Daily Cover	6/5/2003	1'	--	50.5	84.6	16.6	35.3	0.5	4.9	110.94
Daily Cover	6/5/2003	1"	--	51.7	85.8	17.6	35.6	0.5	5.0	113.19
Daily Cover	6/5/2003	1"'	--	53.4	82.0	17.0	34.0	0.5	4.9	101.04
Paper Samples Sent By Gary Hater of Waste Management										
Cardboard	9/5/2003			7.0	97.0	45.0	45.0	1.0		192.82
Magazine	9/5/2003			6.0	76.5	29.1	24.8	1.2		93.03
Newspaper	9/5/2003			8.0	94.1	29.1	25.8	1.1		88.37
Office Paper	9/5/2003			4.8	87.4	47.1	31.3	1.5		280.60
Phonebook	9/5/2003			7.8	95.3	26.3	38.6	0.7		75.37

Table 5.2 – MSW BMP Pilot Study with Different Strengths and Sample Size

Plantation Oaks, Natchez Mississippi: Sampled 8/22/2002

STANDARDS	
Bottle #	Area
1	3.4631
18	3.327
45	7.2798
55	5.4806
Average	4.887625

Trash strength based on cellulose content	
w=	weak
m=	medium
s=	strong

Response factor - RF = 0.000206644 (100 micro liters * 0.001 micro liters/mL*(1.01 % std CH4/100))/area

Bottle #	Sample Type and Number	Sample Weight (g)	Gas in Bag (mL)	Total Gas (mL)	Dilution Ratio	Methane (mL)	BMP (mL/g)
2	w1	0.5	1.0	166.0	1	-0.36	-0.72
47	w2	0.5	5.5	170.5	1	10.25	20.49
42	w3	0.5	2.5	167.5	1	8.70	17.39
54	w4	1.0	3.0	168.0	1	25.11	25.11
53	w5	1.0	9.0	174.0	1	10.82	10.82
52	w6	1.0	4.0	169.0	1	23.21	23.21
43	w7	1.5	4.5	169.5	1	18.04	12.03
35	w8	1.5	9.5	174.5	1	4.87	3.25
39	w9	1.5	4.0	169.0	1	15.94	10.63
40	w10	2.0	5.5	170.5	1	16.32	8.16
33	w12	2.0	13.5	178.5	1	17.60	8.80
36	w11	2.0	43.5	208.5	1	20.64	10.32
41	m1	0.5	147.0	312.0	1	50.06	100.11
4	m3	0.5	11.0	176.0	1	32.49	64.98
50	m4	1.0	5.5	170.5	1	51.18	51.18
24	m5	1.0	191.0	356.0	1	141.07	141.07
3	m6	1.0	11.5	176.5	1	31.69	31.69
21	m7	1.5	2.5	167.5	1	51.74	34.49
23	m8	1.5	1.5	166.5	1	57.41	38.27
5	m9	1.5	27.5	192.5	1	48.42	32.28
19	m10	2.0	5.0	170.0	1	22.96	11.48
20	m11	2.0	40.0	205.0	1	19.98	9.99
44	m12	2.0	4.5	169.5	1	75.79	37.89
28	s1	0.5	5.0	170.0	0.5	47.67	95.33
29	s2	0.5	186.0	351.0	0.5	99.93	199.85
30	s3	0.5	363.0	528.0	0.5	161.54	323.07
31	s4	1.0	212.0	377.0	0.5	196.04	196.04
51	s5	1.0	57.5	222.5	0.5	131.67	131.67
34	s6	1.0	251.0	416.0	0.5	219.52	219.52
48	s7	1.5	12.5	177.5	0.5	83.90	55.94
49	s8	1.5	433.5	598.5	0.5	266.23	177.49
46	s9	1.5	316.5	481.5	0.5	165.95	110.64
27	s10	2.0	48.0	213.0	0.5	125.91	62.95
22	s11	blank	0.0	165.0	1	1.55	
25	s12	blank	0.0	165.0	1	2.26	

Table 5.3 – MSW BMP pilot study sample data [ref. Graphs 3.1 and 3.2]

Sample	Strength	Weight (g)	BMP (mL/g)	BMP Ave	VS%	Cellulose%	Lignin%
5_4_6	w1	0.5	-0.721908334		4.01	3.65	1.45
5_4_6	w2	0.5	20.49475272		4.01	3.65	1.45
5_4_6	w3	0.5	17.39473811	18.94474541	4.01	3.65	1.45
5_4_6	w4	1.0	25.11012868		4.01	3.65	1.45
5_4_6	w5	1.0	10.82064401		4.01	3.65	1.45
5_4_6	w6	1.0	23.20782725	19.71286665	4.01	3.65	1.45
5_4_6	w7	1.5	12.02811677		4.01	3.65	1.45
5_4_6	w8	1.5	3.248362056		4.01	3.65	1.45
5_4_6	w9	1.5	10.62759856	8.634692462	4.01	3.65	1.45
5_4_6	w10	2.0	8.157549526		4.01	3.65	1.45
5_4_6	w12	2.0	8.799438484		4.01	3.65	1.45
5_4_6	w11	2.0	10.32097308	9.092653698	4.01	3.65	1.45
5_2_3	m1	0.5	100.1122657		33.50	17.60	12.60
5_2_3	m3	0.5	64.98275264	82.54750917	33.50	17.60	12.60
5_2_3	m4	1.0	51.17728721		33.50	17.60	12.60
5_2_3	m5	1.0	141.0689317		33.50	17.60	12.60
5_2_3	m6	1.0	31.685408	74.64387563	33.50	17.60	12.60
5_2_3	m7	1.5	34.49319213		33.50	17.60	12.60
5_2_3	m8	1.5	38.27413156		33.50	17.60	12.60
5_2_3	m9	1.5	32.27783826	35.01505398	33.50	17.60	12.60
5_2_3	m10	2.0	11.47828792		33.50	17.60	12.60
5_2_3	m11	2.0	9.989971706		33.50	17.60	12.60
5_2_3	m12	2.0	37.89311459	19.78712474	33.50	17.60	12.60
5_4_5	s1	0.5	95.33077482		80.35	36.60	46.15
5_4_5	s2	0.5	199.8506926		80.35	36.60	46.15
5_4_5	s3	0.5	323.0730016	206.084823	80.35	36.60	46.15
5_4_5	s4	1.0	196.0393254		80.35	36.60	46.15
5_4_5	s5	1.0	131.6658748		80.35	36.60	46.15
5_4_5	s6	1.0	219.518797	182.4079991	80.35	36.60	46.15
5_4_5	s7	1.5	55.93631695		80.35	36.60	46.15
5_4_5	s8	1.5	177.4872883		80.35	36.60	46.15
5_4_5	s9	1.5	110.6356453	114.6864169	80.35	36.60	46.15
5_4_5	s10	2.0	62.9535782	62.9535782	80.35	36.60	46.15

Table 5.4 – Data Table for Tests on Five Types of Paper

Paper	BMP (mL/g)	%VS	%Moisture	%Cellulose	%Lignin	Cell/Lig
Cardboard	201.1084	96.7611	6.0000	41.2322	17.9680	2.2948
	196.0583	97.4085	7.0000	45.0723	29.0064	1.5539
	181.2878	96.8405	8.0000	48.7236	27.3305	1.7828
Magazine	89.1186	75.9372	6.0000	33.4633	25.4401	1.3154
	101.9730	76.1978	6.0000	28.2523	25.4573	1.1098
	88.0056	76.6515	6.0000	25.5142	26.3896	0.9668
Newspaper	81.9466	93.9043	8.0000	24.5381	35.5706	0.6898
	58.4425	94.4977	8.0000	30.7761	26.4694	1.1627
	109.7201	94.4165	8.0000	32.1334	31.7666	1.0115
Office Paper	324.0799	87.1976	5.0000	44.4947	13.9086	3.1991
	245.4608	88.2232	5.0000	53.8131	13.6466	3.9433
	272.2480	87.2792	5.0000	42.9536	13.9352	3.0824
Phone Book	76.5146	94.9221	8.0000	27.2182	37.2420	0.7308
	86.1948	95.4937	8.0000	31.1473	38.6283	0.8063
	63.3868	94.9749	7.0000	20.5675	39.8089	0.5167

Table 5.5 – Data for all landfills tested in project XL [ref. Graphs 3.11-3.14]

Landfill	Sample Date	Location	Moisture (%)	VS (%)	Cellulose (%)	Lignin (%)	Cell/Lig	pH	BMP (mL/g)
Atlantic	12/07/99	control 3-1	41.0	69.0	36.3	22.5	1.62	6.15	165.65
Atlantic	12/07/99	3-1	39.0	86.0	45.8	27.1	1.69	5.74	173.53
Atlantic	12/07/99	3-1	31.0	50.0	22.7	15.9	1.44	5.71	115.13
Atlantic	12/07/99	3-1	35.0	80.0	37.7	21.0	1.80	6.32	134.46
Atlantic	12/07/99	control 3-2	46.0	82.0	40.1	19.9	2.04	6.30	127.75
Atlantic	12/07/99	3-2	31.0	60.0	13.4	33.3	0.40	6.39	182.30
Atlantic	12/07/99	3-2	64.0	77.0	35.8	31.5	1.14	6.87	119.53
Atlantic	12/07/99	3-2	64.0	72.0	34.8	23.7	1.48	7.11	133.37
Atlantic	12/08/99	2-1	70.0	59.0	33.3	21.6	1.55	7.39	65.18
Atlantic	12/08/99	2-1	70.0	51.0	21.9	27.1	0.81	7.51	60.85
Atlantic	12/08/99	2-2	41.0	53.0	22.9	22.0	1.04	6.58	72.54
Atlantic	12/08/99	2-2	49.0	67.0	24.4	25.6	0.95	6.73	161.09
Atlantic	12/08/99	2-2	60.0	78.0	32.2	23.4	1.38	6.81	137.80
Atlantic	12/08/99	2-2	57.0	77.0	34.6	30.0	1.16	6.94	141.15
Atlantic	12/08/99	2-2	60.0	56.0	25.9	22.3	1.17	7.17	101.23
Atlantic	12/08/99	2-2	65.0	64.0	25.7	26.8	0.97	7.41	115.18
Atlantic	12/08/99	2-2	64.0	66.0	29.4	24.9	1.18	7.56	163.07
Atlantic	12/08/99	2-3	49.0	51.0	36.4	27.3	1.34	7.21	166.21
Atlantic	12/08/99	2-3	47.0	53.0	35.2	23.3	1.52	6.52	196.23
Atlantic	12/08/99	2-3	32.0	67.0	17.7	25.6	0.69	7.31	112.51
Atlantic	12/08/99	2-3	47.0	78.0	25.3	25.1	1.01	11.51	114.68
Atlantic	12/08/99	2-3	54.0	77.0	29.5	23.8	1.24	6.93	104.40
Atlantic	12/08/99	2-3	55.0	65.0	34.1	26.2	1.31	6.28	152.31
Atlantic	12/08/99	2-3	62.0	66.0	31.4	30.3	1.04	6.63	140.50
Atlantic	12/10/99	2-4	41.0	67.0	32.4	25.7	1.27	6.71	131.30
Atlantic	12/10/99	2-4	40.0	77.0	41.5	24.8	1.68	5.54	162.75
Atlantic	12/10/99	2-4	44.0	84.0	41.2	25.3	1.63	5.65	144.09
Atlantic	12/10/99	2-4	38.0	79.0	27.8	26.7	1.04	6.13	118.81
Atlantic	12/10/99	2-4	43.0	68.0	33.9	24.1	1.41	6.81	136.59
Atlantic	12/10/99	2-4	53.0	59.0	24.6	25.9	0.96	7.06	118.20
Central	05/21/00	7	28.0	27.5	11.4	10.5	1.07	8.26	15.79
Central	05/21/00	7	29.6	35.7	12.3	13.1	0.92	8.15	30.80
Central	05/21/00	7	29.5	39.7	11.2	10.6	1.05	7.59	14.58
Central	05/22/00	8	20.7	22.0	5.3	7.0	0.76	8.24	9.24
Central	05/22/00	8	25.3	28.2	7.1	13.1	0.54	8.07	31.28
Central	05/22/00	8	31.9	41.2	17.8	18.9	0.94	7.83	27.11
Central	05/22/00	8	27.9	18.4	7.6	9.3	0.81	8.95	13.57
Central	05/22/00	8	33.0	50.3	13.3	19.4	0.69	7.31	16.82
Central	05/22/00	8	37.0	29.9	7.6	11.8	0.65	7.74	18.54
Central	05/22/00	8	43.0	41.4	18.9	25.1	0.75	7.56	39.48
Central	05/22/00	8	37.0	42.3	14.7	18.0	0.83	6.83	41.33
Central	05/22/00	8	26.0	33.1	15.2	24.7	0.62	7.29	54.22
Central	05/23/00	9	41.4	27.1	8.7	15.1	0.58	8.24	47.88
Central	05/23/00	9	40.5	28.1	10.1	14.7	0.69	7.56	14.51
Central	05/23/00	9	54.4	41.2	5.9	10.8	0.55	7.86	24.07
Central	05/23/00	9	35.8	34.1	7.8	12.7	0.60	7.92	12.00
Central	05/23/00	9	29.3	26.9	8.8	14.1	0.63	7.80	24.39
Central	05/23/00	9	34.2	29.3	7.2	9.3	0.78	7.82	25.74
Central	05/23/00	9	32.5	38.0	12.0	18.2	0.66	7.68	22.29
Central	05/23/00	9	35.7	24.6	4.2	16.3	0.26	7.67	16.56
Central	05/23/00	9	30.8	40.3	11.8	18.3	0.64	7.73	36.27
Columbia Ridge	03/28/03	1	56.2	81.2	29.2	25.7	1.1	6.8	145.25
Columbia Ridge	03/28/03	2	29.1	82.9	25.8	29.8	0.9	5.0	190.27

Table 5.5 – Data for all landfills tested in project XL [ref. Graphs 3.11-3.14] (cont.)

Landfill	Sample Date	Location	Moisture (%)	VS (%)	Cellulose (%)	Lignin (%)	Cell/Lig	pH	BMP (mL/g)
Columbia Ridge	03/28/03	4	42.9	67.4	23.3	25.9	0.9	5.5	126.55
Columbia Ridge	03/28/03	5	45.9	85.4	38.9	40.0	1.0	4.9	249.53
Columbia Ridge	11/21/03	PIT #1	40.31	72.25	24.31	23.41	1.04	7.33	--
Columbia Ridge	11/21/03	PIT #1	31.82	64.30	17.94	22.31	0.80	7.54	--
Columbia Ridge	11/21/03	PIT #2	29.01	65.48	18.95	19.15	0.99	6.46	--
Columbia Ridge	11/21/03	PIT #2	25.12	77.57	40.19	22.86	1.76	6.97	--
Columbia Ridge	11/21/03	PIT #3	16.11	41.08	20.45	23.72	0.86	6.60	--
Columbia Ridge	11/21/03	PIT #3	24.19	81.43	32.47	21.94	1.48	7.06	--
Columbia Ridge	11/21/03	PIT #4	39.37	72.26	15.15	31.85	0.48	5.93	--
Columbia Ridge	11/21/03	PIT #4	36.05	49.03	11.43	23.36	0.49	5.71	--
Columbia Ridge	11/21/03	PIT #5	30.60	59.24	22.26	24.71	0.90	5.94	--
Columbia Ridge	11/21/03	PIT #5	29.66	66.97	26.69	23.05	1.16	5.90	--
Evergreen	07/26/00	LR-1	21.6	40.4	12.5	22.3	0.56	7.51	36.50
Evergreen	07/26/00	LR-1	43.1	30.2	0.7	25.1	0.03	8.04	7.50
Evergreen	07/26/00	LR-1	35.5	44.3	15.4	24.4	0.63	7.21	21.50
Evergreen	07/26/00	LR-1	20.7	34.2	12.5	16.8	0.74	7.18	41.00
Evergreen	07/26/00	LR-1	27.5	22.3	7.3	12.8	0.57	7.53	26.00
Evergreen	07/26/00	LR-2	27.1	24.2	0.9	17.8	0.05	6.96	5.50
Evergreen	07/26/00	LR-2	34.7	57.2	4.7	28.3	0.17	6.88	2.65
Evergreen	07/26/00	LR-2	40.5	30.4	9.2	15.3	0.60	6.69	26.50
Evergreen	07/26/00	LR-2	42.9	26.6	8.9	18.0	0.56	7.26	13.58
Evergreen	07/26/00	LR-3	13.8	26.7	8.4	11.6	0.73	6.83	56.55
Evergreen	07/26/00	LR-3	22.5	33.1	9.6	19.5	0.50	7.38	26.35
Evergreen	07/26/00	LR-3	37.5	28.3	9.6	13.8	0.70	7.43	43.15
Evergreen	07/26/00	LR-3	48.5	30.0	9.5	10.1	0.93	7.43	49.16
Evergreen	07/27/00	Cntrl-4	28.4	63.7	24.9	23.6	1.05	6.00	94.66
Evergreen	07/27/00	Cntrl-4	19.8	28.8	14.6	15.8	0.93	6.73	49.21
Evergreen	07/27/00	Cntrl-4	32.9	41.8	12.8	16.4	0.78	6.82	52.84
Evergreen	07/27/00	Cntrl-4	25.0	41.0	16.7	23.1	0.72	7.05	55.32
Evergreen	07/27/00	Cntrl-4	29.6	39.1	14.3	17.1	0.85	7.14	59.71
Evergreen	07/27/00	Cntrl-4	33.0	50.6	18.6	22.6	0.83	6.79	96.27
Evergreen	07/27/00	Cntrl-4	31.9	23.6	4.4	7.9	0.76	7.82	18.98
Evergreen	07/27/00	Cntrl-4	42.5	38.0	8.0	23.8	0.34	7.81	22.55
Evergreen	07/27/00	Cntrl-5	24.8	32.0	17.3	15.7	1.11	6.57	73.87
Evergreen	07/27/00	Cntrl-5	27.9	32.4	10.2	15.4	0.65	7.03	75.41
Evergreen	07/27/00	Cntrl-5	18.1	29.8	4.7	8.4	0.55	8.29	31.02
Evergreen	07/27/00	Cntrl-5	22.4	36.9	8.7	18.2	0.49	8.05	56.14
Evergreen	07/27/00	Cntrl-5	23.1	29.4	6.0	12.5	0.48	7.69	29.93
Evergreen	07/27/00	Cntrl-5	17.7	8.9	7.3	6.5	1.13	7.55	70.86
Evergreen	07/27/00	Cntrl-5	30.7	44.5	15.7	7.2	2.21	6.56	106.09
Evergreen	07/27/00	Cntrl-5	33.8	48.3	17.5	20.5	0.86	7.17	62.82
Green Valley	08/02/01	TB 1	33.0	74.7	47.8	29.5	1.64	6.28	--
Green Valley	08/02/01	TB 1	37.4	38.8	24.4	19.5	1.26	--	--
Green Valley	08/02/01	TB 1	31.1	39.0	23.0	16.4	1.40	--	--
Green Valley	08/02/01	TB 1	23.1	58.6	36.1	17.1	2.11	6.09	--
Green Valley	08/02/01	TB 2	46.3	60.5	37.0	17.3	2.10	--	--
Green Valley	08/02/01	TB 2	33.9	63.0	37.9	22.1	1.71	6.45	--
Green Valley	08/02/01	TB 2	32.5	53.7	27.7	22.5	1.23	--	--
Kettleman City, CA	11/02/03	#1	27.12	12.81	12.81	33.16	0.39	5.26	--
Kettleman City, CA	11/02/03	#1	31.93	40.44	22.39	17.78	1.26	6.02	--
Kettleman City, CA	11/02/03	#2	29.98	72.69	28.04	30.67	0.91	5.24	--
Kettleman City, CA	11/02/03	#2	37.19	56.28	8.68	26.29	0.33	6.29	--

Table 5.5 – Data for all landfills tested in project XL [ref. Graphs 3.11-3.14] (cont.)

Landfill	Sample Date	Location	Moisture (%)	VS (%)	Cellulose (%)	Lignin (%)	Cell/Lig	pH	BMP (mL/g)
Kettleman City, CA	11/02/03	#3	16.51	41.22	6.77	13.09	0.52	5.70	--
Kettleman City, CA	11/02/03	#3	16.91	37.45	10.83	6.21	1.74	6.77	--
Kettleman City, CA	11/02/03	#4	23.84	45.19	11.71	13.39	0.87	5.36	--
Kettleman City, CA	11/02/03	#4	17.49	60.66	35.83	14.73	2.43	6.58	--
Kettleman City, CA	11/02/03	#5	54.84	82.23	35.66	20.49	1.74	5.74	--
Kettleman City, CA	11/02/03	#5	19.32	49.51	11.86	27.82	0.43	5.56	--
Kettleman Hills	07/07/01	3279371715	--	56.0	26.8	23.2	1.16	6.26	53.14
Kettleman Hills	07/07/01	3248921347	--	48.3	25.5	20.4	1.25	6.55	34.65
Kettleman Hills	07/07/01	3279372171	--	43.6	27.7	25.1	1.11	7.20	35.43
King George	07/31/01	Bio 2	47.5	67.4	37.1	23.0	1.61	6.3	59.18
King George	07/31/01	Bio 2	46.3	64.9	32.8	22.2	1.49	5.8	54.98
King George	07/31/01	Bio 2	40.0	54.8	35.5	21.4	1.65	6.6	51.47
King George	07/31/01	Bio 2	45.4	71.5	35.0	23.5	1.54	5.6	67.17
King George	07/31/01	Bio 2	40.2	70.8	39.5	25.7	1.54	5.4	60.72
King George	07/31/01	Bio 3	30.7	72.0	48.2	15.3	3.17	5.4	61.84
King George	07/31/01	Bio 3	35.7	59.1	35.2	14.4	2.44	5.8	53.76
King George	08/01/01	Bio 1	43.2	40.4	35.6	15.0	2.38	6.2	54.07
King George	08/01/01	Bio 1	33.2	56.9	30.8	17.8	1.76	6.3	59.40
King George	08/01/01	Bio 1	30.0	85.4	45.2	22.2	2.04	6.7	60.06
King George	08/01/01	Bio 1	29.6	70.8	42.2	19.9	2.12	6.7	68.69
King George	08/01/01	Bio 1	28.4	75.2	45.4	16.3	2.80	6.5	65.32
King George	08/01/01	Bio 3	39.9	53.1	26.3	26.5	1.00	8.3	53.95
King George	08/01/01	Bio 3	43.9	69.2	35.5	20.4	1.74	7.6	62.57
King George	08/01/01	Bio 3	35.2	45.5	18.9	20.5	0.92	5.8	56.48
King George	08/02/01	Control 1	46.8	55.2	34.3	16.2	2.12	6.5	61.04
King George	08/02/01	Control 1	38.8	44.9	37.5	15.9	2.40	7.1	61.20
King George	08/02/01	Control 1	24.0	44.8	31.5	15.4	2.05	6.5	51.00
King George	08/02/01	Control 1	31.6	43.0	31.3	20.4	1.54	5.9	53.39
King George	08/02/01	Control 1	26.2	52.2	35.8	15.9	2.25	5.4	57.58
King George	08/02/01	Control 2	26.9	53.6	29.2	17.5	1.67	6.8	66.98
King George	08/02/01	Control 2	37.9	71.7	35.5	29.5	2.41	6.8	58.09
King George	08/03/01	Control 2	34.1	66.7	40.8	17.7	2.30	5.6	50.50
King George	08/03/01	Control 2	25.7	40.8	30.8	15.2	2.04	5.7	47.35
King George	08/03/01	Control 2	31.0	65.3	38.6	19.7	1.96	5.8	60.53
King George	11/26/02	1A	17.8	9.8		5.0	0.0	8.1	2.23
King George	11/26/02	2A	48.2	57.8	20.9	41.2	0.5	7.2	24.30
King George	11/26/02	3A	47.1	56.6	24.2	16.8	1.4	7.1	249.19
King George	11/26/02	4A	40.7	67.1	21.6	32.1	0.7	7.1	294.24
King George	11/26/02	1B	39.9	35.0	17.7	17.5	1.0	7.5	93.95
King George	11/26/02	2B	47.5	14.8	26.0	27.5	0.9	7.0	119.47
King George	11/26/02	3B	69.6	16.2	19.9	46.0	0.4	8.6	52.42
King George	11/26/02	4B	31.6	5.5	23.4	19.5	1.2	7.3	15.26
King George	11/26/02	1C	36.2	11.0	18.6	18.9	1.0	7.5	87.96
King George	11/26/02	2C	47.4	11.4	38.1	28.0	1.4	6.7	229.36
King George	11/26/02	3C	47.5	11.4	20.7	14.9	1.4	7.4	136.92
King George	11/26/02	4C	34.1	7.4	11.2	20.9	0.5	8.1	31.09
King George	11/26/02	1D	40.4	14.1	22.9	26.4	0.9	7.2	109.98
King George	11/26/02	2D	51.1	9.7	8.0	17.4	0.5	8.5	47.85
King George	11/26/02	3D	39.5	10.6	10.4	19.3	0.5	7.6	12.38
King George	11/26/02	4D	50.0	15.9	28.7	39.5	0.7	6.2	201.79
King George	11/12/03	C1	40.99	52.78	27.71	22.61	1.23	6.68	--
King George	11/12/03	C1	36.89	52.87	25.96	24.70	1.05	8.74	--
King George	11/12/03	C1	42.75	65.63	23.04	22.28	1.03	8.46	--

Table 5.5 – Data for all landfills tested in project XL [ref. Graphs 3.11-3.14] (cont.)

Landfill	Sample Date	Location	Moisture (%)	VS (%)	Cellulose (%)	Lignin (%)	Cell/Lig	pH	BMP (mL/g)
King George	11/12/03	C1	33.14	70.47	32.69	21.95	1.49	7.38	--
King George	11/12/03	C2	32.36	51.09	20.34	14.04	1.45	6.74	--
King George	11/12/03	C2	41.05	73.80	37.52	23.52	1.60	7.17	--
King George	11/12/03	C2	32.97	49.18	17.62	17.38	1.01	8.18	--
King George	11/12/03	C2	30.57	47.97	17.35	18.54	0.94	7.77	--
King George	11/12/03	T1	36.27	56.87	23.80	23.02	1.03	7.52	--
King George	11/12/03	T1	41.76	71.58	41.90	23.01	1.82	7.14	--
King George	11/17/03	T1	35.23	51.80	25.57	17.06	1.50	7.35	--
King George	11/17/03	T1	54.09	53.75	21.30	21.21	1.00	7.33	--
King George	11/17/03	T2	36.47	45.54	21.26	20.51	1.04	7.41	--
King George	11/17/03	T2	40.69	63.73	36.49	22.15	1.65	7.44	--
King George	11/17/03	T2	51.23	31.20	20.62	16.02	1.29	7.59	--
King George	11/17/03	T2	32.50	15.05	12.49	8.25	1.51	7.86	--
King George	11/17/03	T3	39.82	55.80	28.93	22.61	1.28	7.25	--
King George	11/17/03	T3	42.07	57.12	25.04	20.86	1.20	6.68	--
King George	11/17/03	T3	41.55	51.01	21.52	16.79	1.28	6.91	--
Lake Mills	04/22/02	east gas well 200'MH	54.5	54.1	26.3	20.6	1.3	6.1	35.97
Lake Mills	04/22/02	east gas well 200'MH	31.5	50.1	20.4	20.6	1.0	6.0	36.05
Lake Mills	04/22/02	east gas well 200'MH	31.6	49.5	12.9	17.6	0.7	6.4	27.94
Lake Mills	04/22/02	east gas well 200'MH	52.2	41.1	16.3	13.8	1.2	6.6	18.74
Lake Mills	04/22/02	east gas well 200'MH	52.8	60.3	25.2	21.3	1.2	7.0	58.14
Lake Mills	04/22/02	east gas well 200'MH	52.5	35.7	21.2	--	--	6.7	82.62
Lake Mills	04/22/02	east gas well 200'MH	35.7	28.6	22.3	--	--	7.0	104.36
Lake Mills	03/27/03	TLG1	33.0	57.0	29.8	16.1	1.9	6.0	160.52
Lake Mills	03/27/03	TLG1	23.3	49.4	25.6	18.1	1.4	5.0	103.04
Lake Mills	03/27/03	TLG1	43.0	73.1	33.2	26.4	1.3	5.8	115.48
Lake Mills	03/27/03	TLG3	37.7	81.1	62.3	19.2	3.2	6.0	54.51
Lake Mills	03/27/03	TLG3	32.5	64.2	38.9	22.1	1.8	6.7	168.73
Lake Mills	03/27/03	TLG4	35.9	65.9	33.6	25.3	1.3	5.8	128.82
Lake Mills	03/27/03	TLG4	60.7	53.8	40.4	16.4	2.5	5.9	149.69
Lake Mills	03/27/03	TLG4	38.0	48.4	27.5	12.1	2.3	6.0	132.74
Lake Mills	03/27/03	TLG10	28.3	54.7	32.4	21.3	1.5	6.1	62.51
Lake Mills	03/27/03	TLG10	55.7	80.7	38.8	36.3	1.1	8.5	212.67
Lake Mills	03/27/03	TLG10	49.7	51.2	14.8	14.8	1.0	6.7	89.61
Lake Mills	03/27/03	TLG11	93.3	55.8	17.1	16.1	1.1	6.9	148.08
Lake Mills	03/27/03	TLG11	32.3	20.4	24.1	14.7	1.6	5.6	106.38
Lake Mills	03/27/03	TLG11	40.0	41.2	14.9	19.4	0.8	8.4	49.65
Lake Mills	03/27/03	TLG11	51.5	64.3	28.0	27.5	1.0	5.5	95.54
Lake Mills	03/27/03	TLG12	42.1	79.0	37.0	29.1	1.3	6.4	125.02
Lake Mills	03/27/03	TLG12	34.4	20.8	9.1	8.6	1.1	6.9	31.03
Lake Mills	03/27/03	TLG12	62.3	52.8	21.1	18.6	1.1	6.2	85.65
Lake Mills	03/27/03	TLG13	29.6	38.8	28.0	27.3	1.0	6.3	95.65
Lake Mills	03/27/03	TLG13	47.7	30.3	10.2	16.1	0.6	7.7	43.01
Lake Mills	03/27/03	TLG14	28.8	64.0	39.5	35.8	1.1	5.1	162.28
Lake Mills	03/27/03	TLG14	57.2	64.4	17.5	13.8	1.3	8.1	41.76
Lake Mills	03/27/03	TLG15	19.0	10.1	5.8	6.6	0.9	6.9	43.38
Lake Mills	03/27/03	TLG15	57.5	78.6	42.4	20.6	2.1	5.8	202.29
Maplewood	05/10/01	Bio 2	28.8	77.8	34.7	24.2	1.44	5.8	106.98
Maplewood	05/10/01	Bio 2	51.2	63.9	22.9	22.3	1.02	8.4	131.41
Maplewood	05/10/01	Bio 2	40.6	68.9	26.7	23.5	1.14	8.2	71.69
Maplewood	05/10/01	Bio 2	27.8	69.8	31.6	24.0	1.32	7.5	37.74
Maplewood	05/10/01	Bio 3	39.9	79.2	34.5	26.4	1.31	5.3	25.40
Maplewood	05/10/01	Bio 3	38.6	62.0	36.9	16.9	2.19	8.5	89.76

Table 5.5 – Data for all landfills tested in project XL [ref. Graphs 3.11-3.14] (cont.)

Landfill	Sample Date	Location	Moisture (%)	VS (%)	Cellulose (%)	Lignin (%)	Cell/Lig	pH	BMP (mL/g)
Maplewood	05/10/01	Bio 3	38.5	80.1	39.7	24.2	1.64	5.5	79.24
Maplewood	05/10/01	Bio 3	32.8	74.7	40.4	18.6	2.18	6.2	134.67
Maplewood	05/11/01	Bio 1	42.6	75.9	29.5	30.2	1.03	5.7	125.56
Maplewood	05/11/01	Bio 1	39.8	61.8	23.8	19.4	1.22	7.7	80.49
Maplewood	05/11/01	Bio 1	33.6	51.0	21.0	20.4	2.06	5.3	113.07
Maplewood	05/11/01	Bio 1	37.2	73.0	29.5	28.0	1.05	5.6	104.50
Maplewood	08/07/01	Control-1	31.6	46.9	27.4	22.2	1.23	5.5	71.63
Maplewood	08/07/01	Control-1	40.7	55.3	29.1	21.4	1.37	5.5	73.89
Maplewood	08/07/01	Control-1	33.2	51.1	35.0	15.3	2.30	5.8	81.48
Maplewood	08/07/01	Control-1	38.5	57.5	30.4	27.0	1.14	7.8	81.02
Maplewood	08/07/01	Control-2	41.8	48.3	30.5	18.7	1.63	6.7	77.83
Maplewood	08/07/01	Control-2	52.7	74.6	36.1	25.3	1.44	8.2	101.80
Maplewood	08/12/02	S1T1	35.6	14.6	4.0	7.8	0.5	6.5	0.68
Maplewood	08/12/02	S1T2	33.8	40.7	38.8	26.7	1.5	7.9	59.82
Maplewood	08/12/02	S1T3	42.2	23.5	10.2	9.7	1.1	6.4	9.23
Maplewood	08/13/02	S2T1	20.7	15.9	7.2	10.6	0.7	7.0	3.70
Maplewood	08/13/02	S2T2	45.5	83.1	30.0	23.4	1.3	5.7	93.80
Maplewood	08/13/02	S2T3	33.0	53.9	18.3	16.7	1.1	6.0	76.59
Maplewood	08/14/02	S3T1	33.0	70.4	25.9	29.8	0.9	6.2	38.88
Maplewood	08/14/02	S3T2	43.0	80.6	29.9	19.2	1.6	5.6	301.02
Maplewood	08/14/02	S3T3	59.4	51.0	12.1	28.1	0.4	8.6	3.82
Maplewood	01/11/04	C1	36.86	67.58	34.97	22.23	1.57	6.23	--
Maplewood	01/11/04	C1	34.33	74.11	30.06	27.13	1.11	6.21	--
Maplewood	01/11/04	C1	43.85	19.27	1.48	9.12	0.16	8.12	--
Maplewood	01/11/04	C1	42.70	36.17	7.05	15.26	0.46	7.30	--
Maplewood	01/11/04	C2	52.55	51.08	22.36	28.11	0.80	6.62	--
Maplewood	01/11/04	C2	27.54	19.97	6.36	7.13	0.89	6.42	--
Maplewood	01/11/04	C2	36.41	76.61	30.18	30.00	1.01	6.11	--
Maplewood	01/11/04	C2	39.83	47.11	17.78	14.86	1.20	6.40	--
Maplewood	01/11/04	T1	50.72	50.88	26.88	17.71	1.52	7.11	--
Maplewood	01/11/04	T1	30.55	66.56	23.01	26.29	0.88	6.07	--
Maplewood	01/11/04	T1	44.93	62.26	19.68	28.83	0.68	8.95	--
Maplewood	01/11/04	T1	33.85	63.46	26.93	22.18	1.21	5.80	--
Maplewood	01/11/04	T2	47.61	38.91	18.40	15.86	1.16	7.00	--
Maplewood	01/11/04	T2	57.16	58.28	12.28	31.54	0.39	8.77	--
Maplewood	01/11/04	T2	36.74	85.83	34.39	24.85	1.38	6.44	--
Maplewood	01/11/04	T2	37.19	69.65	18.17	29.76	0.61	5.82	--
Maplewood	01/11/04	T3	39.79	49.09	15.69	24.00	0.65	7.92	--
Maplewood	01/11/04	T3	50.12	35.34	7.63	21.10	0.36	8.58	--
Maplewood	01/11/04	T3	44.68	58.38	20.76	20.43	1.02	6.37	--
Maplewood	01/11/04	T3	26.24	22.70	0.94	9.13	0.10	8.20	--
Metro	11/17/99	B	24.5	71.3	24.0	25.9	0.95	6.95	123.33
Metro	11/17/99	C	25.6	67.1	25.4	28.5	0.93	7.12	125.34
Metro	11/17/99	D	20.8	74.0	23.9	20.4	1.18	7.07	131.33
Metro	12/03/99	B	23.0	33.0	12.8	11.6	1.19	6.51	95.70
Metro	12/03/99	C	26.8	40.3	11.7	20.8	0.55	7.01	122.10
Metro	12/03/99	D	34.5	50.7	15.2	24.6	0.63	7.15	144.17
Metro	01/19/00	B	26.4	64.7	26.9	17.9	1.73	6.52	131.88
Metro	01/19/00	C	30.5	60.6	31.2	21.3	1.46	6.32	126.88
Metro	01/19/00	D	31.6	59.2	34.8	19.0	1.91	6.15	121.04
Metro	01/19/00	B	31.2	66.4	29.9	20.4	1.50	6.16	132.60
Metro	01/19/00	C	33.0	61.1	24.6	21.1	1.15	5.89	135.53
Metro	01/19/00	D	39.2	58.1	25.1	20.9	1.20	6.80	118.44
Metro	02/16/00	A-B	32.9	59.3	30.4	24.5	1.25	7.05	129.40

Table 5.5 – Data for all landfills tested in project XL [ref. Graphs 3.11-3.14] (cont.)

Landfill	Sample Date	Location	Moisture (%)	VS (%)	Cellulose (%)	Lignin (%)	Cell/Lig	pH	BMP (mL/g)
Metro	02/16/00	A-B	38.0	78.9	32.6	30.0	1.09	5.78	127.63
Metro	02/16/00	C-D	25.7	70.3	30.6	30.3	1.02	6.21	152.30
Metro	02/16/00	C-D	27.6	50.6	16.8	32.1	0.54	6.65	91.38
Metro	02/16/00	C-D	24.2	33.8	16.3	23.4	0.69	6.71	89.35
Metro	02/16/00	C-D	35.4	71.1	31.5	28.7	1.11	6.41	102.14
Metro	02/16/00	A-B	31.8	70.9	36.0	20.7	1.75	6.14	57.21
Metro	02/16/00	A-B	36.5	57.0	21.7	18.5	1.17	6.81	111.02
Metro	02/16/00	A-B	31.4	64.1	30.4	22.3	1.37	6.72	81.71
Metro	02/16/00	A-B	33.1	66.9	29.8	29.3	1.02	6.29	103.99
Metro	02/16/00	B-C	40.6	69.7	36.6	23.1	1.59	6.20	73.17
Metro	02/16/00	B-C	40.3	80.6	41.1	25.3	1.62	6.46	74.15
Metro	02/16/00	B-C	28.2	70.8	26.6	27.9	0.94	6.21	137.39
Metro	02/16/00	B-C	28.3	67.8	35.0	15.4	2.28	6.23	139.94
Metro	02/16/00	C-D	42.5	76.5	37.8	18.8	2.03	5.95	139.67
Metro	02/16/00	C-D	42.3	72.5	30.8	25.5	1.21	5.01	175.39
Metro	02/16/00	C-D	40.9	75.1	31.7	20.3	1.58	6.48	173.54
Metro	02/16/00	C-D	34.2	68.1	30.5	22.1	1.39	6.49	128.27
Metro	06/14/00	C-D	35.1	51.7	20.2	7.1	0.35	6.10	75.81
Metro	06/14/00	C-D	36.0	43.9	20.9	15.7	0.75	5.97	76.94
Metro	06/14/00	C-D	29.5	43.5	13.0	9.7	0.75	6.09	67.91
Metro	06/14/00	C-D	59.3	61.0	15.8	13.9	0.89	6.16	122.02
Metro	06/14/00	B-C	22.5	27.7	8.9	7.1	0.82	6.41	34.52
Metro	06/14/00	B-C	30.8	31.6	13.8	11.7	0.85	5.94	77.05
Metro	06/14/00	B-C	33.4	42.0	18.2	15.0	0.83	6.10	61.12
Metro	06/14/00	B-C	28.9	33.6	20.0	11.8	0.60	6.55	75.73
Metro	06/14/00	B-C	25.3	22.4	9.9	8.7	0.89	6.47	102.50
Metro	06/14/00	B-C	27.3	37.6	12.6	9.0	0.72	5.75	89.78
Metro	06/14/00	B-C	31.8	41.8	18.7	15.7	0.84	6.00	100.24
Metro	06/14/00	B-C	31.9	46.1	25.9	15.6	0.63	5.49	91.87
Metro	06/14/00	C-D	32.5	63.5	26.2	22.5	0.86	5.07	136.92
Metro	06/14/00	C-D	22.6	36.5	21.0	14.3	0.68	6.02	71.48
Metro	06/14/00	C-D	26.5	52.8	17.0	27.2	1.60	6.01	90.75
Metro	06/14/00	C-D	24.3	48.8	19.9	15.8	0.80	5.92	114.75
Metro	10/16/00	A-B	23.5	25.3	8.7	9.0	0.96	6.90	35.97
Metro	10/16/00	A-B	35.9	42.2	14.5	19.0	0.77	6.83	69.44
Metro	10/16/00	A-B	31.8	50.0	20.5	22.5	0.91	7.32	54.76
Metro	10/16/00	C-D	36.6	36.4	14.4	25.9	0.58	8.04	56.54
Metro	10/16/00	C-D	26.3	50.3	16.3	21.6	0.75	7.11	68.50
Metro	10/16/00	C-D	35.5	56.9	26.7	26.8	1.00	7.12	108.98
Metro	10/16/00	A-B	31.0	52.1	25.9	21.0	1.25	6.62	109.02
Metro	10/16/00	A-B	32.3	60.4	27.7	19.5	1.41	6.64	125.87
Metro	10/16/00	A-B	27.5	55.7	23.4	30.5	0.77	6.73	97.30
Metro	10/16/00	C-D	23.8	50.9	22.3	18.9	1.19	6.39	92.25
Metro	10/16/00	C-D	22.6	39.2	21.0	17.8	1.19	6.53	102.19
Metro	10/16/00	C-D	23.0	60.9	19.3	31.4	0.62	6.86	117.64
Metro	12/28/00	3E	28.1	55.4	29.1	14.2	2.05	6.45	91.00
Metro	12/28/00	4B	41.2	65.9	30.6	19.5	1.58	6.29	127.67
Metro	12/28/00	4C	30.0	53.2	25.2	19.4	1.30	6.31	192.33
Metro	12/28/00	4D	26.8	48.7	23.2	16.3	1.43	6.83	143.33
Metro	12/28/00	4E	31.1	60.7	29.7	24.4	1.22	6.30	72.00
Metro	12/28/00	4B	36.6	47.4	16.7	21.4	0.79	6.89	172.00
Metro	12/28/00	4E	36.8	69.6	28.5	17.9	1.59	5.80	125.33
Metro	12/28/00	5B	29.5	38.4	15.6	15.5	1.02	6.53	131.00
Metro	12/28/00	5C	38.2	67.2	20.6	16.7	1.23	5.96	114.00
Metro	12/28/00	5D	20.2	34.6	19.5	12.8	1.53	6.85	148.67
Metro	12/28/00	5E	31.3	57.0	33.7	13.8	2.45	6.19	75.33

Table 5.5 – Data for all landfills tested in project XL [ref. Graphs 3.11-3.14] (cont.)

Landfill	Sample Date	Location	Moisture (%)	VS (%)	Cellulose (%)	Lignin (%)	Cell/Lig	pH	BMP (mL/g)
Metro	12/28/00	5E	26.3	48.7	38.7	17.2	2.26	6.70	114.67
Middle Peninsula	12/13/99	LR 1	36.0	41.2	28.4	14.2	2.01	6.34	115.62
Middle Peninsula	12/13/99	LR 1	40.0	72.8	35.4	24.7	1.43	6.75	137.85
Middle Peninsula	12/13/99	LR 1	38.0	74.6	40.8	18.8	2.17	6.86	142.99
Middle Peninsula	12/13/99	LR 1	44.0	80.6	45.4	24.7	1.84	7.40	125.79
Middle Peninsula	12/13/99	LR 1	37.0	61.5	31.3	17.8	1.82	6.69	129.53
Middle Peninsula	12/13/99	LR 1	38.0	60.8	33.9	20.7	1.63	6.58	115.78
Middle Peninsula	12/15/99	GW-5	40.0	85.5	47.6	22.2	2.14	6.32	135.77
Middle Peninsula	12/15/99	GW-6	29.0	84.2	53.7	15.0	3.63	6.41	140.93
Middle Peninsula	02/22/01	A	34.1	64.6	36.3	20.6	1.77	5.08	--
Middle Peninsula	02/22/01	A	30.8	45.7	29.2	15.3	1.92	5.28	--
Middle Peninsula	02/22/01	B	31.2	42.1	17.1	12.4	1.38	5.15	--
Middle Peninsula	02/22/01	B	39.6	63.9	36.6	18.1	2.02	5.15	--
Middle Peninsula	02/22/01	C	38.5	61.4	28.8	20.0	1.44	4.71	--
Middle Peninsula	02/22/01	C	40.4	73.1	30.8	25.8	1.20	5.09	--
Middle Peninsula	02/22/01	D	32.2	56.9	35.8	15.8	2.27	5.42	--
Middle Peninsula	02/22/01	D	28.2	58.1	34.2	18.6	2.22	5.50	--
Middle Peninsula	02/22/01	E	34.2	64.9	23.8	17.9	2.00	5.69	--
Middle Peninsula	02/22/01	E	30.1	71.7	35.7	19.9	1.80	5.10	--
Middle Peninsula	12/15/99	LR 2	38.0	71.6	34.8	28.2	1.23	5.84	145.20
Middle Peninsula	12/15/99	LR 2	38.0	73.4	38.8	19.9	1.95	6.62	153.04
Middle Peninsula	12/15/99	LR 2	30.0	54.5	29.8	18.3	1.63	6.70	112.81
Middle Peninsula	12/15/99	LR 2	38.0	64.2	33.0	23.4	1.41	6.81	110.62
Middle Peninsula	12/15/99	LR 2	37.0	91.2	43.2	34.2	1.26	6.16	83.24
Middle Peninsula	12/15/99	LR 2	41.0	78.3	43.5	24.0	1.85	6.41	104.65
Mohawk Valley	05/22/02	LFB 6	26.6	14.2	3.8	9.6	0.4	6.9	--
Mohawk Valley	05/22/02	LFB 6	26.2	9.6	1.8	7.7	0.2	6.9	--
Mohawk Valley	05/22/02	LFB 6	24.6	12.4	4.0	10.0	0.4	6.9	--
Plantation Oaks	11/07/03	S1	45.60	52.25	12.38	21.11	0.59	5.55	--
Plantation Oaks	11/07/03	S2	34.35	54.93	23.67	28.95	0.82	5.83	--
Plantation Oaks	11/07/03	S2	49.87	80.05	42.15	28.00	1.51	5.84	--
Plantation Oaks	11/07/03	S2	41.36	85.70	32.51	27.68	1.17	5.00	--
Plantation Oaks	11/07/03	S3	50.00	62.85	36.88	19.09	1.93	6.04	--
Plantation Oaks	11/07/03	S3	24.32	47.02	31.40	14.44	2.17	6.21	--
Plantation Oaks	11/07/03	S4	36.88	40.09	17.15	12.78	1.34	6.15	--
Plantation Oaks	11/07/03	S4	35.19	50.84	30.79	16.35	1.88	6.03	--
Plantation Oaks	08/22/02	5-2-1	23.8	13.1	3.9	5.0	0.8	6.7	0.43
Plantation Oaks	08/22/02	5-2-2	25.0	10.6	2.9	4.7	0.6	7.6	1.71
Plantation Oaks	08/22/02	5-2-3	40.3	33.5	17.6	12.6	1.4		50.31
Plantation Oaks	08/22/02	5-2-4	36.7	70.9	38.8	14.3	2.7	7.0	135.59
Plantation Oaks	08/22/02	5-2-5	27.6	75.9	36.1	24.8	1.5	6.0	132.21
Plantation Oaks	08/22/02	5-2-6	25.6	14.1	4.0	6.3	0.6	5.9	2.32
Plantation Oaks	08/22/02	5-4-1	32.2	17.5	10.6	9.7	1.1	6.1	3.93
Plantation Oaks	08/22/02	5-4-2	29.4	26.7	10.0	7.2	1.4	6.8	5.44
Plantation Oaks	08/22/02	5-4-3	30.7	63.9	13.8	30.1	0.5	6.6	78.08
Plantation Oaks	08/22/02	5-4-4	34.7	80.4	35.6	23.5	1.5	5.8	177.72
Plantation Oaks	08/22/02	5-4-5	31.2	80.4	36.6	46.2	0.8	7.0	157.25
Plantation Oaks	08/22/02	5-4-6	26.0	4.0	3.7	1.5	2.5	6.3	12.77
Plantation Oaks	08/22/02	5-5-1	28.5	33.4	8.4	8.9	0.9	6.6	1.87
Plantation Oaks	08/22/02	5-5-2	15.7	7.5	1.3	3.6	0.4	7.6	1.39
Plantation Oaks	08/22/02	5-5-3	19.3	18.8	6.5	6.9	0.9	5.7	3.18
Plantation Oaks	08/22/02	5-5-4	16.0	17.2	5.5	5.0	1.1	5.7	5.86
Plantation Oaks	08/22/02	5-5-5	31.8	53.6	18.6	25.7	0.7	7.0	6.75
Riverbend	08/03/99	Bio-3	40.0	47.0	3.6	7.7	0.47	6.96	25.47
Riverbend	08/03/99	Bio-3	53.0	48.0	6.8	14.2	0.48	6.61	66.18
Riverbend	10/11/99	Bio-1	25.0	14.0	1.9	11.0	0.19	6.35	6.59

Table 5.5 – Data for all landfills tested in project XL [ref. Graphs 3.11-3.14] (cont.)

Landfill	Sample Date	Location	Moisture (%)	VS (%)	Cellulose (%)	Lignin (%)	Cell/Lig	pH	BMP (mL/g)
Riverbend	10/11/99	Bio-1	43.0	43.0	5.0	31.5	0.16	8.59	4.39
Riverbend	10/11/99	Bio-2	52.0	40.0	3.5	19.3	0.17	8.55	9.43
Riverbend	10/11/99	Bio-2	66.0	42.0	14.0	16.0	0.88	6.86	12.19
Riverbend	10/11/99	Bio-2	41.0	21.0	4.1	10.1	0.40	7.51	31.01
Riverbend	10/12/99	Bio-2	52.0	18.0	1.7	7.0	0.24	7.35	2.97
Riverbend	10/12/99	Bio-2	71.0	22.0	3.0	10.1	0.31	7.23	24.79
Riverbend	10/12/99	Bio-3	61.0	48.0	16.5	13.9	1.19	5.82	90.38
Spruce Ridge	11/16/1999	LR 4	24.0	17.0	6.9	14.8	0.47	7.03	18.19
Spruce Ridge	11/16/1999	4	19.0	40.0	35.8	29.4	1.21	6.78	40.93
Spruce Ridge	11/16/1999	Cont A	28.0	43.0	15.7	17.8	0.88	6.23	59.86
Spruce Ridge	11/16/1999	A	31.0	60.0	19.6	19.0	1.05	6.60	128.34
Spruce Ridge	11/16/1999	A	31.0	80.0	16.7	18.3	0.91	6.74	140.71
Spruce Ridge	11/16/1999	A	14.0	27.0	6.4	8.8	0.72	7.26	45.30
Spruce Ridge	11/17/99	LR 3	30.0	28.0	7.9	10.8	0.73	6.95	15.69
Spruce Ridge	11/17/99	3	41.0	27.0	21.1	20.5	1.03	7.10	18.24
Spruce Ridge	11/17/99	3	45.0	28.0	19.6	22.9	0.86	7.14	27.86
Spruce Ridge	11/17/99	3	24.0	20.0	5.9	12.8	0.47	7.70	17.91
Spruce Ridge	11/17/99	Cont B	16.0	71.0	18.5	20.6	0.90	6.71	114.96
Spruce Ridge	11/17/99	B	26.0	50.0	16.1	18.7	0.86	6.20	75.42
Spruce Ridge	11/17/99	B	25.0	49.0	8.3	10.7	0.77	6.55	113.55
Spruce Ridge	11/18/99	LR 1	46.0	44.0	22.6	30.5	0.74	6.95	62.98
Spruce Ridge	11/18/99	1	32.0	44.0	8.4	10.1	0.84	6.56	91.96
Spruce Ridge	11/18/99	1	35.0	41.0	4.7	9.5	0.55	6.94	56.15
Spruce Ridge	11/18/99	1	47.0	39.0	8.5	10.0	0.86	6.60	38.80
Spruce Ridge	11/18/99	1	34.0	18.0	7.5	11.4	0.66	6.77	35.74

Table 5.6 – Calculations for Leachate Pilot Study at 80% Concentration (Fig 4.1)

I. Methane Standard = 1.01% [0.0101]

Injection Volume = 100 uL = 0.1 mL

mL CH_4 in 0.1mL injection = 0.1mL injection * (0.0101mL methane/1mL standard injection) = 0.00101 mL methane/standard

Average Area of Standard= 5.0216

Response factor - RF = 0.0002= (100 micro liters * 0.001 mL/micro liters*(1.01 % std CH4/100))/Standard Area Average

**units of response factor of std are just mL Methane/Area

II. Average mL Methane in Blanks Calculation

mL Methane in Blank = mL total gas * (Blank Area/0.1mL total gas)*(RF)

Blank Label #	Sample Type	Incubation Days	Bottle #	Leachate Vol.(mL)	Gas in Bag (mL)	Total Gas (mL)	Area from Blank injection (0.1mL total gas)	mL Methane in Blank Bottle
14	blank	15	12	0	3.5	168.5	18.0280	6.1098
16	blank	15	11	0	25.5	190.5	17.879	6.8504
17	blank	15	17	0	14.0	179.0	14.980	5.3932
18	blank	15	10	0	3.5	168.5	17.9540	6.0847
						Average mL Methane in Blanks		6.1095
23	blank	30	15	0	2.0	167.0	21.9190	7.3624
25	blank	30	13	0	3.0	168.0	23.9360	8.0880
26	blank	30	14	0	3.5	168.5	25.0560	8.4916
28	blank	30	16	0	2.0	167.0	0.202	0.0678
						Average mL Methane in Blanks		6.0025

III. mL Methane in sample corrected for blanks and BMP

mL methane in each sample corrected = [mL total gas*(sample area/0.1mL total gas)*(RF)]-average mL Methane in Blanks

IV. BMP = mL methane in each sample corrected/mL leachate *(1000mL/L)= mL BMP/L leachate

Sample Label #	Sample Type	Incubation Days	Bottle #	Leachate Vol.(mL)	Gas in Bag (mL)	Total Gas (mL)	Area from Sample injection (0.1mL total gas)	mL Methane in sample bottle (corrected for blanks)
15	Leachate	15	3	80	15.0	180.0	42.4630	9.2884
19	Leachate	15	1	80	3.0	168.0	45.5650	9.3117
20	Leachate	15	2	80	23.5	188.5	37.2100	8.0228
21	Leachate	15	4	80	14.0	179.0	38.7170	7.8544
24	Leachate	30	5	80	32.5	197.5	58.9430	17.4117
27	Leachate	30	8	80	16.0	181.0	56.0110	14.3882
29	Leachate	30	6	80	19.0	184.0	54.1750	14.0467
30	Leachate	30	7	80	7.0	172.0	55.1990	13.0934

Sample Label #	Sample Type	Incubation Days	Bottle #	BMP mL Methane/L leachate
15	Leachate	15	3	116.1052
19	Leachate	15	1	116.3964
20	Leachate	15	2	100.2849
21	Leachate	15	4	98.1795
24	Leachate	30	5	217.6464
27	Leachate	30	8	179.8525
29	Leachate	30	6	175.5837
30	Leachate	30	7	163.6674

Table 5.7 – Data of Samples Run for 55Days at 50% Concentration (Figure 4.2)

I. Methane Standard = 1.01% [0.0101]

Injection Volume = 100 uL = 0.1 mL

mL meth in 0.1mL injection = 0.1mL injection * (0.0101mL methane/1mL standard injection) = 0.00101 mL methane/standard

Average Area of Standard=1.6392...=(100 micro liters * 0.001 mL/micro liters*(1.01 % std CH4/100))/Standard Area Average

Response factor - RF = 0.000616

**units of response factor of std are just mL Methane/Area

II. Average mL Methane in Blanks Calculation

mL Methane in Blank = mL total gas * (Blank Area/0.1mL total gas)*(RF)

Blank Label #	Sample Type	Incubation Days	Bottle #	Leachate Vol.(mL)	Gas in Bag (mL)	Total Gas (mL)	Area from Blank injection (0.1mL total gas)	mL Methane in Blank Bottle
91	blank	55	91	0.0	18.0	183.0	8.654	9.7583
96	blank	55	96	0.0	12.0	177.0	9.099	9.9232
							Average mL Methane in Blanks	9.8407

III. mL Methane in sample corrected for blanks and BMP

mL methane in each sample corrected = [mL total gas*(sample area/0.1mL total gas)*(RF)]-average mL Methane in Blanks

IV. BMP = mL methane in each sample corrected/mL leachate *(1000mL/L)= mL BMP/L leachate

Sample Label #	Sample Date	Incubation Days	Bottle #	leachate (mL)	Gas Volume (mL)	Total Gas (mL)	Injection Area	mL Methane (corrected for blanks)	BMP mL/L
7.3B	6.12.02	55	61	50.0	20	185.0	11.174	2.8967	57.9338
7.3B	6.12.02	55	62	50.0	23	188.0	11.501	3.4811	69.6221
7.4B	6.12.02	55	67	50.0	6	171.0	48.412	41.1669	823.3376
7.4B	6.12.02	55	68	50.0	102	267.0	50.603	73.4082	1468.1641
5.1A	6.12.02	55	73	50.0	22	187.0	12.116	4.1197	82.3932
5.1A	6.12.02	55	74	50.0	21	186.0	10.984	2.7472	54.9444
5.1A	8.7.02	55	79	50.0	30	195.0	13.001	5.7795	115.5900
5.1A	8.7.02	55	80	50.0	10	175.0	13.077	4.2595	85.1897
big	mix	55	81	50.0	53	218.0	25.568	24.5025	490.0498
big	mix	55	82	50.0	47	212.0	23.530	20.8947	417.8948

Table 5.8 – Data for Samples Run at 80% Concentration for 15 Days (figures 4.3-4.7)

Blank Label #	Sample Type	Incubation Days	Bottle #	Leachate Vol. (mL)	Gas in Bag (mL)	Total Gas (mL)	Area (0.1mL total gas)	mL Methane in Blank Bottle
1	blank	15	1	0	7	172	1.521	2.227235807
2	blank	15	2	0	5	170	1.265	1.830829856
3	blank	15	3	0	7	172	1.549	2.268236861
4	blank	15	4	0	5	170	0.996	1.441507144
5	blank	15	5	0	7	172	1.214	1.77768854
6	blank	15	6	0	8	173	1.64	2.415452438
7	blank	15	7	0	7	172	1.625	2.379525435
8	blank	15	8	0	12	177	1.762	2.655141737
9	blank	15	9	0	5	170	1.942	2.810649471
10	blank	15	10	0	8	173	1.505	2.216619463
11	blank	15	11	0	8	173	1.706	2.51265967
12	blank	15	12	0	8	173	1.792	2.63932364
13	blank	15	13	0	7	172	0.886	1.297390483
14	blank	15	14	0	5	170	1.418	2.052266195

Sample Label #	Sample type	Incubation Days	Bottle #	Leachate Vol.(mL)	Gas in Bag (mL)	Total Gas (mL)	Area (0.1mL total gas)	mL Methane	BMP mL/L
15	Leachate	15	15	80	12	177	0.219	-1.851	-23.133
16	Leachate	15	16	80	29	194	0.211	-1.832	-22.898
17	Leachate	15	17	80	12	177	0.198	-1.882	-23.524
18	Leachate	15	18	80	17	182	0.178	-1.905	-23.806
19	Leachate	15	19	80	10	175	0.198	-1.885	-23.567
20	Leachate	15	20	80	18	183	0.167	-1.920	-24.002
21	Leachate	15	21	80	16	181	0.155	-1.941	-24.268
22	Leachate	15	22	80	20	185	0.187	-1.886	-23.572
23	Leachate	15	23	80	9	174	0.173	-1.924	-24.051
24	Leachate	15	24	80	11	176	0.138	-1.974	-24.669
25	Leachate	15	25	80	7	172	0.170	-1.931	-24.142
26	Leachate	15	26	80	6	171	0.181	-1.917	-23.960
27	Leachate	15	27	80	7	172	0.201	-1.886	-23.575
28	Leachate	15	28	80	5	170	0.124	-2.001	-25.011
29	Leachate	15	29	80	6	171	0.136	-1.982	-24.779
31	Leachate	15	31	80	12	177	0.405	-1.570	-19.627
32	Leachate	15	32	80	12	177	0.448	-1.505	-18.815
33	Leachate	15	33	80	9	174	0.194	-1.893	-23.662
34	Leachate	15	34	80	8	173	0.232	-1.839	-22.983
35	Leachate	15	35	80	8	173	0.261	-1.796	-22.449
36	Leachate	15	36	80	8	173	0.221	-1.855	-23.185
37	Leachate	15	37	80	13	178	0.663	-1.175	-14.689
38	Leachate	15	38	80	14	179	0.580	-1.296	-16.206
39	Leachate	15	39	80	11	176	0.996	-0.688	-8.599
40	Leachate	15	40	80	8	173	1.214	-0.392	-4.904
41	Leachate	15	41	80	13	178	0.573	-1.312	-16.400
42	Leachate	15	42	80	10	175	0.613	-1.267	-15.838
43	Leachate	15	43	80	16	181	6.119	7.249	90.609

Table 5.8 – Data for Samples Run at 80% Concentration for 15 Days (figures 4.3-4.7) (cont.)

Sample Label #	Sample type	Incubation Days	Bottle #	Leachate Vol.(mL)	Gas in Bag (mL)	Total Gas (mL)	Area (0.1mL total gas)	mL Methane	BMP mL/L
44	Leachate	15	44	80	16	181	5.392	6.128	76.606
45	Leachate	15	45	80	22	187	4.180	4.474	55.929
46	Leachate	15	46	80	11	176	6.836	8.063	100.782
47	Leachate	15	47	80	13	178	0.541	-1.360	-16.999
48	Leachate	15	48	80	15	180	0.459	-1.477	-18.462
49	Leachate	15	49	80	9	174	0.576	-1.327	-16.588
50	Leachate	15	50	80	8	173	0.661	-1.207	-15.085
51	Leachate	15	51	80	11	176	1.042	-0.619	-7.738
52	Leachate	15	52	80	8	173	0.909	-0.842	-10.519
53	Leachate	15	53	80	11	176	0.964	-0.736	-9.199
54	Leachate	15	54	80	16	181	1.122	-0.451	-5.642
55	Leachate	15	55	80	7	172	0.982	-0.742	-9.279
56	Leachate	15	56	80	5	170	0.689	-1.183	-14.789
57	Leachate	15	57	80	12	177	0.846	-0.905	-11.319
58	Leachate	15	58	80	9	174	0.861	-0.905	-11.311
59	Leachate	15	59	80	6	171	0.747	-1.093	-13.660
60	Leachate	15	60	80	8	173	0.678	-1.182	-14.772
61	Leachate	15	61	80	7	172	0.807	-0.999	-12.483
62	Leachate	15	62	80	10	175	0.859	-0.901	-11.257
63	Leachate	15	63	80	15	180	10.763	14.313	178.915
64	Leachate	15	64	80	9	174	11.014	14.135	176.691
65	Leachate	15	65	80	19	184	11.186	15.342	191.776
66	Leachate	15	66	80	19	184	10.525	14.307	178.837
67	Leachate	15	67	80	9	174	1.913	0.653	8.169
68	Leachate	15	68	80	8	173	1.831	0.516	6.456
69	Leachate	15	69	80	9	174	2.607	1.682	21.019
70	Leachate	15	70	80	10	175	2.063	0.893	11.166
71	Leachate	15	71	80	9	174	2.409	1.388	17.353
72	Leachate	15	72	80	8	173	2.836	1.997	24.958
73	Leachate	15	73	80	8	173	0.920	-0.825	-10.316
74	Leachate	15	74	80	11	176	0.746	-1.063	-13.282
75	Leachate	15	75	80	9	174	1.520	0.071	0.892
76	Leachate	15	76	80	13	178	1.545	0.161	2.012
77	Leachate	15	77	80	10	175	1.353	-0.165	-2.057
78	Leachate	15	78	80	12	177	1.568	0.182	2.281
79	Leachate	15	79	80	9	174	0.721	-1.112	-13.903
80	Leachate	15	80	80	8	173	0.857	-0.918	-11.476
81	Leachate	15	81	80	8	173	0.348	-1.668	-20.847
82	Leachate	15	82	80	8	173	0.723	-1.115	-13.943
83	Leachate	15	83	80	4	169	0.561	-1.373	-17.165
84	Leachate	15	84	80	6	171	0.460	-1.511	-18.883
85	Leachate	15	85	80	11	176	0.592	-1.293	-16.166
86	Leachate	15	86	80	9	174	0.526	-1.401	-17.514
87	Leachate	15	87	80	10	175	3.276	2.700	33.756

Table 5.8 – Data for Samples Run at 80% Concentration for 15 Days (figures 4.3-4.7) (cont.)

Sample Label #	Sample type	Incubation Days	Bottle #	Leachate Vol.(mL)	Gas in Bag (mL)	Total Gas (mL)	Area (0.1mL total gas)	mL Methane	BMP mL/L
88	Leachate	15	88	80	11	176	3.254	2.695	33.692
89	Leachate	15	89	80	10	175	3.139	2.496	31.204
90	Leachate	15	90	80	12	177	3.147	2.562	32.023
91	Leachate	15	91	80	12	177	2.178	1.102	13.771
92	Leachate	15	92	80	10	175	2.597	1.689	21.111
93	Leachate	15	93	80	13	178	3.339	2.880	35.995
94	Leachate	15	94	80	9	174	2.473	1.483	18.538
95	Leachate	15	95	80	8	173	0.530	-1.400	-17.496
96	Leachate	15	96	80	8	173	0.307	-1.728	-21.602
97	Leachate	15	97	80	8	173	0.392	-1.603	-20.037
98	Leachate	15	98	80	12	177	0.279	-1.760	-21.999
99	Leachate	15	99	80	23	188	5.650	6.863	85.784
100	Leachate	15	100	80	15	180	5.947	6.933	86.663
101	Leachate	15	101	80	15	180	5.786	6.686	83.579
102	Leachate	15	102	80	20	185	6.017	7.296	91.206
103	Leachate	15	103	80	10	175	0.450	-1.510	-18.874
104	Leachate	15	104	80	12	177	0.459	-1.489	-18.608
105	Leachate	15	105	80	10	175	0.527	-1.395	-17.440
106	Leachate	15	106	80	16	181	0.732	-1.052	-13.154
107	Leachate	15	107	80	10	175	0.828	-0.947	-11.834
108	Leachate	15	108	80	10	175	0.828	-0.947	-11.834
109	Leachate	15	109	80	10	175	0.674	-1.176	-14.702
110	Leachate	15	110	80	8	173	0.700	-1.149	-14.367
111	Leachate	15	111	80	7	172	0.754	-1.076	-13.453
112	Leachate	15	112	80	9	174	0.722	-1.111	-13.883
113	Leachate	15	113	80	8	173	0.806	-0.993	-12.415
114	Leachate	15	114	80	7	172	0.712	-1.138	-14.222

Table 5.9 – Data for Samples Run at 50% Concentration (Not Including Injection Areas)

Sample	DATE	COD	BMP mL/L 20 Days	BMP mL/L 33 Days	BMP mL/L 42 Days	BMP mL/L 55 Days
5.1A	6/12/2002	2130	28.48724885	-230.5755557	81.49092178	82.39316532
5.1A	6/12/2002	2130	-29.51118518	12.91779715	73.755241	54.94440666
5.1A	7/23/2002	2410			-26.9836605	
5.1A	7/23/2002	2410			-57.76092353	
5.1A	8/7/2002	2270	61.46641343	254.622312	60.62115194	115.5900267
5.1A	8/7/2002	2270	-1.379745224	281.6730301	21.73675057	85.1896552
5.1A	6/5/2003	1580			-33.74173325	
5.1A	6/5/2003	1580			-80.83555854	
5.1B	7/23/2002	1420			-13.58334361	
5.1B	7/23/2002	1420			-40.65559624	
5.1B	8/7/2002	1390			54.85034397	
5.1B	8/7/2002	1390			40.23796165	
5.1B	6/5/2003	2052			-50.41645869	
5.1B	6/5/2003	2052			-86.87797228	
5.2A	7/23/2002	2410			-42.4262481	
5.2A	7/23/2002	2410			-67.25299349	
5.2A	8/7/2002	1820			33.6540767	
5.2A	8/7/2002	1820			46.6881177	
5.2B	7/23/2002	1340			-30.088304	
5.2B	7/23/2002	1340			-70.38826902	
5.2B	8/7/2002	1380			464.7179811	
5.2B	6/5/2003	1068			-92.553783	
5.2B	6/5/2003	1068			-20.30551106	
7.3A	7/23/2002	890			43.41408862	
7.3A	7/23/2002	890			27.92834662	
7.3A	8/7/2002	1090			53.135081	
7.3A	8/7/2002	1090			-20.54588288	
7.3A	6/5/2003	610			-87.69980314	
7.3A	6/5/2003	610			-64.20868502	
7.3B	6/12/2002	510	-127.0423364	-124.9339002	-13.16061895	57.93382674
7.3B	6/12/2002	510	-102.982529	-70.44593809	-4.606627174	69.62208748
7.3B	7/23/2002	1220			-11.20597862	
7.3B	7/23/2002	1220			-36.7304173	
7.3B	8/7/2002	1160			-77.71677014	
7.3B	8/7/2002	1160			145.7638346	
7.3B	6/5/2003	600			-46.55170636	
7.3B	6/5/2003	600			-44.31087048	
7.4A	7/23/2002	1410			-16.78759028	
7.4A	7/23/2002	1410			-46.17825989	
7.4A	8/7/2002	4016			564.9464752	
7.4A	8/7/2002	4016			606.2816878	
7.4A	6/5/2003	2976			-61.46105321	
7.4A	6/5/2003	2976			61.87300891	
7.4B	6/12/2002	1060	1939.049547	1468.252403	215.5225637	823.337619
7.4B	6/12/2002	1060	3168.923248	2678.503184	791.1060154	1468.16406
7.4B	7/23/2002	3140			494.6583655	
7.4B	7/23/2002	3140			433.0127415	
7.4B	8/7/2002	3536			1367.937752	
7.4B	8/7/2002	3536			606.9791848	
7.4B	6/5/2003				458.0596685	
7.4B	6/5/2003				739.7356784	
7.4B	6/5/2003				887.9190314	
7.4B	6/5/2003				1039.097428	

Table 5.10 – Summary of Landfills in the leachate study (Waste Management, 2000).

Landfill Unit	Subunit	Sub cell	Title	Operational Variables
5	1	A	FLB	Addition of nitrate/nitrite enriched leachate from the SBR Unit through series of retrofit surface trenches.
5	2	B	FLB Duplicate	Addition of nitrate/nitrite enriched leachate from the SBR Unit through series of retrofit surface trenches.
5	1	B	FLB	Addition of nitrate/nitrite enriched leachate from the SBR Unit through series of retrofit surface trenches. Although subject to FLB operation, participation in the study is restricted to a limited section of the sampling strategy and landfill gas collection.
5	2	A	FLB Duplicate	Addition of nitrate/nitrite enriched leachate from the SBR Unit through series of retrofit surface trenches. Although subject to FLB operation, participation in the study is restricted to a limited section of the sampling strategy and landfill gas collection.
7	3	A	Control	Operated as a Subtitle D landfill Unit.
7	3	B	Control Duplicate	Operated as a Subtitle D landfill Unit.
7	4	A	AALB	Air injected through a series of pipes constructed on the surface of each lift during waste placement, for a period of 30-60 days per lift. Moisture, primarily leachate, added after aeration is complete through the piping network.
7	4	B	AALB Duplicate	Air injected through a series of pipes constructed on the surface of each lift during waste placement, for a period of 30-60 days per lift. Moisture, primarily leachate, added after aeration is complete through the piping network.

Table 5.11 – Area of Injection (50% conc. 42-Day) and Average COD (ref. Fig 4.8)

Sample Label #	Sample Date	Area from Sample injection (0.1mL total gas)	average cod
5.1A	6/12/2002	12.6872	2130
5.1A	6/12/2002	12.2425	2130
5.1A	7/23/2002	8.5038	2410
5.1A	7/23/2002	7.2185	2410
5.1A	8/7/2002	12.365	2270
5.1A	8/7/2002	11.5481	2270
5.1A	6/5/2003	8.3586	1580
5.1A	6/5/2003	6.5784	1580
5.1B	7/23/2002	9.7565	1420
5.1B	7/23/2002	8.59	1420
5.1B	8/7/2002	11.1306	1390
5.1B	8/7/2002	10.615	1390
5.1B	6/5/2003	8.0533	2052
5.1B	6/5/2003	6.3495	2052
5.2A	7/23/2002	8.1253	2410
5.2A	7/23/2002	6.9358	2410
5.2A	8/7/2002	10.7426	1820
5.2A	8/7/2002	11.0376	1820
5.2A	6/5/2003	5.1201	1824
5.2A	6/5/2003	5.9494	1824
5.2B	7/23/2002	8.1083	1824
5.2B	7/23/2002	6.6548	1824
5.2B	8/7/2002	9.982	1380
5.2B	8/7/2002	31.82	1380
5.2B	6/5/2003	6.1701	1068
5.2B	6/5/2003	9.132	1068
7.3A	7/23/2002	10.2156	890
7.3A	7/23/2002	10.0297	890
7.3A	8/7/2002	11.4131	1090
7.3A	8/7/2002	9.4435	1090
7.3A	6/5/2003	6.3499	600
7.3A	6/5/2003	7.1848	600
7.3B	6/12/2002	8.9346	510
7.3B	6/12/2002	9.387	510
7.3B	7/23/2002	9.1129	1220
7.3B	7/23/2002	7.5985	1220
7.3B	8/7/2002	6.2153	1160
7.3B	8/7/2002	14.1694	1160
7.3B	6/5/2003	8.038	610
7.3B	6/5/2003	8.5256	610
7.4A	7/23/2002	9.2323	1410
7.4A	7/23/2002	8.2912	1410
7.4A	8/7/2002	36.4067	4016
7.4A	8/7/2002	38.2983	4016
7.4B	6/12/2002	19.3722	2976
7.4B	7/23/2002	24.8554	1060
7.4B	7/23/2002	24.0362	1060
7.4B	8/7/2002	53.8178	3140
7.4B	8/7/2002	29.9119	3140
7.4B	6/5/2003	30.0746	3536
7.4B	6/5/2003	37.2649	3536
7.4B	6/5/2003	37.3283	3536
7.4B	6/5/2003	41.4681	3536

Table 5.12 – Outer Loop Landfill MSW/Leachate Data

Samples from Outer Loop Landfill in Louisville, KY							
LEACHATE						MSW	
SAMPLE	DATE	INCUBATION(d)	TOTAL GAS(mL)	BMP(mL/L)		Cellulose (%)	Lignin (%)
5.1A	6/12/02	42	190	73.755241		14.2	15.5
5.1A	6/12/02	42	188	81.49092178		14.2	15.5
7.4B	6/12/02	42	176	215.5225637		12.14	15.35
7.4B	6/12/02	42	170	791.1060154		12.14	15.35
7.3A	7/23/02	42	197	27.92834662		18.13	17.83
7.3A	7/23/02	42	205	43.41408862		18.13	17.83
7.4B	7/23/02	42	211	433.0127415		12.14	15.35
7.4B	7/23/02	42	223	494.6583655		12.14	15.35
5.1A	8/7/02	42	167	21.73675057		14.2	15.5
5.1B	8/7/02	42	195	40.23796165		14.2	15.5
5.2A	8/7/02	42	192	46.6881177		13.53	14.95
7.3A	8/7/02	42	190	53.135081		18.13	17.83
5.1B	8/7/02	42	196	54.85034397		14.2	15.5
5.1A	8/7/02	42	180	60.62115194		14.2	15.5
7.3B	8/7/02	42	203	145.7638346		23.91	18.79
5.2B	8/7/02	42	167	464.7179811		13.53	14.95
7.4A	8/7/02	42	167	564.9464752		13.4	19.24
7.4A	8/7/02	42	167	606.2816878		13.4	19.24
7.4B	8/7/02	42	214	606.9791848		12.14	15.35
7.4B	8/7/02	42	227	1367.937752		12.14	15.35
5.2A	8/7/02	42	188	33.6540767		13.53	14.95

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