DEVELOPMENT OF STATISTICAL MODELS FOR PREDICTING LEACHATE PARAMETERS FROM SIMULATED LANDFILLS

by

ARPITA HETAL BHATT

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ABSTRACT

DEVELOPMENT OF STATISTICAL MODELS FOR PREDICTING LEACHATE PARAMETERS FROM SIMULATED LANDFILLS

Arpita Hetal Bhatt, PhD

The University of Texas at Arlington, 2013

Supervising Professor: Melanie Sattler

Leachate generation and management is recognized as one of the greatest problems associated with environmentally sound operation of landfills, as leachate can cause major pollution problems to surrounding soil, ground water, and surface waters. There are many landfills, especially in developing parts of the world like India, Bangladesh, Africa, and Latin America, where open dump systems are used for final disposal of solid waste rather than engineered landfills. In the near future, regulations in developing countries will likely require installation of liner systems, leachate collection systems, and treatment operations. A major requirement for successful leachate treatment is quantifying its typical composition. Models for predicting leachate parameters would be useful in designing leachate treatment systems for new landfills in developing countries.

Even in the developed countries, it is quite possible that the frequency of monitoring various leachate quality parameters will increase, along with the number of parameters to be measured. In the absence of gas composition data, leachate composition data provides important information about different phases of waste decomposition. However, the analyses of these types of leachate quality parameters are very expensive and time consuming. Models for

estimating leachate parameters would be useful in reducing leachate parameter modeling frequency, and thus reducing costs.

Previous studies have shown that waste composition, rainfall and temperature of a landfill significantly influence leachate composition. Most studies have focused on leachate quality data from a single or few regional-specific landfills considering general waste composition, temperature, and moisture content. The few attempts to develop regression models to predict leachate characteristics using statistical techniques have focused on a single or few regional landfills.

The goal of this research was to develop Multivariate Adaptive Regression Splines (MARS) equations for predicting leachate parameters: biochemical oxygen demand (BOD), chemical oxygen demand (COD), alkalinity, pH, conductivity, total dissolved solids (TDS), total suspended solids (TSS), volatile suspended solid (VSS), ammonia-nitrogen (NH_3-N), and chloride (Cl^-), with basic information on temperature, rainfall, waste composition, and time. A statistical experimental design was developed using incomplete block design to determine leachate quality parameters, where the waste composition served as a blocking variable and combinations of temperature and rainfall were the predictor variables. Leachate characteristics were measured from total 27 - 16L size lab-scale reactors with varying waste compositions (0-100%); rainfall rates of 2, 6, and 12 mm/day; and temperatures of 70, 85, and 100 °F. Waste components considered for the study were major biodegradable wastes, food, paper, yard, textile, as well as inorganic waste.

Initially many attempts were made on total alkalinity (as $CaCO_3$) to develop a multiple linear regression (MLR) model equation. However, it was concluded that basic MLR method was insufficient to analyze lab-scale leachate data due to nonlinearity between response and predictor variables. Therefore, a more sophisticated modeling approach of regression splines was used for the model development of all leachate parameters. Multivariate Adaptive Regression Splines (MARS) equations were developed using Salford Predictive Modeler

Builder, Version 6.6, which incorporated predictor variables (temperature, rainfall, and waste components) in predicting leachate parameters.

Overall, reactors at 70 °F had lower concentrations of almost all leachate parameters. Also, reactors with 100% food waste showed the highest concentrations for all leachate parameters. Time or Rain was the most important variable in the MARS model equations developed for the leachate parameters except NH_3-N, where Food variable was given the highest importance. Paper vs. Rain 3D-interaction plots showed decreased concentrations of total alkalinity and TDS with increasing rainfall and paper percentage. Leachate Volume vs. Time 3D-interaction plots showed decreased concentrations for total alkalinity, TDS, and conductivity with increasing time and leachate volume. Furthermore, Temperature vs. Rain, Paper vs. Rain, Food vs. Temperature 3D-interaction plots showed similar trends for TSS and VSS. The total alkalinity model had the highest adjusted R^2 value of 0.961; conductivity was second with an adjusted R^2 of 0.958. Also, the model equations for COD, TDS and BOD had high adjusted R^2 values of 0.950, 0.947, and 0.923, respectively. It was observed that 85 °F was the optimum temperature based on interaction plots for BOD, VSS, and NH_3-N.

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CHAPTER 1

INTRODUCTION

1.1 Background

Integrated solid waste management programs, which include source reduction, reuse, recycling and composting, have led to a decrease in the use of landfills. However, there is a limit to the amount of waste that can be reused and recycled, and incineration is not a preferred alternative in many communities. Consequently, sanitary landfilling still remains the primary method of disposal in many developing countries as well as United States. Municipal Solid Waste (MSW) includes the material that we use and then discard such as food scraps, packaging, grass clippings, sofas, computers, tires, and refrigerators. However, MSW does not include industrial, hazardous, or construction waste. According to the United States Environmental Protection Agency (USEPA), out of a total MSW generation of 250 million tons, about 136 million tons (54.2%) were discarded in landfills in 2010.

Landfill leachate is generated mainly due to the infiltration of rainwater which percolates through the waste layers and accumulates at the bottom of landfills. Even though solid waste management techniques for landfilling of wastes have advanced, the treatment of leachate still remains a major environmental concern. Various physical, chemical, and microbial processes in the solid waste transfer pollutants from the waste material to the leaching water (Christensen and Kjeldsen, 1989; Reinhart et. al., 2002). Leachate generation and management is recognized as one of the greatest problems associated with environmentally sound operation of landfills, since this leachate can cause major pollution problems to surrounding soil, ground water, and surface waters. The risk of ground water pollution is probably the most extreme environmental impact from landfills because traditionally most landfills were built without engineered liners and leachate collection systems. Even in 21st century, there are many landfills, especially in developing parts of the world like India, Bangladesh, Africa, and Latin

America, where open dump systems are used for the final disposal of solid waste rather than engineered landfills (Waste Management Anchor Team, The World Bank, 1999). In the near future, regulations in developing countries will require installation of liner systems, leachate collection systems, and treatment operations. In addition, in the absence of gas composition data, leachate data provides important information about the phases of waste decomposition.

In recent years, many or possibly all operating and/or closed landfills will have monitoring programs for leachate, groundwater and/or surface water. Additionally, it is quite possible that the frequency of monitoring various leachate quality parameters will increase, along with the number of parameters to be measured. However, a limitation in this aspect is that the analyses of these types of parameters are very expensive. The associated cost may limit the number of analyses included in monitoring programs. An understanding of leachate composition is crucial for predicting long-term impacts of landfills and designing leachate treatment systems. Multivariate Adaptive Regression Splines (MARS) statistical technique may be a useful tool in predicting leachate parameters for the design of leachate treatment systems in developing countries where regulatory compliance and monitoring programs are yet to come.

Leachate quality depends on many factors such as waste composition, waste age, climate, and landfilling operations (Alkalay et. al., 1998). A major requirement for successful leachate treatment is quantifying its typical composition. Focusing on landfills receiving mostly municipal solid wastes, pollutants in landfill leachate may be categorized into four groups: dissolved organic matter, inorganic macro components, heavy metals, and xenobiotic organic compounds (Christensen et. al., 1994).

1.2 Problem Statement

Several parameters change radically over time as landfills stabilize. Kjeldsen et al. (2002) provided a review of leachate composition from various studies available in the literature. This report shows that there is a wide variation in leachate composition. Depending on the study objectives, many investigations of leachate composition have been restricted to leachate quality data from a single landfill or from a few regional-specific landfills.

Similarly, many studies have been conducted to assess leachate quality (Al-Yaqout and Hamoda, 2003; Kulikowska and Klimiuk, 2008; Sormunen et al. 2008; Tatsi and Zouboulis, 2002). These studies considered general waste composition, temperature, and moisture content, or site-specific data from a few landfills. Besides, the few attempts to model leachate quality/characteristics using statistical techniques or software have focused on a single landfill or few regional landfills (Eusuf et al., 2007; Go´mez Martı´n et al., 1995; Kylefors, 2003).

Multivariate Adaptive Regression Splines (MARS) statistical approach has not been yet applied in the solid waste management field. Results of previous studies of correlations within one or several leachates have been presented (Ettala et al., 1988; Fatta et al., 1998; Go´mez Martı´n et al., 1995a,b). However, the application of such matrices limits the use of the results without any statistical models. Contradictions between the results of the various studies are also observed, indicating that each landfill produces unique leachate characteristics. Other statistical techniques have been used on a few occasions to categorize leachates based on landfill site or degradation phase (Andreas et al., 1999; Go´mez Martı´n et al., 1995b). However, none of these studies have focused on the possibilities of predicting leachate parameters.

MARS is the modern nonparametric regression analysis method used in many studies (Walker 1990; Moore et al., 1991; White and Sifneos, 1997). MARS enables to rapidly search through all possible models and to quickly identify the optimal model. It builds models by fitting piecewise linear regressions; meaning, the nonlinearity of a model is approximated through the use of separate regression slopes (MARS User Guide, 2001). Hence, MARS has the potential to be a useful statistical approach for predicting leachate characteristics.

1.3 Research Objectives

1. To measure leachate parameters as functions of time from lab-scale landfill reactors with varying waste components operated at different temperatures and rainfall rates.
2. To develop Multivariate Adaptive Regression Splines (MARS) models for predicting leachate parameters.

1.4 Report Organization

This report will discuss the leachate composition of municipal solid waste in simulated landfills, while focusing on the effect of rainfall and temperature on the strength of leachate compositions and waste decomposition over time. The dissertation is organized into a series of six chapters followed by appendices.

Chapter 2 presents an extensive literature review of MSW landfill leachate composition, effect of climate on chemical characteristics of leachate, quality and quantity of leachate, and leachate recirculation. It summarizes leachate characteristics, leachate formation mechanisms, and the importance of leachate quality in ensuring proper landfill leachate treatment.

Chapter 3 presents the project methodology and procedures. This section includes the experimental design of the simulated lab-scale landfill reactors; and also it summarizes the measurement methods used to analyze the leachate parameters. Moreover, it gives an idea of how the data were collected, reported, and analyzed.

Chapter 4 discusses in detail the experimental results obtained, and compares them with the existing literatures. Chapter 5 illustrates the statistical modeling approach using Multivariate Adaptive Regression Splines (MARS). Finally, regression splines equations for predicting leachate parameters are developed.

Chapter 6 summarizes the main conclusions from the current research work and provides some recommendations for future direction of study.

The appendices include raw data table, graphs, and output files of statistical analysis.

CHAPTER 2

LITERATURE REVIEW

2.1 Background

The safe, reliable and sustainable disposal of solid waste is an important aspect of solid waste management. Municipal solid waste consists of substances such as boxes, grass clippings, wood, textile, bottles, food scraps, paper and appliances. The U.S. Environmental Protection Agency (EPA) has recommended the most environmentally sound strategies for municipal solid waste management: source reduction and reuse are the most preferred methods, followed by recycling and composting, and finally landfill disposal and combustion, being the least preferred methods as displayed in Figure 2.1.

Figure 2.1 Waste Management Hierarchy (U.S. EPA)

Landfilling or land disposal remains the most commonly used method for refuse disposal. For several decades, landfills have been the most economical and environmentally acceptable method for waste disposal throughout the world. Even with the implementation of waste reduction, recycling, and reuse, disposal of solid waste in the landfills still remains an important component of the solid waste management strategies, since many items cannot be recycled or reused. There are many concerns related to landfilling of solid waste: (1) the controlled release of landfill gases that might migrate off-site and cause odor and other dangerous conditions, (2) the impact of uncontrolled release of landfill gases in the atmosphere which increases greenhouse gases (GHG) emissions., (3) the uncontrolled release of leachate that may migrate to groundwater or surrounding surface water, (4) the breeding and harboring of disease vectors in an improperly managed landfills, and (5) the health and environmental impacts associated with the release of trace gases from hazardous materials.

However, landfill leachate production and management are recognized as some of the greatest problems associated with the environmentally sound operation of landfills. Variations in leachate composition and quantity of pollutants released from solid waste are mostly attributed to the amount of water which infiltrates into the landfill, liquid generation from waste as it decomposes, and other physiochemical and biological activities within waste layers.

2.2 Landfill Leachate Generation

Many factors contribute toward variability in quantity and quality of leachate from landfills. Leckie et al. (1979) reported some of the most relevant factors that influence leachate generation: annual precipitation, runoff, infiltration, evaporation, transpiration, freezing, mean ambient temperature, waste composition, waste density, initial moisture content, and depth of the landfill. Landfills pass through a series of stages. Initially, little or no leachate is produced until the landfill reaches its field capacity; in other words, leachate is produced once the waste is completely saturated, or contains the maximum moisture it can hold without producing downward percolation. Percolation occurs when the gravitational forces exceed the holding capacity. This process is influenced by many factors which contribute to landfill moisture and leachate and moisture distribution within the landfill (El-Fadel et al., 2002). These factors are displayed as a flow chart in Figure 2.2. Several researchers determined that the field moisture capacity of the solid waste varied from 20 to 35% (200 to 300 mm water per meter refuse) by volume (Remson et al. 1968; Qasim and Burchinal 1970a, 1970b; Korfiatis and Demetracopoulos, 1984).

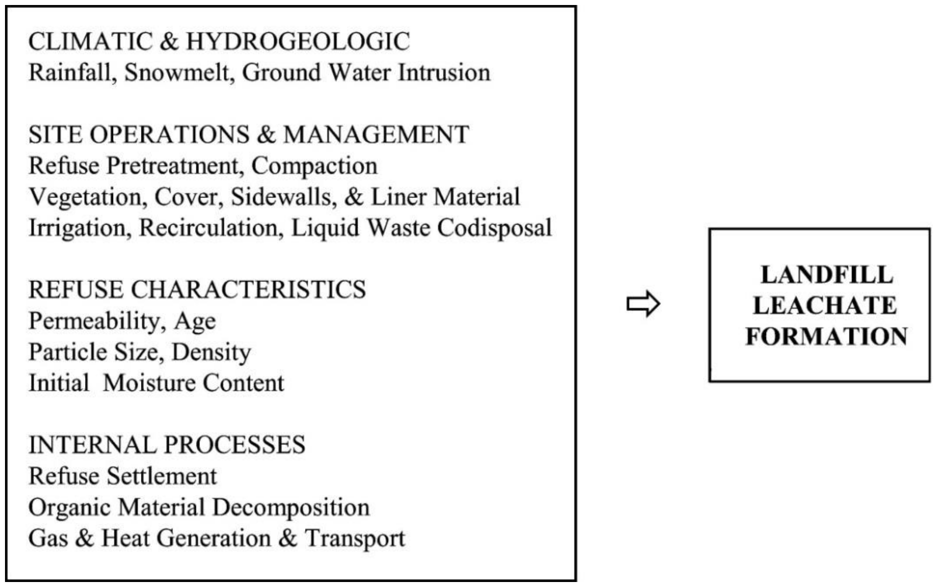


Figure 2.2 Factors Influencing Leachate Formation in Landfills

In general, the more water that passes through the waste, the more pollutants are leached. As such, it is vital to develop methods to estimate amount of leachate generation in sanitary landfills.

Numerous mathematical models have been developed to simulate quantity of leachate production. Lu et al. (1981, 1984) summarized techniques available for leachate generation estimation. Fenn et al. (1975) and Dass et al. (1977) provided a water budget analysis, where precipitation is the principal source of moisture at the landfill site. Some part of moisture results in surface runoff, a part is return to atmosphere via evapotranspiration and the remaining water goes to soil moisture storage. Different components of the moisture used in the water budget are shown in Figure 2.3. Tchobanoglous et al. (1993) provided an example of leachate quantity calculations. Lately, computer simulation models have been developed for estimation of leachate generation. Many models have been applied and evaluated for actual landfill sites. A model designed specifically for landfills, is the HSSWDS (Hydrologic Simulation on Solid Waste Disposal Sites) model, developed by Perrier and Gibson (1980). Another computer program, the

Hydrologic Evaluation of Landfill Performance (HELP), was developed by U.S. Army Corps of Engineers (Schroeder et al., 1984). It is a quasi-two dimensional hydrologic model for the movement of water in the landfills. This model has been widely used across the globe to estimate the leachate generation from landfills under different design conditions. HSSWDS and HELP, however, only estimate leachate quantity; they do not predict quality.

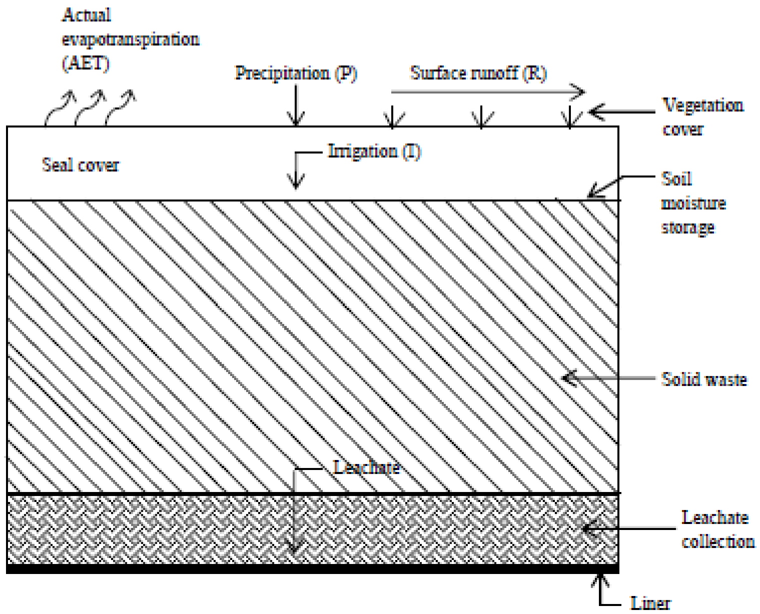


Figure 2.3 Moisture Components at a Sanitary Landfill

2.3 Factors Affecting Leachate Quality

Several researchers provided detailed literature reviews of landfill composition and observed wide variations in leachate quality (Chian and Dewalle, 1976; Chian, 1977; Lu et al, 1981, 1984, 1985). Several factors affecting leachate quality are discussed below.

2.3.1. Waste Composition

Characteristics and composition of solid waste vary widely (Reinhart & Grosh, 1998; Al-Yaqout & Hamoda, 2003). The composition of waste determines the extent of biological activity within the landfill (Chen and Bowerman, 1974). Rubbish, food and garden wastes, and crop and animal residues contribute to the organic material in leachate (Pohland and Harper, 1985). Inorganic components found in leachate come from construction and demolition wastes and ash

(Reinhart and Grosh, 1998). Many interesting facts were found while conducting this literature review on waste composition in a landfill. Komilis et al. (1999) observed that shredding of putrescible waste enhances decomposition in a landfill. Furthermore, leachate from shredded waste has significantly higher concentrations of pollutants than those from unshredded waste (Kemper and Smith 1981). Collins (1991) investigated that recycling of paper and inorganic components reduced COD leaching by 25% and iron loadings by 80% compared to unsorted waste.

Numerous reports have been published of municipal solid waste (MSW) composition. Municipal solid waste's composition is heterogeneous, reflecting the economic status and lifestyle of a community. National average MSW composition according to EPA (2010) is shown in Figure 2.4.

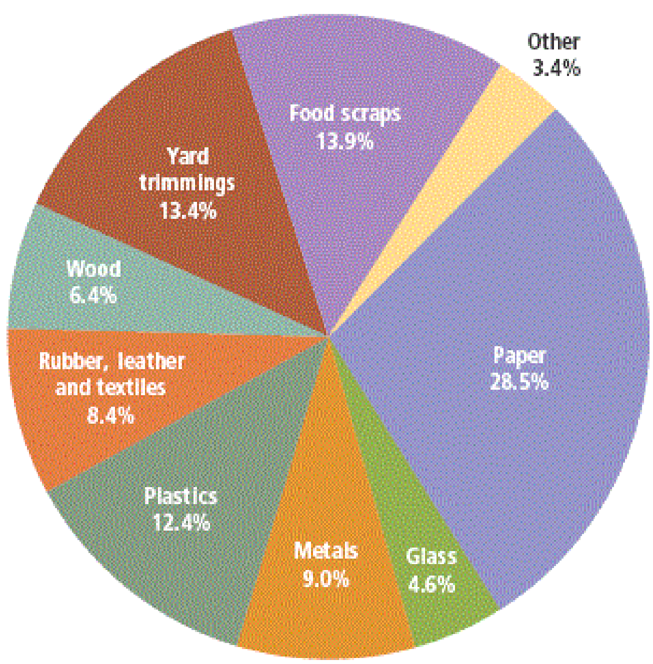


Figure 2.4 Total MSW Generation by Material Type (EPA, 2010)

2.3.2. Depth of Waste

Substantially higher concentrations of constituents are found in leachate from deeper landfills under similar conditions of precipitation and percolation (Qasim and Burchinal, 1970a, b; Qasim and Chiang, 1994). Deeper fills require a greater amount of water to reach field moisture capacity, allow a longer time for degradation, and distribute the bulk of extracted material over a longer period of time (Lu et al, 1985; Qasim and Chiang, 1994). Water entering the landfill will travel down through the solid waste. As the water percolates through the landfill, it comes in wastes contact and carries chemicals from the waste. Higher concentrations of contaminants in the leachate from deeper landfills are due to greater contact time and longer travel distance (McBean et al, 1995).

2.3.3. Moisture Content/Rainfall Rates

Moisture content is the amount of water within the waste mass. The moisture content is defined in three different ways: (a) the ratio of mass of water to the dry mass of waste, (b) the ratio of mass of water to the wet mass of the waste, or (c) the ratio of volume of water to the volume of waste (Reddy, 2006). Water is the most significant factor affecting waste stabilization and leachate quality (Reinhart & Grosh, 1998). Pohland (1975) indicated that control of moisture content is the single most vital factor in enhancing waste decomposition in landfills. Therefore, increased methanogenesis, nutrient transport, and microbial degradation are stimulated with increased moisture content of the waste. Furthermore, previous experience and research indicate that in dry areas or dry seasons, biological degradation will take longer or even cease due to lack of moisture, while in wet conditions the stabilization rate increases (Klinck & Stuart, 1999; Reinhart & Grosh, 1998; Trankler et al., 2005). Figure 2.5 shows variability in the leachate generation due to amount of rainfall. During dry seasons, leachate generation is very low due to evaporation losses whereas in rainy seasons, leachate generation is related to amount of rainfall rates. Therefore, while designing landfills for waste disposal, and developing a system for leachate treatment, the quality and quantity of leachate may be influenced by climate and microbial activity. Although high rainfall rates increase leachate production, they reduce leachate strength due to dilution.

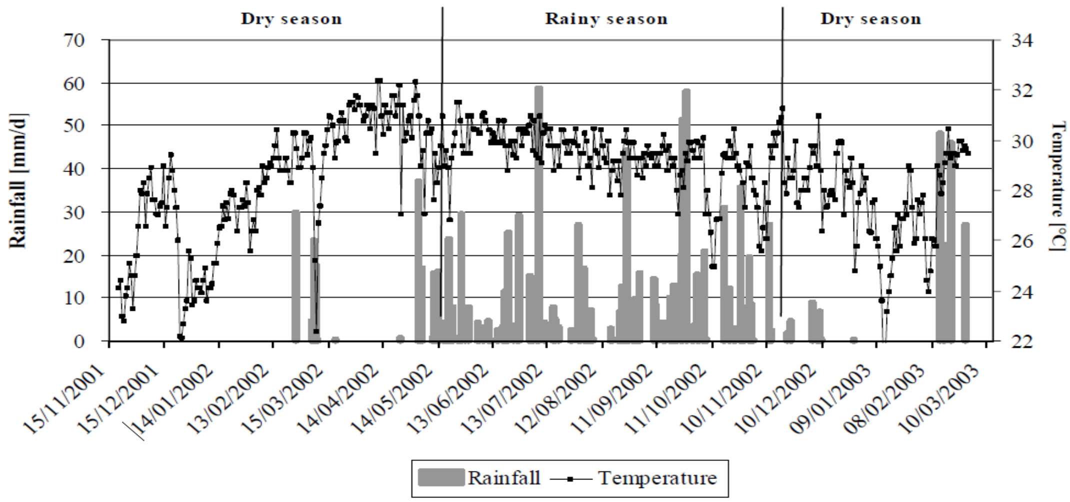


Figure 2.5 Variability in Leachate Generation due to Rainfall (Visvanathan, et al., 2003)

Recommended moisture content reported in previous studies range from a minimum of 25% to optimum levels of 40-70% (by wet basis) (Barlaz et al., 1990; Chen and Bowerman, 1974). The various ranges of moisture content values reported by various authors, as summarized by Hossain (2002), is presented below in Table 2.1.

Table 2.1 Range of Moisture Contents Reported by Various Authors (Hossain, 2002)

Authors	**Moisture Content (%)**
Sowers (1973)	10 -50
Gifford (1990)	14 -68
Landva and Clark (1990)	15 -125
Blight et al (1992)	10 -100
Huitritic (1981)	15 -40
Tchobanoglous et.al. (1993)	15 -45
Coumoulos et. al. (1995)	20 -125
Gabr and Valero (1995)	30 -130

2.3.4. Temperature

Seasonal ambient temperature variations and temperature within landfills are largely uncontrollable factors influencing leachate quality (Lu et al., 1985). Temperature affects bacterial growth and chemical reactions within landfills. The temperature range over which microorganisms have been found to survive varies from -5 to 80 °C. The anaerobic processes occur best within 30-38 °C for mesophilic and 50 to 65 °C for thermophilic organisms (Parkin and Owen, 1986).

Several researchers have studied the effect of climate on quantity and quality of leachate (Al-Yaqout and Hamoda, 2003; Eusuf et al., 2007). A study conducted by Tatsi and Zouboulis (2002) in Mediterranean climate (semi-arid) reported seasonal fluctuations in the quality and quantity of leachate produced. Furthermore, another study focused on the influence of temperature on electrical conductivity of leachate (Grellier et al., 2006). The authors concluded that the variations in electrical resistivity are linked to variations in temperature.

2.3.5. Age of Waste/Landfill

Leachate quality is significantly influenced by the length of time elapsed since waste was placed in the landfill. Generally, leachate quality reaches a peak in the beginning of landfill life (within 2-3 years) and then decreases in the remaining years (McBean et al., 1995; Lu et al., 1985). Most of the studies have observed that leachate quality improves as the waste degraded (Fan, et al., 2006; Kulikowska & Klimiuk, 2008; Lo, 1996; Pivato & Gaspari, 2006; Qasim & Chiang, 1994).

As the landfill ages, the proportion of organic components change. In the initial phase (acetogenic phase) of the landfill, the degradation of waste peaks, which causes high levels of BOD and COD. In the later methanogenic phase, most organic matter has been degraded, producing carbon dioxide (CO_2) and methane (CH_4) with low concentrations of organic matter. Due to biodegradability of organic matter, its content in leachate decreases more rapidly than inorganics with increasing age of the landfill (Chian and DeWalle, 1977). Inorganics are removed as a result of washout by infiltrating rain water (Qasim and Chiang, 1994). Organics decrease in concentrations via decomposition as well as washout.

2.3.6. Processed Waste

Leachate characteristics from shredded or baled waste can differ greatly. Leachate from shredded waste is more highly contaminated during the initial stages of waste stabilization and less contaminated during later stages than leachate from unprocessed waste (Reinhardt and Ham 1974). Many researchers conducted experiments on processed waste and reported that leachate from shredded waste has significantly higher concentrations of contaminants than unshredded waste (Kemper and Smith, 1981; Lu et. al., 1985; Qasim and Chiang, 1994). The resulting higher concentrations of leachate constituents may be due to increased surface area and consequently, increased degradation rates in shredded waste landfills (Lu et. al., 1985). Qasim and Chiang (1994) found that the time to reach field moisture capacity was delayed for shredded waste landfills, but the rate of pollutant removal, waste decomposition and cumulative mass of pollutants leached per unit volume of leachate were greatly increased compared to unshredded waste. On the contrary, Tittlebaum (1982) observed that shredding had no effect on waste degradation in laboratory-scale lysimeters.

Unlike shredding, baling of waste has shown opposite results on leachate generation and strength. Baling results in a large volume of dilute leachate with a longer stabilization time than for unbaled waste. However, once the moisture field capacity of the shredded and baled waste is reached, the cumulative mass of pollutants removal per kg of waste will be same in the long run regardless of the type of waste processing (Lu et al., 1985).

2.4 Leachate Composition

Landfills are considered to be heterogeneous systems due to the broad spectrum of solid waste characteristics. As a result, leachate composition will vary tremendously. The variation in leachate composition is more usefully expressed in terms of trends and ranges of leachate parameters (factors), rather than mean values, which are not meaningful if standalone (Lema et al., 1988). Major factors which directly affect leachate composition include the composition of the waste and degree of compaction, climate, site hydrogeology, seasons, and age of the landfill (Lema et al., 1988).

2.4.1. Phases of Waste Stabilization

Once the waste is buried in a landfill, a complex series of biological and chemical reactions occur as the waste decomposes. Numerous studies based on field and laboratory-scale data have been suggested that the stabilization of waste proceeds in four or five sequential and distinct phases (Pohland and Harper, 1985; Barlaz et al., 1990; Reinhart and Al-Yousfi, 1996).

A generalized reaction for anaerobic degradation can be written as:

$$C_xH_yO_z + \frac{4x-y-2z}{4H_2O} \rightarrow \frac{4x-y+2z}{8CO_2} + \frac{4x+y-2z}{8CH_4}$$

The waste degradation phases are discussed below. Since landfills have various sections, a landfill will experience many phases of waste stabilization simultaneously rather than a single phase of stabilization. Figure 2.6 illustrates the five phases of waste stabilization.

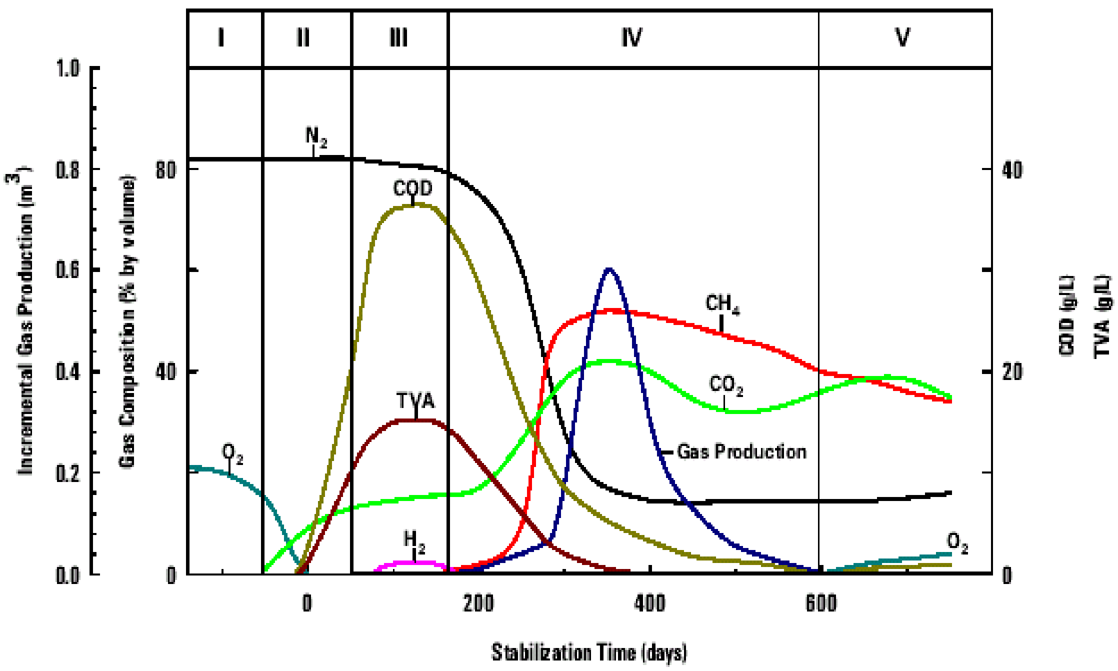


Figure 2.6 Phases of MSW Degradation in a Typical Landfill (WMI, 2000)

2.4.1.1 Phase 1 - Initial Adjustment Phase

In this phase preliminary changes in the environmental components occur to create favorable conditions for the biochemical degradation. During this initial aerobic phase, oxygen present in the void spaces of the freshly buried waste is rapidly consumed, resulting in the production of CO_2 and H_2O. This partial degradation of organics produces considerable heat (McBean et al., 1995). The aerobic phase in a landfill lasts only for a few days, as oxygen is not replenished once the waste is covered. The waste is not typically at the field moisture capacity in this phase (Barlaz and Ham, 1993). Most leachate generated during this phase is a result of moisture squeezed out of the waste during compaction and cell construction (Lu et al., 1985).

Leachate formation in this phase is characterized by the entrainment of particulate matter, dissolution of highly soluble salts, and the presence of relatively small amounts of organic species from aerobic decomposition (Lu et al., 1985; McBean et al., 1995).

2.4.1.2 Phase 2 – Transition Phase

In the transition phase, the field moisture capacity is often exceeded, and a transformation from an aerobic to an anaerobic environment takes place, as evidenced by the depletion of oxygen trapped within the landfill media. Cellulose and hemicellulose comprise 45 to 60% of the dry weight of MSW and are major biodegradable components (Barlaz et al., 1990; Pohland and Harper, 1986; Bookter and Ham, 1982). Cellulose and hemicellulose biodegradation is carried out by three groups of bacteria: (1) hydrolytic and fermentative bacteria that hydrolyze polymers and ferment the resulting monosaccharides to carboxylic acids and alcohols; (2) the acetogenic bacteria that convert acids and alcohols to acetate, hydrogen, and carbon dioxide; and (3) the methanogens that convert the end products of the acetogenic reactions to methane and carbon dioxide (Zehnder, 1982). This process occurs efficiently over a narrow pH range around neutral. A trend toward reducing conditions is established in accordance with shifting of electron acceptors from oxygen to nitrates and sulfates, and the displacement of oxygen by carbon dioxide. By the end of this phase, measurable concentrations of chemical oxygen demand (COD) and volatile organics can be detected in the leachate.

2.4.1.3 Phase 3 – Acid Formation Phase

During this phase, the hydrolytic, fermentative, and acetogenic bacteria dominate, resulting in an accumulation of carboxylic acids, and a pH decrease. Due to acidic pH, the leachate is chemically aggressive and will increase the solubility of many compounds. The highest BOD and COD concentrations in the leachate are observed during this acidic phase (Barlaz and Ham, 1993; Reinhart and Grosh, 1998). The BOD:COD ratio in this phase has been reported to be above 0.4 (Ehrig, 1988) or 0.7 (Robinson, 1995).

2.4.1.4 Phase 4 - Methane Fermentation Phase

In this phase, measurable quantities of methane are produced. In landfills, the methane fermentation phase occurs somewhere between 4 to 10 years after waste is buried and may continue over a period of several years (Krug and Ham, 1995). During this phase, the acids that accumulated in the acid phase are converted to methane and carbon dioxide by methanogenic bacteria, and the methane production rate will increase (Christensen and Kjeldsen, 1989; Barlaz et al., 1989a). BOD and COD concentrations begin to decline and pH increases as acids are consumed (McBean et al., 1995). The elevated pH is controlled by the bicarbonate buffer system, which consequently supports the growth of methanogenic bacteria. Cellulose and hemicellulose decomposition also begins in this phase; however, lignin type aromatic compounds of organic content are not degraded anaerobically and remain in the landfill.

2.4.1.5 Phase 5 - Maturation Phase

During this final stage of stabilization, nutrients and available substrate become limiting and the biological activity shifts to relative latency. The rate of methane production decreases significantly but the methane and carbon dioxide concentrations remain the same as the previous phase, 60% and 40%, respectively. Leachate strength remains steady at much lower concentrations. Oxygen and oxidized species may reappear slowly. Some COD is present in the leachate, but it is mostly recalcitrant compounds such as humic and fulvic acids (Barlaz and Ham, 1993; Christensen et al., 1994). The BOD:COD ratio will fall below 0.1 in this phase as carboxylic acids are consumed rapidly.

2.4.2 Organic Compounds

BOD and COD are the most common parameters to measure the organic matter in leachate. Various researchers have provided BOD and COD ranges over time. Chian and DeWalle (1977) found that organic matter in leachate range from small volatile acids to refractory fulvic and humic-like compounds. They reported COD and BOD values in the range of 31.1 to 71,680 mg/l and 3.9 to 57,000 mg/l, respectively (Chian and DeWalle, 1976). Ehring

(1989) provided a BOD range between 20 to 40,000 mg/l. BOD and COD concentrations decrease over time.

Organic contaminants in leachate are primarily soluble waste components or decomposition products of biodegradable fractions of waste. The class of organic compounds found at highest concentrations in leachates is generally volatile fatty acids (e.g. acetic, butyric, valeric, propionic) produced during the decomposition of proteins, lipids, and carbohydrates (Albaiges et al., 1986; Schultz and Kjeldsen, 1986). The dominant organic class in leachate shifts as the waste age increases due to continuous microbial and physical/chemical processes within the landfill.

Table 2.2 presents the ranges of general leachate parameters from various reports (Kjeldsen et al., 2002). The data in this table is from newer landfills. The ranges are based on Andreottola and Cannas (1992), Chu et al.(1994), Robinson (1995), Ehrig (1980), Ehrig (1983), Ehrig (1988), Garland and Mosher (1975), Johansen and Carlson (1976), Karstensen (1989), Krug and Ham(1997), Lu et al. (1985), Naturvårdsverket (1989), Owen and Manning (1997), and Robinson and Maris (1979).

Table 2.2 Composition of Landfill Leachate (Kjeldsen et al., 2002)

Parameter	**Range (mg/l)**
pH	4.5-9
Spec. Cond. (μS cm-1)	25,00-35,000
Total Solids	2000-60,000
Heavy Metals	
Arsenic	0.01-1
Cadmium	0.0001-0.4
Chromium	0.02-1.5
Cobalt	0.005-1.5
Copper	0.005-10
Lead	0.001-5
Mercury	0.00005-0.16
Nickel	0.015-13
Zinc	0.03-1000
Inorganic Macrocomponents	
Total phosphorous	0.1-23
Chloride	150-4500
Sulphate	8-7750
Carbonic acid	610-7320
Sodium	70-7700

Table 2.2 – *Continued*

Potassium	50-3700
Ammonium-N	50-2200
Calcium	10-7200
Magnesium	30-15,000
Iron	3-5500
Manganese	0.03-1400
Silica	4-70*
Organic Matter	
Total Organic Carbon (TOC)	30-29,000
Biological Oxygen Demand (BOD)	20-57,000
Chemical Oxygen Demand (COD)	140-152,000
BOD5/COD (ratio)	0.02-0.80
Organic nitrogen	14-2500

* Values based on Owen and Manning (1997)

Chian and DeWalle (1977) found that many ratios of chemical properties, such as BOD/COD, COD/TOC, reflect the composition of organic matter present in leachate and are in turn related to the landfill age. BOD to COD ratio, an indicator of the proportion of biologically degradable organic matter to total organic matter, decreases as the landfill ages and more degraded constituents are removed from deposited residues (Copa et al., 1995; Westlake, 1995). Furthermore, various researchers (Reinhart and Al-Yousfi, 1996; Reinhart and Townsend, 1998; Kjeldsen et al.; 2002; Kulikowska and Klimiuk, 2008) suggest that BOD/COD ratio is higher (> 0.4) during the acid forming phase, and this ratio decreases below 0.1 during the methane fermentation phase, indicating heavily decomposed waste. Table 2.3 represents organic ratios and ammonia concentrations in landfills leachate at different ages from various studies (Pawłowska and Pawlowski, 2008).

Table 2.3 Organic Ratios and Ammonia Concentrations in Landfill Leachate at Different Ages

Landfill Age (years)	COD (mg/l)	BOD/COD	NNH4 (mg/l)	NNH4/COD	References
<5	5028	0.6	76	0.015	Robinson & Maris, 1983
	13,780	0.7	42	0.003	Henry et al., 1987
	5400	0.65	158	0.029	Robinson & Grantham, 1988
	58,400	0.69	1720	0.029	Chang, 1989
	17,350	0.47	1692	0.098	Avezzu et al., 1992
	38,000	0.22	2109	0.06	Szpadt, 1995
	4100-5000	0.2	2100-3000	-	Chiang et al., 1995
	204-3641	0.05-0.79	29-2505	0.016-0.73	Chen, 1996
	14,900	0.46	280	0.19	Timur & Ozturk, 1997
	16,200-20,000	-	1120-2500	-	Timur & Ozturk, 1999
	41,507	0.79	1896	0.046	Kang et al., 2002
	1188-1596	-	100-189	-	Klimiuk & Kulikowska, 2005
5-10	3750	0.29	36	0.0096	Henry et al., 1987
	3100	0.25	641	0.21	Avezzu et al., 1992
	2150	0.1	790	0.37	Trebouet et al., 2001[1]
	5348	0.5	1826	0.34	Kang et al. 2002
	757	0.14	362	0.48	Kulikowska & Klimiuk, 2004
	2483	0.06	n.r.	-	Fan et al., 2006
	875	0.23	657	0.75	Koe-Jurezyk, 2006
10-20	1870	0.49	10	0.0053	Henry et al., 1987
	4140	0.46	998	0.24	Avezzu et al., 1992
	6610-30,000	0.17-0.38	1500-11,000	0.1-0.85	Lo, 1996
	550	0.03	390	0.71	Trebouet et al., 2001[2]
	685-15,000	-	39-1750	-	Tatsi & Zouboulis, 2002
	1367	0.11	892	0.65	Kang et al., 2002
	590-1180	0.31-0.44	71-260	0.12-0.22	Marttinen et al., 2006
	7622-8000*	0.07-0.09	2390-2620	-	Kurniawan et al., 2006
	3038	0.06	n.r.	-	Fan et al., 2006
>20	1000	0.1	340	0.34	Knox, 1985
	800-1300	-	460-600	-	Welander et al., 1997
	190-2800	0.07-0.46	53-210	0.07-0.37	Marttinen et al., 2003

n.r. – No Results
1 – Intermediary leachate
2 – Stabilized leachate

2.4.3 Inorganic Macrocomponents

The concentrations of some inorganics macrocomponents depend on the stabilization of landfill. In the methanogenic phase, the concentrations of cations such as calcium, magnesium, iron, and manganese are lower due to higher pH, which enhances sorption and precipitation. However, macrocomponents such as chloride, sodium, and potassium, the effects of sorption and precipitation are negligible.

Chloride is a non-degradable, inorganic macrocomponent and the change of its concentration is commonly used to assess the variation in leachate dilution. Kulikowska and Klimiuk (2007) observed no difference in chloride and other ions as a function of landfill age. They reported that fluctuation in concentrations of chloride and other ions depend on season of the year, rather than landfill age. Furthermore, Tatsi et al. (2002) noticed slight variations in chloride concentrations, contrary to other studies where chloride concentrations were found to increase with increasing landfill age (Chu et al., 1994). Various studies (Ehrig and Scheelhaase, 1993; Adnreottola and Cannas, 1992; Bilgili et al., 2006) suggested no observable difference in chloride concentration between acidogenic and methanogenic phases. Decreasing trends in concentration with time of these pollutants might be due to wash out effect, although Ehrig (1983, 1988) observed no decrease in concentration for these parameters even up to 20 years of leaching.

2.4.4 Nutrients

Most of the nitrogen in solid waste bioreactor landfills is in the form of ammonia. Ammonia concentrations between 50 to 200 mg/l have been shown to be beneficial to anaerobic reactions. Ammonia concentrations between 200 to 1000 mg/l have been shown to have no adverse effects on anaerobic processes, while concentrations ranging from 1500 to 3000 mg/l have been shown to have inhibitory effects at higher pH levels. Concentrations above 3000 mg/l were toxic to microorganisms (Pohland et al., 1992). Ammonia is produced from the degradation of proteins and amino acids (Kjeldsen, 2002; Tatsi and Zouboulis, 2002; Crawford and Smith, 1985), and no decreasing trend in the concentration is observed with time.

Hence, several researchers have identified ammonia as the most substantial component of leachate for the long term (Robinson, 1995; Krumpelbeck and Ehrig, 1999; Christensen et al., 1994; Christensen et al., 1999), as there is no mechanism for its degradation in anaerobic landfills. Unlike ammonia, phosphate levels remain generally low throughout the life of the landfill. During later stages of waste stabilization, phosphorous may be limiting (Pohland and Harper, 1985).

2.5 Effects of Leachate on Liner System

Due to the chemical strength of the leachate, bottom liners can be adversely affected by continued contact with the high strength leachate. In efforts to protect ground water and surrounding surface water and soils, the EPA is requiring increased and diversified liner systems for solid waste landfills. The performance requirements for a membrane liner include low permeability, chemical compatibility, mechanical strength and durability. Common types of membranes are chlorinated polyethylene (CPE), chlorosulfonated polyethylene (CSPE), low density polyethylene (LDPE), high density polyethylene (HDPE) and polyvinyl chloride (PVC) (Bagchi, 1990).

Although the high molecular weights of synthetic liners make them highly resistant to biodegradation, organic liquids can cause swelling of the polymers and changes its properties (Mitchell et. al., 1995). In a study conducted by Emcon Associates (1983), low density polyethylene exposed to full strength leachate appeared unaffected for nine years. However, when polyethylene is exposed to chlorinated solvents, it exhibited high permeability (McBean et. al., 1995). The high leachate head would also significantly affect the stability of the liner system (Blight, 2008; Chen et al., 2010b).

Leachate can also affect the integrity of natural liner systems. Quigley and Rowe (1986) studied the impacts landfill leachate on barrier systems. The barrier consisted of in-situ grey clay to a depth of around 30 m, and the landfill was in operation for 15 years prior to the investigation. Concentrations were measured as high as 2000 mg/l and 2890 mg/l for chloride and sodium, respectively. Chloride concentrations in excess of 1000 mg/l are common in MSW leachate but sodium concentrations greater than 2500 mg/l are not. It was believed that sodium was released from the clay, exchanged with other cationic species in the leachate (Farquhar and Parker, 1989).

2.6 Leachate Treatment

The strength and quantity of leachate directly affects viable leachate treatment alternatives. Leachate quality differs from landfill to landfill and over time as a particular landfill ages. As a result, neither conventional biological waste treatment nor physical/chemical treatment processes separately achieve high removal efficiency of the pollutants (Forgie, 1988; Copa et al., 1995).

Leachate treatment depends on the quality and quantity of the leachate, degree of treatment required, ultimate disposal methods of effluent and residues. Many nontechnical factors, such as legal issues, regulatory constraints and public participation may also influence the planning and design of leachate treatment.

However, high ammonia concentrations and the typical phosphorus deficiency in landfill leachate can inhibit biological treatment efficiencies. Therefore, a general consensus among researchers is to remove high nitrogen levels prior to discharge which are still hazardous to receiving waters. To adjust the level of these constituents, biological nitrification-denitrification processes for young leachate and thorough physical-chemical processes for stabilized landfill leachate are frequently employed.

Various wastewater treatment processes have been generally used to treat landfill leachate for decades (Amokrane et al., 1997). The major biological treatment processes include activated sludge (AS), sequencing batch reactors (SBR), rotating biological contactors (RBC); physical and chemical treatment processes include floatation, oxidation, coagulation-flocculation, chemical precipitation, activated carbon absorption and membrane processes such as microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO). Renou et al. (2008) provided a comprehensive report on landfill leachate treatment. The authors provided some results of the treatment process performances also discussed the advantages and drawbacks of the various treatments options. They concluded that the use of membrane technologies, especially reverse osmosis (RO), can act a main step in the treatment chain or as single post-treatment step to achieve purification.

2.7 Rationale for Leachate Parameters Chosen

Environmental engineers measure dozens of water quality parameters in different situations. For this research, the leachate parameters to be measured had to be chosen. The parameters were chosen based on following four criteria:

1. Importance of measuring
2. Ability to measure in the Civil Engineering Department
3. Time required to measure
4. Cost of measuring

Table 2.4 provides information concerning these criteria for potential leachate quality parameters to be measured. The "Overall Importance of Measuring" reflects a judgment based on a parameter's importance in terms of water/wastewater quality, and it's listing as a primary or secondary. EPA recommended bioreactor landfill leachate monitoring parameter (EPA/600/R-04/301, December 2004). A similar list for traditional landfills unfortunately does not exist. The overall decision to measure certain leachate parameters, listed in the right-hand most column, reflects a judgment that balances the 4 criteria listed above.

Table 2.4 Decision Matrix for Leachate Parameters

Leachate Parameters	**Importance in terms of Water/Wastewater Quality**	**EPA Primary Bioreactor Leachate Monitoring Parameter**	**EPA Secondary Bioreactor Leachate Monitoring Parameter**	**Overall Importance of Measuring**	**Method of measure-ment**	**Ability to measure in Civil Dept.**	**Approximate Time required for measurement of 3-4 reactors sample**	**Cost of measure-ment**	**Overall decision for Measuring Leachate Parameter**
Biochemical Oxygen Demand (BOD)	Determines amount of oxygen microbes require to oxidize organic matter. Higher BOD means higher oxygen depletion potential of the receiving water body, which can harm aquatic organisms.	Yes		High	Standard Method 5210 B	Yes	3-4 hrs	Low	Yes
Chemical Oxygen Demand (COD)	Determines amount of organic and inorganic matters present in water. BOD/COD ratio is important to signify the decomposition of waste with time.	Yes		High	Standard Method 5220 C	Yes	3 hrs	Low	Yes
Total Organic Carbon (TOC)	Determines total amount of carbon in the water.	Yes		High	Standard Method 5310 B & C	Yes, however availability to use the TOC instrument was low		High	No
Total Alkalinity as $CaCO_3$	Determines acid-neutralizing capacity of water and useful to a great extent in wastewater treatment plant operations.	Yes		High	Standard Method 2320 B	Yes	1 hr	Low	Yes

Table 2.4 – *Continued*

pH	Determines hydrogen ions concentration in the sample. Practically, every phase of water and wastewater treatment, e.g. water softening, precipitation, coagulation, disinfection, is pH dependent.	Yes		High	Probe	Yes	5 min	Low	Yes
Conductivity	Determines an ability of liquid to carry an electric current. Indirect measurement of total ions.	Yes		High	Probe	Yes			Yes
Chloride	Major inorganic anions in water systems. Chloride content of water is important for irrigation of agricultural crops.	Yes		High	Probe	Yes	0.5 hr	Low	Yes
Bromide	Bromine can be used as a disinfectant in drinking water treatment. However, it is not one of the major constituent in landfill leachate.	Yes		Low	N/A	Yes	Depends on method selection	Low	No
Floride	It is not an important inorganic macrcomponent for leachate; however, for drinking water optimum level should be there to avoid dental fluorosis.	Yes		Low	N/A	Yes		Low	No
Sulfate	Amount of sulfate in wastewater is of concern in determining the magnitude of problems that can arise from reduction of sulfates to hydrogen sulfide in anaerobic digestion, which is evolved with methane and carbon dioxide.	Yes		low	N/A	Yes		Low	No
Total Phosphorous	Important for growth of microorganisms. Ortho-Phosphate is inorganic compound.	Yes		High	N/A	Yes	Depends on method selection	Medium-High	No
Ortho Phosphate		Yes		High	N/A	Yes			No

Table 2.4 – *Continued*

Total Volatile Fatty Acid (TVFA)	Determines the acidic accumulation phase of waste degradation process.	No	Yes	High	GC-MS	No	5-6 hrs/6 samples	High	No
Total Dissolved Solids (TDS)	Solids determination is important for the operation of water and wastewater treatment plant. It determines the strength of the effluent liquid.	Yes		High	Probe	Yes	2 min	Low	Yes
Volatile Suspended Solids (VSS)		No		High	Standard Method 2540 E	Yes	4 hrs	Medium	Yes
Total Suspended Solids (TSS)		No		High	Standard Method 2540 D	Yes			Yes
Ammonia-Nitrogen	Important for growth of microorganisms.	Yes		High	Probe	Yes	1 hr	Low	Yes
Nitrite	In water/wastewater the nitrogen is present in form of nitrate, nitrite, ammonia, and organic nitrogen. However, in landfill leachate nitrogen is mainly present in ammonia form. Also, in anaerobic environment these constituents are not present after maturation.	Yes		Low	N/A	Yes	Depends on method selection	Medium-High	No
Nitrate		Yes		low	N/A	Yes			No

2.8 Statistical Modeling for Predicting Leachate Parameters

Multivariate Adaptive Regression Splines (MARS) statistical approach has not been yet applied in the solid waste management field. Results of previous studies of correlations within one or several leachates have been presented in correlation matrixes (Fatta et. al., 1998; Go´mez Martı´n et al., 1995a,b; Ettala et al., 1988). However, the application of such matrixes limits the use of the results without any statistical models. Contradictions between the results of the various studies are also observed, indicating that each landfill produces unique leachate characteristics. Other statistical techniques have been used on a few occasions to categorize leachates based on landfill site (Go´mez Martı´n et al., 1995b) or degradation phase (Andreas et al., 1999). However, none of these studies have focused on the possibilities of predicting leachate quality.

MARS is the modern nonparametric regression analysis method used in many studies (Walker 1990; Moore et al., 1991; White and Sifneos, 1997). MARS enables to rapidly search through all possible models and to quickly identify the optimal model. It builds models by fitting piecewise linear regressions; meaning, the nonlinearity of a model is approximated through the use of separate regression slopes (MARS User Guide, 2001). Hence, MARS has the potential to be a useful statistical approach for predicting leachate characteristics.

CHAPTER 3

MATERIALS AND METHODS

3.1 Introduction

This chapter discusses the experimental design, solid waste collection and sample preparation, reactor building and setup procedure, reactor monitoring, and procedures to measure leachate parameters: biochemical oxygen demand (BOD), chemical oxygen demand (COD), total alkalinity as $CaCO_3$, pH, conductivity, total dissolved solids (TDS), total suspended solids (TSS), volatile suspended solid (VSS), ammonia-nitrogen (NH_3-N), and chloride (Cl^-) from total 27 simulated laboratory-scale landfills operated in an anaerobic environment. The reactors were operated to simulate 3 different rainfall rates of 2 mm/day, 6 mm/day, and 12 mm/day; along with 3 different temperatures of 70 °F, 85 °F, and 100 °F.

3.2 Design of Experiment

The basic step for an experimenter or scientist to obtain a mathematical model in order to predict future responses is to design an experiment. In designing the experiment to study various leachate parameters, the analysis that would be performed was taken into consideration. The efficiency of the data analysis depends upon the particular experimental design that is used to collect the data. The three basic techniques fundamental to experimental design are replications, blocking, and randomization. The first two techniques help to increase precision in an experiment and the last is useful to minimize biases.

3.2.1 Rainfall Rates

Rainfall rates of 2, 6, and 12 mm/day were used, corresponding to 60, 180, and 360 mm/month. These rates encompasses monthly precipitation rates for most developing countries in Central America, South America, Africa (with the exception of the Sahara countries), and the

Far East (India, China, Thailand, and Indonesia), as shown in Figure 3.1. Although testing a larger number of rainfall rates would better characterize leachate variation with rainfall, the time involved in measuring leachate parameters for each reactor is extensive; thus, an effort was made to limit the overall number of reactors. Moreover, constant temperature room space was limited. Leachate accumulating at the bottom of the reactors was removed daily and characterized, as discussed later.

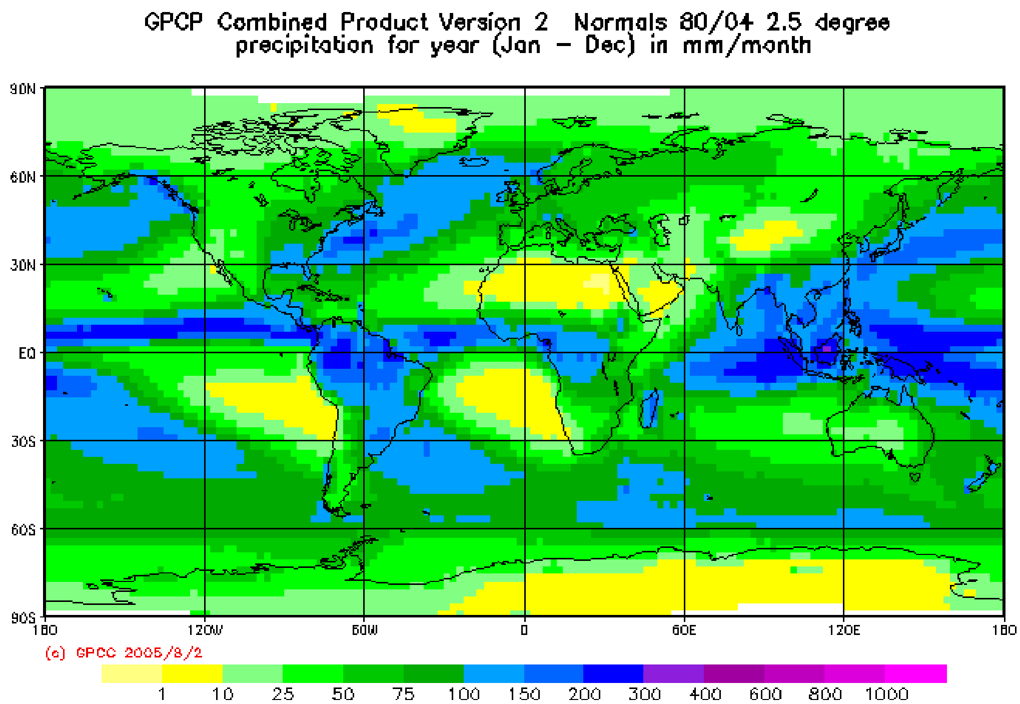


Figure 3.1 Mean Annual Global Precipitation
(Source: http://www.physicalgeography.net/fundamentals/8g.html)

3.2.2 Temperature

To determine leachate composition variation with temperature, reactors were placed at 3 temperatures, 70 °F, 85 °F, and 100 °F, as representative ambient temperatures. Annual mean temperatures for most of South America, Central America, Africa, India, and Indonesia range from 68 °F to 86 °F. Average monthly summer temperatures in these areas can range up to 95 °F. Reactors were placed in constant temperature rooms at 85 °F and 100 °F. Reactors left open in the lab room were maintained at approximately 70 °F.

3.2.3 Waste Composition

Solid waste components considered for this study were highly biodegradable wastes: food, paper, yard, and textile (Weitz et al., 2002), as well as inert inorganic waste. Although inorganic waste is not biodegradable, it may interfere with microbial access to organics, which can impact the waste degradation; hence, it was considered as a variable in the design.

3.2.4 Experimental Design

A cyclic incomplete block design was used for the experimental setup (Dean and Voss, 1999). This design enabled us to keep the number of reactors to a minimum due to the time involved in measuring leachate parameters and limited space in the constant temperature rooms. Five types of waste, food, paper, yard, textile and inorganic; were considered for this study. The specific combined waste cases were determined by a mixture design such that each biodegradable waste component (food, paper, yard, and textile) could range from 0-100% except inorganic waste, which ranged from 0-40%, since it does not have a potential to degrade (Mason et al., 1989). However, inorganic wastes were included in the experimental design to see if there was any interaction between different refuse components. These combined waste cases served as blocking variable levels for a balanced incomplete block design, such as a Latin hypercube, to study the primary factors, temperature and rainfall (Chen et al., 2006).

Table 3.1 summarizes the 9 waste compositions used in the experimental design as discussed above.

Table 3.1 Component Percent by Weight for Each Waste Combination

Component	**Component % by Weight for each Waste Combination**								
	a	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**
Food	100	0	0	0	0	60	30	10	20
Paper	0	100	0	0	60	0	10	30	20
Textile	0	0	100	0	0	30	0	60	20
Yard	0	0	0	100	0	10	60	0	20
Inorganic	0	0	0	0	40	0	0	0	20

Table 3.2 exhibits the matrix with treatments and block combinations used in the experimental design for setting up each lab-scale landfill reactors. For example, Reactor 4 was operated with 2 mm/day rainfall at a temperature of 85 °F, and contains waste component combination a, which according to Table 3.1 is 100% food waste.

Table 3.2 Rainfall, Temperature, and Waste Component Combinations for the Lab-Scale Landfill Reactors

Rainfall (mm/day)	**Temperature (ºF)**	**Waste Component Combination**								
		a	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**
2	**70**		1					2		3
2	**85**	4		5					6	
2	**100**		7		8					9
6	**70**	10*		11*		12				
6	**85**		13		14		15			
6	**100**			16		17		18		
12	**70**				19		20		21	
12	**85**					22		23		24
12	**100**	25					26		27	

Note: Each blue number denotes a number of the lab-scale landfill reactor.
*reactors failed due to excessive acid accumulation and excessive washout.

3.3 Fresh Solid Waste Collection

Wastes were collected from individual places to represent pure and non-degraded waste. Food waste was collected from UTA's cafeteria and dining hall; a mixture of grass, leaves, and tree/brush trimmings were obtained from UTA's composting facility to represent yard waste; textiles wastes were obtained from local tailors' shops; paper wastes were obtained from UTA recycling bins (office paper), researcher's personal recycling bins (newspapers, mail, magazines, tissues and towels, diapers), and local restaurants and grocery stores (corrugated boxes and cartons). Paper waste components were mixed together to represent the percentages found in the United States (EPA, 2007). Inorganics such as plastic bottles and aluminum cans were collected from UTA's recycling bins, and construction and demolition (C & D) wastes were collected from UTA's structural testing laboratory at the Civil Engineering Laboratory Building (CELB). Food and yard wastes were kept in a cold room at 4°C until use to avoid any possible degradation.

3.3.1 Solid Waste Samples Preparation

Various combinations of solid waste components were prepared by weight percentage according to the experimental design discussed previously. Large pieces of textile and paper wastes were cut into pieces to accommodate in the reactor. However, these wastes were not finely shredded to represent the actual landfilled waste. The collected waste was placed on a floor and mixed thoroughly. Anaerobic digested sludge obtained from Village Creek Wastewater Treatment Plant, was added as a seed to each reactor to achieve 15-20% by weight. The seed was added to initiate the degradation process of the waste. After proper mixing, the waste was placed in the reactor which had passed the leak test and connections were made to a leachate bag and gas bag. Figure 3.2 below shows the mixed waste components.

Figure 3.2 Mixed Waste Components

3.4 Reactor Building Process

A total of 27 – 6 gallon (16 liter) size wide mouth plastic reactors (U.S. Plastic Corp.) were built to simulate lab-scale landfills. Most previous lab studies have used 2-L reactors; we chose 16-L to avoid shredding the waste, which would increase degradation rates. These plastic reactors were filled with various proportions and types of waste and were operated at different rainfall rate and temperature combinations as discussed in the experimental design section.

Before filling the reactors with solid wastes, all reactors were leak-checked. Leak tests were conducted using a simple U-tube manometer after proper sealing of reactors as displayed in Figure 3.3. To verify that there was no significant leakage, reactors were monitored for 1-2 days. The head difference at 12 and 48 hours was recorded to confirm that it was within permissible limits of 0.5 to 3 inches H_2O, respectively (Haque, 2007). Once reactors were leak-tested, their empty weight was measured.

Reactors were then filled with waste components, as described in the experimental design section. Anaerobic digested sewage sludge was used as seed to initiate the active decomposition of solid waste. Seed obtained from continuously-stirred anaerobic sludge digester operated at a hydraulic loading rate of 19 days at 20 °C, was added to each reactor to achieve 15-20 % by weight. Sufficient quantity of moisture required to bring the waste to the optimum moisture content was calculated based on the initial moisture content on a dry weight basis. Each type of waste (food, paper, textile, yard, and inorganics) has different moisture absorbance capacity. Hence, amount of tap water required for each waste component to reach saturation limit was calculated (Stone and Kahle, 1972). Each reactor’s final weight was measured after adding wastes and placed in one of the constant temperature locations (see Experimental Design section). After placing each reactor, it was connected to a leachate collection bag (2-L Kendall-KenGuard Drainage Bag) and gas collection bag (22-L Cali 5-Bond Bag, Calibrated Instruments, Inc.), as shown in Figure 3.4.

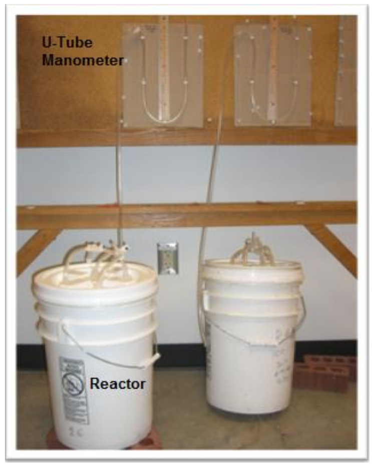
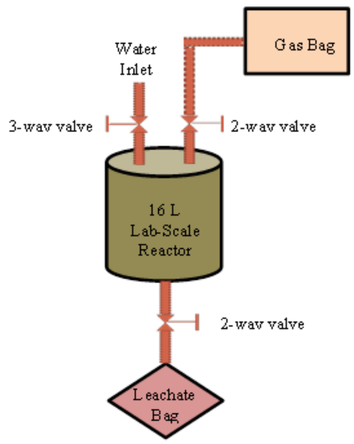


Figure 3.3 Leak Testing of Reactors



(a)

(b) (c)

Figure 3.4 Laboratory Scale Reactor Setup (a) Schematic, and (b) & (c) Reactors in Constant Temperature Room at 100 °F & 70 °F respectively.

3.5 Reactor Monitoring

The reactors were monitored on a daily basis. First the quantity of leachate generation and leachate pH were measured and recorded for each reactor daily, and then the fixed amount of tap water as discussed in the experimental design section was added to each reactor to simulate the rainfall. The step by step process followed in leachate volume measurement, pH measurement and water addition is displayed in Figure 3.5.

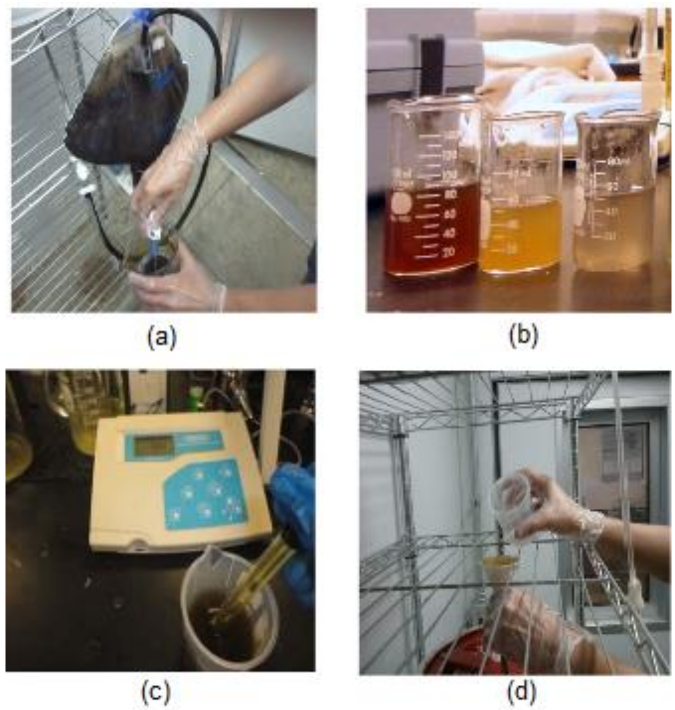


Figure 3.5 Reactor Monitoring Process: (a) Emptying Leachate Bag, (b) Measuring Leachate Volume, (c) Measuring Leachate pH, and (d) Water Addition

3.6 Leachate Parameter Measurements

Leachate samples from the 27 reactors were collected on a regular and analyzed promptly. Leachate parameters were measured on a weekly, biweekly, and monthly basis for 100 °F, 85 °F and 70 °F reactors, respectively. Reactors at high temperature tend to degrade faster than the lower temperature reactors, hence leachate quality for high temperature reactors vary faster than low temperature reactors. However, leachate parameters for reactors having 2 mm/day (100 ml/day) rainfall were measured on average every 20 to 30 days, as these reactors did not generate enough leachate volume in a day to measure leachate parameters, so leachate was accumulated over time until the required leachate volume was generated. The leachate parameters included in the study were: pH, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), total alkalinity as $CaCO_3$, conductivity, Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Volatile Suspended Solids (VSS) chloride ions (Cl^-), and ammonia-nitrogen (NH_3-N). Each of these leachate parameter measurements are discussed here. The methods used to measure these parameters are summarized in Table 3.3.

Table 3.3 Methods for Leachate Parameters Measurements

Leachate Parameters	**Methods**
Biochemical Oxygen Demand-5 (BOD)	Standard Method 5210 B
Chemical Oxygen Demand (COD)	Standard Method 5220 C
Total Alkalinity as $CaCO_3$	Standard Method 2320 B
Total Suspended Solids (TSS)	Standard Method 2540 D
Volatile Suspended Solids (VSS)	Standard Method 2540 E
pH, Conductivity and Total Dissolved Solids (TDS), Ammonia-Nitrogen (NH_3-N)	IntelliCAL probes from Hach
Chloride Ions (Cl^-)	SensION+ ISE probe from Hach

3.6.1 pH

pH is one of the most vital environmental factors for any system. It is a way of expressing the hydrogen-ion concentration, or precisely the hydrogen-ion activity. For this study, the pH of the leachate samples was immediately measured using a pH probe (IntelliCAL, Hach) on daily basis. In anaerobic environments, metabolism is limited due to the limited number of hydrogen acceptors. In the anaerobic acid (second) phase of anaerobic waste decomposition, the hydrolytic, fermentative, and acetogenic bacteria dominate, resulting in an accumulation of carboxylic acids, and a pH decrease. However, after the onset of initial methanogenic (third) phase, pH increases as carboxylic acids are consumed. In the final stable methanogenic (fourth) phase, pH continues to increase and then stabilizes. The pH is thus a very good indication of waste degradation phases.

3.6.2 Biochemical Oxygen Demand (BOD)

The BOD was determined in accordance with the Standard Methods 5210 B. BOD is a measurement of the oxygen necessary for the biochemical removal of readily oxidizable substances over 5-day incubation at 20 °C which is known as 5-day BOD. Towards end of this research, it was discovered that the samples were incubated for four days instead of five days unintentionally. It was late to correct the incubation time to five days. Hence, to be consistent remaining samples were analyzed for four days incubation. Later, two samples from R-4 and R-20 were selected randomly to measure the difference between 4-day and 5-day BOD. The percent difference between BOD_4 and BOD_5 ranged from 3.6% to 7.2% for these reactors.

Additionally, BOD is not a precise quantitative test, although it is widely used as an indication of the organic quality of water. The BOD exerted during 5-day incubation is approximately 68%. The complete oxidization requires 20-day incubation period, which is practically not possible most of the time.

The leachate samples for most of the reactors were initially diluted as the leachate samples exceeded the concentration of dissolved oxygen (DO) available in an air-saturated sample. However, once the degradation of waste was stable then no dilution was required. To begin the BOD test, a desired amount of dilution water was prepared adding 1 ml each of phosphate buffer, $MgSO_4$, $CaCl_2$, and $FeCl_3$ per liter of deionized water. The dilution water was aerated until saturated with air. The dilution water blank was prepared. Seeding was needed to have sufficient population of microorganisms capable of oxidizing the biodegradable organic matter in the sample. Seeding was prepared using polyseed (InterLab Supply). The seed control bottles with different dilutions of 15, 20, 25, and 30 mg/l were also prepared. Besides, glucose-glutamic acid standard check was run on a regular basis for quality control.

The desired amounts of leachate samples were filled in 300 ml flared mouth glass bottles. Several dilutions were prepared for a sample to obtain precise results. 4 ml of seed solution was added to each sample bottle, and then the remaining bottles were filled with enough dilution water so that insertion of the stopper would displace all air, leaving no bubbles.

The initial DO was determined using the IntelliCAL probe (Hach). After incubation period, final DO was measured as shown in Figure 3.6. The BOD calculations for each bottle meeting the 2 mg/l minimum DO depletion and the 1 mg/l residual DO as follows:

$$\text{BOD}, \frac{\text{mg}}{\text{l}} = \frac{(D_1 - D_2) - (B_1 - B_2)f}{P}$$

Where,

f = (volume of seed in diluted sample)/(volume of seed in seed control)

D_1 = initial DO of diluted sample immediately after preparation, mg/l

D_2 = final DO of diluted sample after incubation at 20 °C, mg/l

P = decimal volumetric fraction of sample used

B_1 = DO of seed control before incubation, mg/l

B_2 = DO of seed control after incubation, mg/l

Figure 3.6: Dissolved Oxygen Probe and Meter

This test has its widest application in measuring the waste loadings to treatment plants and in evaluating BOD removal efficiency of treatment systems. It is perhaps the best guide to check the strength of the leachable samples. BOD concentration increases gradually in the initial phase of waste decomposition and then decreases after the onset of the methanogenic phase.

3.6.3 Chemical Oxygen Demand (COD)

Chemical Oxygen Demand (COD) is commonly used to indirectly measure the amount of organic matter present in water/wastewater. It is also a useful measure to characterize the strength of leachate. COD is defined as the amount of a specified oxidant that reacts with the sample under controlled conditions.

BOD measures only the biologically degradable organic matter, whereas COD measures the extent to which organics and other compounds react chemically with oxygen, whether biodegradable or not. COD is always higher than BOD because it measures a portion of biodegradable and non-biodegradable matter.

A suitable volume of sample was added into vials containing premixed digestion solution along with a blank. The vials were inverted few times to mix the sample. Then samples were placed into a preheated digester for 2 hours at 150 °C, as shown in Figure 3.7 (a). Dichromate ion ($Cr_2O_7^{-2}$), an oxidant, reacts with the sample under controlled conditions and is reduced to chromic ion (Cr^{+3}) after 2 hours of digestion at 150 °C. Samples were cooled down to room temperature and the absorption of each sample at 620 nm was measured using a Spectronic-D spectrophotometer, as displayed in Figure 3.7 (b). A calibration curve was prepared using 6 standards from potassium hydrogen phthalate solution. COD was determined using the best fit line from the calibration curve. COD concentration increases gradually in the initial phase of waste decomposition and then decreases after the onset of the methanogenic phase.

(a) (b)

Figure 3.7 COD Test Setup: (a) COD digester and, (b) Spectrophotometer

3.6.4 Total Alkalinity as $CaCO_3$

Alkalinity of water is a measure of its acid-neutralizing capacity. Alkalinity of water is principally due to salts of weak acids and strong bases which act as buffers to resist a drop in pH resulting from acid addition. Thus, it is a measure of the buffer capacity and used to a great extent in wastewater treatment practice. Weak acids have small ionization constants, and a pool of un-dissociated molecules exerts a buffering action.

In order to obtain acid-neutralizing capacity of leachate samples, methyl orange end points could not be used for titration, which has been reported in previous study (Qasim, 1965). Since the existing buffer system was mainly due to weak acids with ionization constants around $1*10^{-5}$ and their concentration varied in each leachate sample, as well as due to the dark color of leachate samples, it was necessary to prepare acid titration curves to determine the inflection points for each sample being analyzed. Alkalinity of the leachate samples decreased as refuse decomposition occurred.

Alkalinity of samples was measured volumetrically by titration with 0.2 N H_2SO_4 as a titrant. The amount of leachate sample used for a titration varied as certain samples were having high alkalinity values, which was determined in the beginning to get an initial estimate. The titration curves were prepared for each sample to determine the inflection points for the selection of stoichiometric end points. Differences in the stoichiometric end points occurred in all samples. This may be due to different concentrations of fatty acids.

3.6.5 Conductivity and Total Dissolved Solids (TDS)

Conductivity is a measure of the ability of an aqueous solution to carry an electric current. This ability depends on the total concentration of ions. Thus, it is an indirect measurement of the amount of ions present in a leachate sample. High conductivity indicates the presence of inorganic materials in the leachate samples. Conductivity has a direct relationship with total dissolved solids (TDS). Total dissolved solids (in mg/l) in a sample can be estimated by multiplying conductivity (micromhos per centimeter) by an empirical factor, which ranges from 0.55 to 0.9, depending on the soluble components of the water and on the temperature of measurements (Standard Methods).

For this study, the conductivity and TDS measurements were obtained using single probe (IntelliCAL probe, Hach) as shown in Figure 3.8. The meter provided the readings for conductivity (µs/cm) and TDS (mg/l) simultaneously.

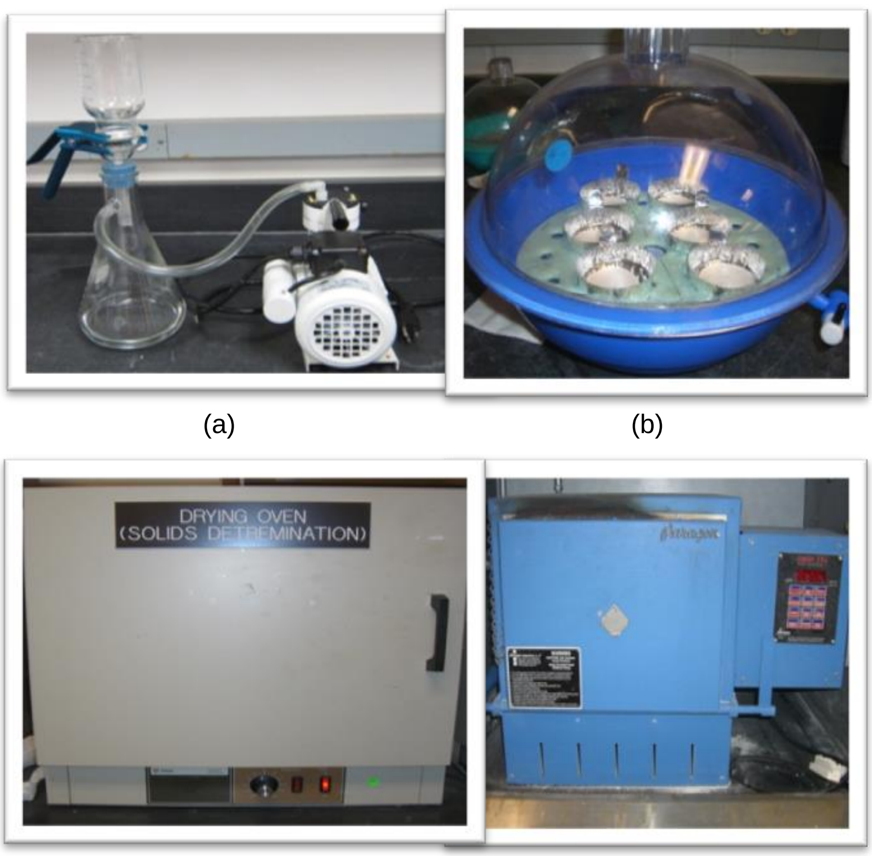
Figure 3.8 Conductivity Probe and Meter

3.6.6 Total Suspended Solids (TSS) and Volatile Suspended Solids (VSS)

Suspended solids determination is extremely valuable in the analysis of polluted and untreated waters like leachate samples. It is one of the major parameters used to evaluate the efficiency of leachate treatment units.

To measure the TSS, filters were prepared as follows. The filter was placed using forceps into filtration apparatus and then a vacuum was applied. The filter was washed with approximately 20 ml of distilled water for 3 times. The filter was removed and placed in an aluminum pan, dried in an oven at 103 to 105 °C for one hour, and then ignited in a muffle furnace at 550 °C. The filters were then placed in a desiccator until ready to use.

For the TSS analysis of a sample, filters were weighed in aluminum pans immediately before analysis. A filter apparatus was assembled and a filter placed into it. A small amount of distilled water was applied to wet the filter. An amount of well-mixed leachate sample was measured and filtered on filter disk via applying suction. The amount of leachate samples varied depending upon the leachate sample. If the leachate sample being analyzed was from 100% food or yard reactors, then smaller amount (10-20 ml) sample was filtered due to visibly high amount of solids present in a sample. However, if the leachate sample was from 100% paper or textile reactors then large amount (50-100 ml) of sample was filtered due to low solids. The filter was then washed with 3-10 ml aliquots of distilled water. Filters were placed in an aluminum pan, dried in oven at 103 to 105 °C for one hour and then ignited in a muffle furnace at 550 °C. Total suspended solids are the portion of total solids retained by a filter. The increase in weight of the filter represents the total suspended solids, while the weight lost on ignition at 550 °C for 15-20 minutes is the volatile suspended solids. This determination is important because it offers a rough approximation of the amount of organic matter present in the leachate samples. TSS and VSS test apparatus are shown in Figure 3.9.



(a) (b)

(c) (d)

Figure 3.9 Solids Test Apparatus: (a) Filter Apparatus (b) Desiccator (c) Drying Oven, and (d) Muffle Furnace

3.6.7 Chloride Ions

Chloride is a non-degradable, inorganic macro component and the change of its concentration is commonly used to assess the variation of leachate dilution. Chloride ions in leachate samples were measured using a chloride ISE probe (Hach). The reference electrode was inserted in leachate samples along with the chloride probe to measure the chloride concentration in leachate. The probe was calibrated with chloride standards before taking measurements. About 25 ml of leachate sample was poured into a beaker and a chloride ionic strength adjustor (ISA) pillow was added into a measured leachate sample and then well mixed. The chloride concentration was measured immediately after adding ISA to a sample. The probe and meter (SensION, Hach) apparatus are displayed in Figure 3.10.

Figure 3.10 Chloride Probe and Meter Setup

3.6.8 Ammonia-Nitrogen

Most of the nitrogen in a solid waste bioreactor landfill is in the form of ammonia. It is produced from the degradation of proteins and amino acids. The anaerobic hydrolysis of solid waste containing protein is slower than that of carbohydrates, resulting in a slow release of the soluble nitrogen, i.e. ammonia. Hence, a high concentration of ammonia and a lower C:N ratio are observed in the stabilized landfill leachate. To measure ammonia-nitrogen concentration is principally important to design the leachate treatment facility and to mitigate the toxic effect of ammonia to ground water and aquatic life.

Ammonia-nitrogen in leachate samples was measured using an ammonia-nitrogen ISE probe (Hach). The probe was calibrated using ammonia-nitrogen standards before measuring the concentration of a leachate sample. About 25 ml of leachate sample was poured in a cup and then ammonia ionic strength adjuster powder pillow was added into a sample. The sample was placed on a magnetic stirrer and the probe was inserted using an air gap assembly and then ammonia concentration was measured. The probe, air gap assembly and meter apparatus are shown in Figure 3.11.

Figure 3.11 Ammonia-Nitrogen Probe and Meter

3.7 Dismantling Reactors

Reactors were dismantled when BOD/COD ratio for each reactor was nearly 0.1 or less than 0.1. BOD/COD ratio is a good indicator of the landfill stabilization phase where most of the waste would have been degraded. Some reactors such as R1, R2, and R21 took the longest time of approximately 370 days to reach the stabilization. Overall, reactors which were operated at 70 °F required long time for stabilization. This is due to the lowest temperature where waste degradation rate is slower than other two temperature range of 85 and 100 °F.

Upon dismantling 100% food reactors, it was observed that they had maximum amount of settlement and weight loss. Perhaps, food waste is the most easily degradable waste among the waste included in this study. In addition, weight loss could be due to faster rate of organic matter leaching.

When 100% paper reactors were dismantled, it was observed that paper towels and office paper had mostly degraded; while cardboard and milk cartons remained as it is.

After dismantling 100% textile reactors, it was observed that they had little or no settlement. The textile material was identifiable.

Observing 100% yard reactors while dismantling, it was obvious that grass was the most degraded component than leaves and branches.

When reactors containing 60% paper & 40% inorganic were dismantled, it was noted that paper waste appeared to be degraded better than 100% paper reactors. Inorganic waste was mostly unchanged and some bottle had water accumulated into it.

Reactors containing 60% food, 30% textile, and 10% yard were dismantled and it was observed that they had more settlement next to 100% food reactors due to 60% food waste. The food waste was mostly disappeared and textile was unaffected.

Upon dismantling reactors having 60% yard, 30% food, and 10% paper; it was seen that food waste was unidentifiable.

While reactors containing 60% textile, 30% paper, and 10% food were dismantled; textile remained identifiable and food waste was almost disappeared. Paper waste was converted into lumps indicating degradation.

While dismantling reactors containing 20% each, it was found that food waste, paper towels, office paper and grass were degraded, while textile waste, inorganics, and milk cartons remained identifiable, indicating less or no degradation.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the experimental results for various leachate quality parameters measured over time, taking into consideration of various factors affecting leachate quality such as temperature, rainfall rate, and waste composition. The development of model equations to predict each leachate quality parameter covered in this study is presented and discussed in Chapter 5.

4.2 Comparison of Leachate Parameters for 100% Yard Reactors

The concentrations of various leachate parameters measured in this study are displayed below. Reactors number 8, 14, and 19 have same waste composition of 100% yard, and they were being operated at three different temperatures of 100 °F, 85 °F, and 70 °F; and three different rainfall rates of 2 mm/day, 6 mm/day, and 12 mm/day, respectively. The raw data plots for the leachate parameters of each reactor are provided in Appendix A.

pH acts as a good indicator of microbial activity in the reactors. Figure 4.1 below shows the pH trend for the reactors. Initially the pH is acidic for R-14 and stabilized to neutral or above neutral over a period of time. In the initial phase of reactor life, the pH is acidic because hydrolytic, fermentative, and acetogenic bacteria dominate, resulting in an accumulation of carboxylic acids, and pH drops. In the later stage, acids are converted to methane and carbon dioxide by methanogenic bacteria and pH stabilizes.

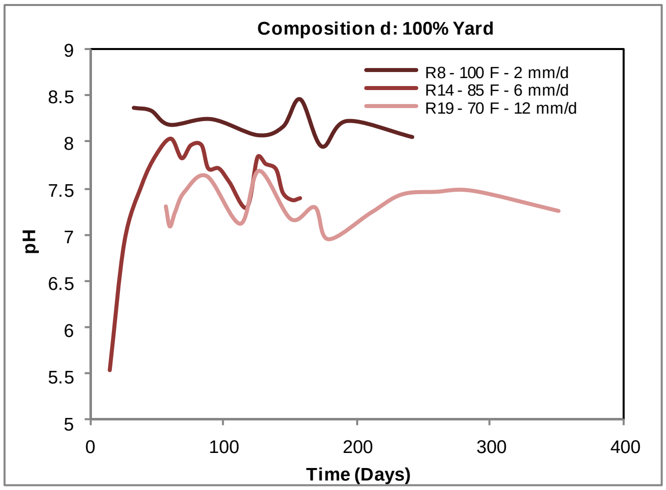


Figure 4.1 pH Trend with Time (100% Yard Reactors)

Figure 4.2 (a) and (b) shows amount of water applied and cumulative leachate production over time in reactors, respectively. The cumulative volume of applied water includes the total volume of water responsible for producing total leachate on a certain day. The water was applied after the leachate was withdrawn. Figure 4.2 shows the water balance in the system, as the total leachate generated is almost equal to the total water applied over time for the reactors. Theoretically, it was expected that leachate generation volume should be somewhat less than volume of water added due to consumption of water by solid waste for methane gas production. However, a lesser amount of leachate was not measureable. The total amounts of water added in R8, R14, and R19 were 25.05, 62.8, and 198.9 liters, respectively. The total amounts of leachate generated from R8, R14, and R19 were 25.85, 61.14, and 194.26 liters, respectively.

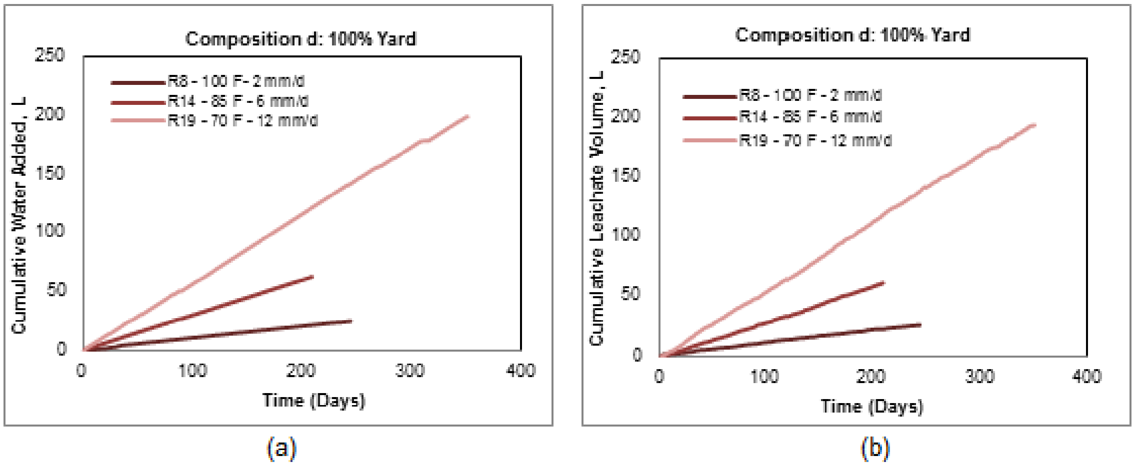
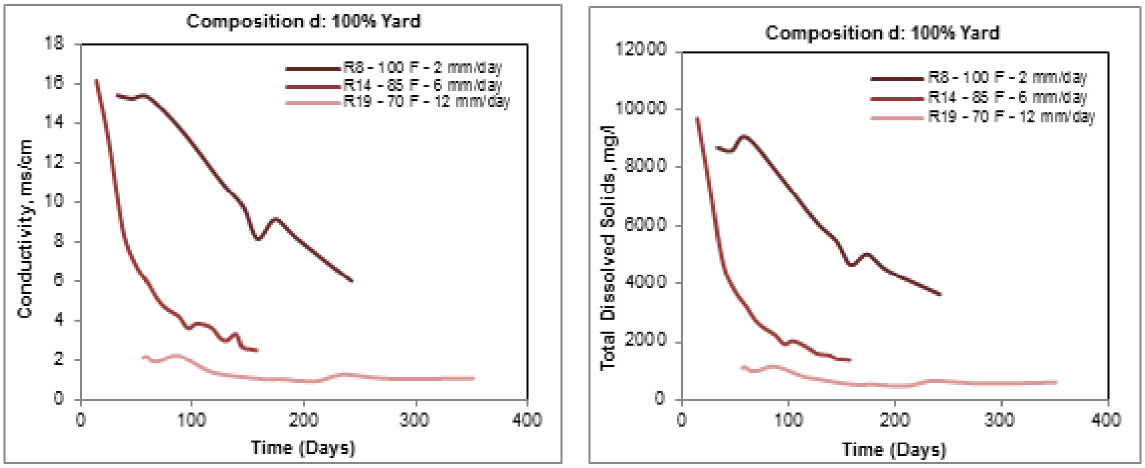


Figure 4.2 (a) Cumulative Water Addition and (b) Cumulative Leachate Generation (100% Yard Reactors)

Figure 4.3 (a) and (b) shows conductivity in ms/cm and total dissolved solids (TDS) in mg/l over time, respectively. The trends for conductivity and TDS for these reactors are similar, which demonstrates the relationship between these two parameters. In theory, conductivity has a direct relationship with TDS. TDS (mg/l) in a sample can be estimated by multiplying conductivity (micromhos per centimeter) by an empirical factor, which ranges from 0.55 to 0.9, depending on the soluble components of the water and on the temperature of measurements. It can be seen that R8 had overall higher values for conductivity and TDS than R14 and R19 (Figure 4.3), which was expected, as R8 had the highest temperature and lowest rainfall. Higher temperature would have increased microbial activities, producing higher values of conductivity and TDS; the lowest rainfall generated concentrated leachate in R8. R19 had the lowest values of conductivity and TDS due to lowest temperature and highest rainfall intensity. R14 shows intermediate values for conductivity and TDS. The maximum values of conductivity for R8, R14, and R19 were 15.41, 16.14, and 2.25 ms/cm, respectively. The maximum values of TDS for R8, R14, and R19 were 9050, 9680, and 1145 mg/l, respectively.



(a) (b)

Figure 4.3 (a) Trend of Conductivity and (b) Trend of Total Dissolved Solids (100% Yard Reactors)

Figure 4.4 displays total alkalinity ($CaCO_3$) concentrations over time. Overall, alkalinity shows a decreasing trend with time, with the exception of some small peaks. R8 has higher concentrations than R14 and R19. Again, this is due to its highest temperature and lowest rainfall. R19 has the lowest alkalinity concentration due to its having the lowest temperature and highest rainfall, which dilutes the leachate and decreases concentration. The maximum values of total alkalinity ($CaCO_3$) for R8, R14, and R19 were 8900, 9600, and 1166.5 mg/l, respectively.

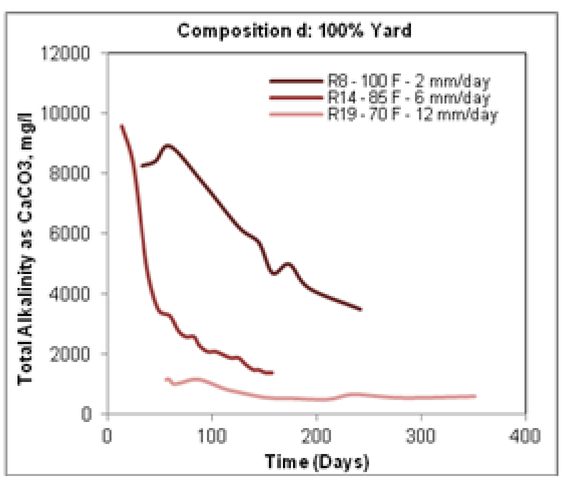


Figure 4.4 Trend of Total Alkalinity as $CaCO_3$ (100% Yard Reactors)

Figure 4.5 (a) and (b) shows Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) with time, respectively. The concentrations of BOD and COD decrease due to decomposition of solid waste over time. Eventually, the BOD/COD ratio of these three reactors is 0.1 or < 0.1, which indicates that the solid waste in these reactors is heavily decomposed. Initially, BOD and COD concentrations for R14 are higher than R8 and R19, indicating that R14 has a slower leaching rate, or in other words, higher concentrations compared to the other two reactors. R14 has a combination of intermediate temperature and rainfall rate of 85 °F and 6 mm/day, respectively. This indicates that in the beginning, the interaction of temperature and rainfall is contributing to maximum degradation and the highest BOD/COD concentration. However, the interaction effect of R14 lasts for a short time and then BOD and COD concentrations drop drastically within 100 days. It is evident that R19 has the lowest concentration of BOD and COD due to the combination of lowest temperature and highest rainfall. Lower temperatures prolong the time for microbial activities to occur and higher rainfall dilutes the leachate due to washout effect. The maximum values of BOD for R8, R14, and R19 were 976.09, 12361.38, and 313.85 mg/l, respectively. The maximum values of COD for R8, R14, and R19 were 13498, 30256.28, and 1264.59 mg/l, respectively.

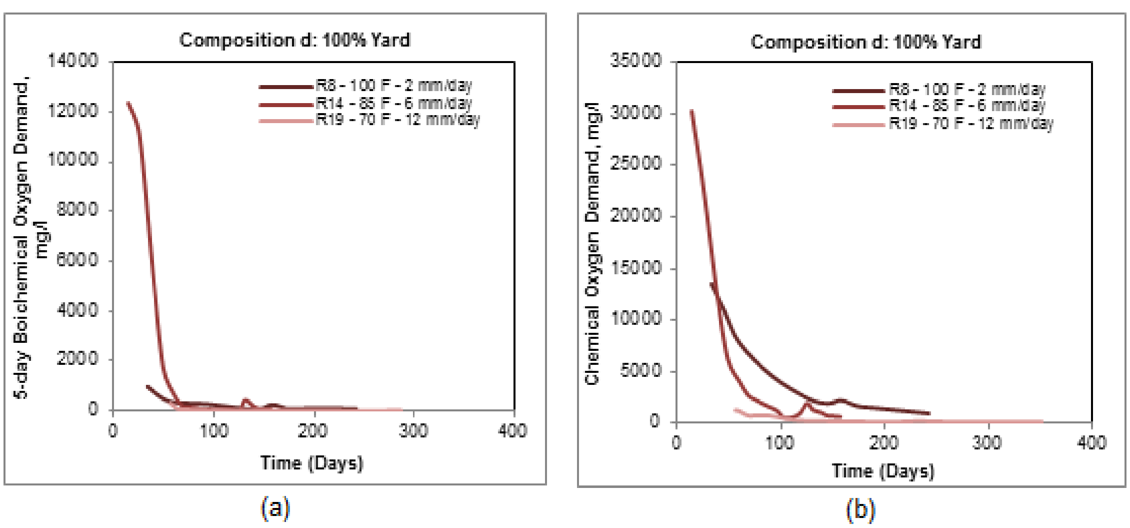


Figure 4.5 (a) Trend of Biochemical Oxygen Demand and (b) Trend of Chemical Oxygen Demand (100% Yard Reactors)

BOD/COD ratio is perhaps the best indicator of the landfill phases. Figure 4.6 displays BOD/COD ratio for 100% yard reactors. Initially, the ratio is high for R14 and R19, which suggests acidic phase and as time progresses, this ratio decreases below 0.1, indicating methanogenic phase when most of the waste would have been degraded. It is also observed that BOD/COD ratio remains at or below 0.1 for R8 over time. The plots of BOD/COD ratio for the remaining reactors are provided in Appendix B.

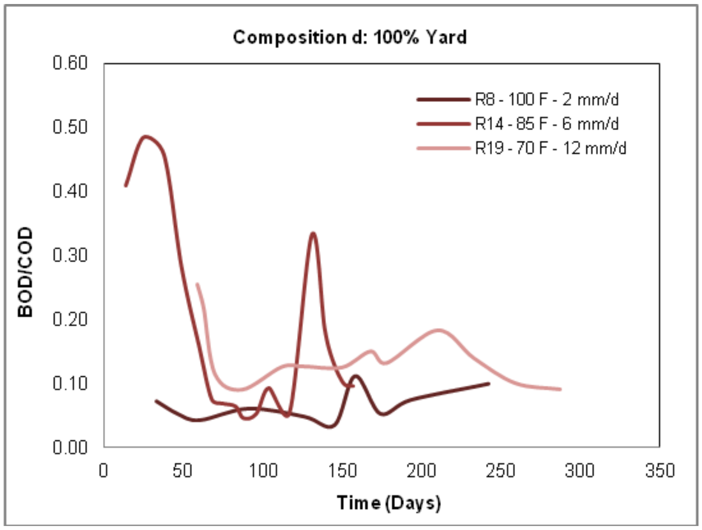


Figure 4.6 BOD/COD Ratio (100% Yard Reactors)

TSS and VSS are very important parameters in many cases to determine the strength of influent and effluent. Volatile solids are mostly organic matter and create substantial pollution problems. Figure 4.7 (a) and (b) displays trends of total suspended solids (TSS) and volatile suspended solids (VSS) over time, respectively. R14 shows gradually increasing and then decreasing trend for TSS and VSS, while other two reactors show mostly decreasing trends for both parameters except for a few peaks. R14 has overall higher concentrations of TSS and VSS. This is somewhat surprising, since R8 had the highest concentrations of TDS and alkalinity. Previous data analysis, however, showed 85 °F to be most effective in degrading waste in terms of BOD and COD leachate concentrations (Altouqi, 2012). R19 has the lowest concentrations of TSS and VSS, which is expected due to combination of lowest temperature and higher rainfall. This might be due to interaction of medium temperature and rainfall is playing an important role which causes microbes to gradually decompose waste than other temperature and rainfall combination. The maximum values of TSS for R8, R14, and R19 were 432, 515, and 34 mg/l, respectively. The maximum values of VSS for R8, R14, and R19 were 345, 412.5, 34 mg/l, respectively.

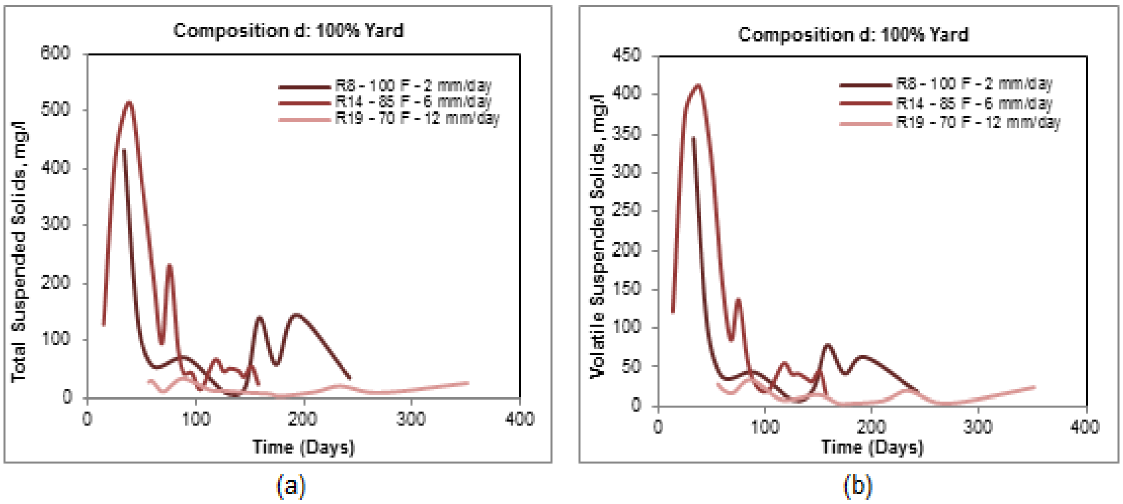


Figure 4.7 (a) Trend of Total Suspended Solids and (b) Trend of Volatile Suspended Solids (100% Yard Reactors)

Figure 4.8 (a) and (b) displays chloride and ammonia-nitrogen concentrations with time. Chloride was present in high concentrations in leachate samples and had a decreasing trend with time. R8 has highest chloride and ammonia-nitrogen concentrations due to the combination of highest temperature and lowest rainfall, which increases microbial activities in the beginning and due to this waste decomposition rate increases. R19 has lowest concentrations of both parameters because of slowest decomposition rate at 70 °F and diluted leachate at highest rainfall of 12 mm/d. Ammonia-nitrogen concentrations for the three reactors show decreasing trends with time except for R8, where the peak is observed around 200 days. There might be decomposition of some organic matter at a later stage which causes this peak. The observed maximum values of chloride for R8, R14, and R19 were 2872.8, 2014.25, and 103.72 mg/l, respectively. The observed maximum values of ammonia-nitrogen for R8, R14, and R19, were 863, 673.33, and 133.67 mg/l, respectively.

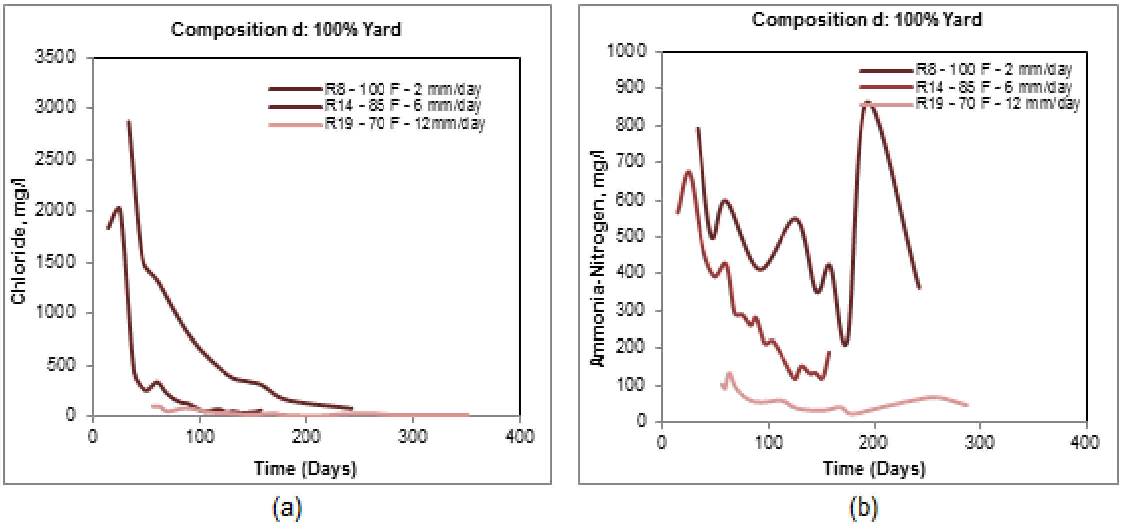


Figure 4.8 (a) Trend of Chloride, and (b) Trend of Ammonia-Nitrogen (100% Yard Reactors)

4.3 Comparison of Leachate Parameters for 100% Food, Textile, and Paper Reactors

Trends of leachate parameters with time for 100% food, textile, and paper, and also for other waste combinations, are provided in Appendix C. Reactor no. 10 (100% food) and reactor no. 11 (100% textile) failed due to excessive acid accumulation and microorganism washout, respectively. Therefore, their results were excluded due to failures.

It is observed that 100% food waste reactors (R4 & R25) had the highest concentrations for all the leachate parameters. This is expected, as food has the most organic matter present and also it is the most biodegradable component in the waste stream.

Among the textile waste reactors, the lowest rainfall reactor (R5) had higher concentrations for almost all the parameters, indicating slowest leaching behavior and concentrated leachate. In paper waste reactors, the higher rainfall and temperature reactor (R13) showed initially higher concentrations for almost all the leachate parameters and then leached faster because of the washout effect. Here the interaction of temperature and rainfall has an important effect.

4.4 Summary Statistics for Leachate Parameters

The decomposition of solid wastes in landfills is essentially due to microbial activities and therefore, the production of leachate is directly related to the activity of microorganisms. In this research, large variations in leachate quality were observed for different reactors with their age. In Table 4.1, the main leachate quality parameters from leachate samples have been summarized.

Table 4.1 Observed Values of Leachate Pollutants in Terms of Range, Mean, Median, and Standard Deviation

Leachate Parameters	**Range**	**Mean (Average)**	**Median**	**Standard Deviation**
	(values in mg/l unless otherwise mentioned)			
pH (no unit)	5.42 - 8.45	7.27	7.35	0.62
Total Alkalinity	150 – 18,500	2053.66	850.00	3014.39
Conductivity, ms/cm	0.365 - 28.3	3.44	1.42	4.78
Total Dissolved Solids (TDS)	104 - 17360	1924.70	746.50	2841.05
Total Suspended Solids (TSS)	3 - 1542.5	96.45	48.00	150.98
Volatile Suspended Solids (VSS)	2 - 1345	73.13	37.50	111.31
Biochemical Oxygen Demand (BOD)	6.5 - 46134.17	1885.66	83.76	5274.53
Chemical Oxygen Demand (COD)	61.75 - 64032.16	3787.46	694.04	9033.34
Ammonia-Nitrogen	0.01 - 3163.33	112.86	20.45	242.42
Chloride	1.04 - 4266.4	188.61	40.31	441.02

It should also be noted that for certain reactors, such as R1, R3, R7, R9, R18, R19, and R21, data was not collected during the early weeks, due to the reactor monitoring schedule. Due to this, peak values of some leachate parameters were likely missed. The graphs are provided in Appendix A.

4.4.1 Comparison of Leachate Parameters with Previous Studies

pH: During the acid formation phase of a landfill, pH values are low due to the presence of volatile organic acids (VOA). The leachate pH ranges between 4.5 and 9 for landfills (Kjeldsen, 2002). This is comparable with the range observed in this study. Dounia states that temperature has no significance on the pH parameter according to the t-test (2010).

Total Alkalinity: The range of observed leachate alkalinity for this study is provided in Table 4.1. In previous studies the alkalinity range for actual landfills is 240-8965 mg/l and 4250-8250 mg/l for USA and Italy, respectively (Al-Yaqout and Hamoda, 2003). The observed upper value in this study is higher than these previously reported values. This might be due to more concentrated leachate from various reactors due to low rainfall rates.

Conductivity: Conductivity is expected to increase during the acidic phase due to mobilization of metals and decreases in the methanogenic phase due to the complexation of metals with sulfides (Pohland, 1992). However, in this study, conductivity decreased over time for almost all reactors. In a previous study, conductivity values ranged from 1-26 ms/cm (Dounia, 2010). These values are comparable with this study.

Total Dissolved Solids (TDS): TDS concentrations varied between 104-17360 mg/l in all reactors. In this study TDS decreased with time for all reactors except for a few peaks. Kylefors and Lagerkvist (1997) reported that as the leachate transitions from acidogenic to methanogenic phase, total solids concentration is expected to decrease. Dounia (2010) concluded based on a t-test that temperature has a significant effect on TDS.

Total Suspended Solids (TSS) and Volatile Suspended Solids (VSS): The observed trend of TSS and VSS with time in this study is similar. In a previous study, the TSS range was 191-740 mg/l and VSS range was 72-329 mg/l (Kulikowska and Klimiuk, 2007). The ranges observed in this research are wider than reported by Kulikowska and Klimiuk (2007). The reason might be the faster and better degradation of wastes in a shorter time in the reactors compared to actual landfills.

Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD): Leachate BOD and COD values are used as indicators of organic strength and the pollution impact that may result from leachate. BOD values reported in the literature for landfills from various reports ranged from 20 to 57,000 mg/l and COD values ranged from 140 to 152,000 mg/l (Kjeldsen, 2002). The BOD and COD range observed in this study has a wider range than these literature values.

Ammonia-Nitrogen (NH_3-N): Ammonia-nitrogen concentrations are higher in 100% food, 100% yard, 60% food and 60% yard reactors. Dounia (2010) found via t-test that temperature had a significant impact on higher ammonium concentration. This was also confirmed in this study. Barlaz et al. (2002) stated that ammonia-nitrogen tends to accumulate in landfills because there is no degradation pathway for ammonia-nitrogen in anaerobic systems. However, in this study ammonia concentrations tend to decrease with time for all reactors except for some fluctuations, likely due to washout.

Chloride: Chloride is a non-degradable, inorganic component. Chloride concentrations in this study decrease over time due to wash out effect, although Ehrig (1983) did not observe any decrease in concentration of chloride every after many years of leaching. The range observed in this study is similar to that found by Kjeldsen et al. (2002).

4.5 Effect of Temperature

Two reactors, R20 and R26, having the same waste composition of 60% food, 30% textile and 10% yard, and same rainfall of 12 mm/day, were chosen to compare the effect of temperature. R20 was operated at 70 °F and R26 at 100 °F. The graphs of leachate parameters for these two reactors over time are provided in Appendix C, Figure C5. It was observed that the concentration of all the leachate parameters for R26 were initially higher than R20 up to 100 days or so due to the higher temperature of R26. This showed that higher temperature increases the waste decomposition and in turn generates higher concentrations of contaminants. However, later in time (approximately after 100 days), the concentration of almost all leachate parameters decreased faster for R26 and was more comparable with R20.

4.6 Initial and Final Weight of Reactors

The reactors' initial and final weights are provided in Table 4.2 and represented in Figure 4.9 to study the effect of water addition and waste degradation. It is obvious from Figure 4.9 that most of the reactors had increased in final weight at the end of operation. This is due to water holding in these reactors. However, a few reactors (R4, R15, R18, R25, and R26) had significant weight loss at the end of operation. These reactors had greater percentages of the most degradable wastes, food and yard wastes. This also led to faster carbon washout from these reactors.

Table 4.2 Weight of Reactors

Reactor Numbers	Initial Wt. of Reactors at the Beginning of Operation (Kg)	Final Wt. of Reactors at the end of Operation (Kg)
1	5.274	12.54
2	9.896	10.334
3	11.38	14.262
4	21.956	5.686
5	16.84	18.368
6	14.082	15.264
7	10.018	12.934
8	14.962	13.554
9	11.25	11.05
10*	-	-
11*	-	-
12	10.786	11.168
13	12.484	14.814
14	12.28	13.436
15	17.084	12.212
16	11.824	15.914
17	11.988	12.482
18	12.536	8.182
19	11.012	10.704
20	11.406	9.966
21	7.322	14.238
22	11.442	11.542
23	12.658	15.684
24	10.738	14.654
25	19.382	2.856
26	15.656	12.272
27	12.646	14.086

Note: Reactor 10 & 11 failed due to excessive acid accumulation and washout

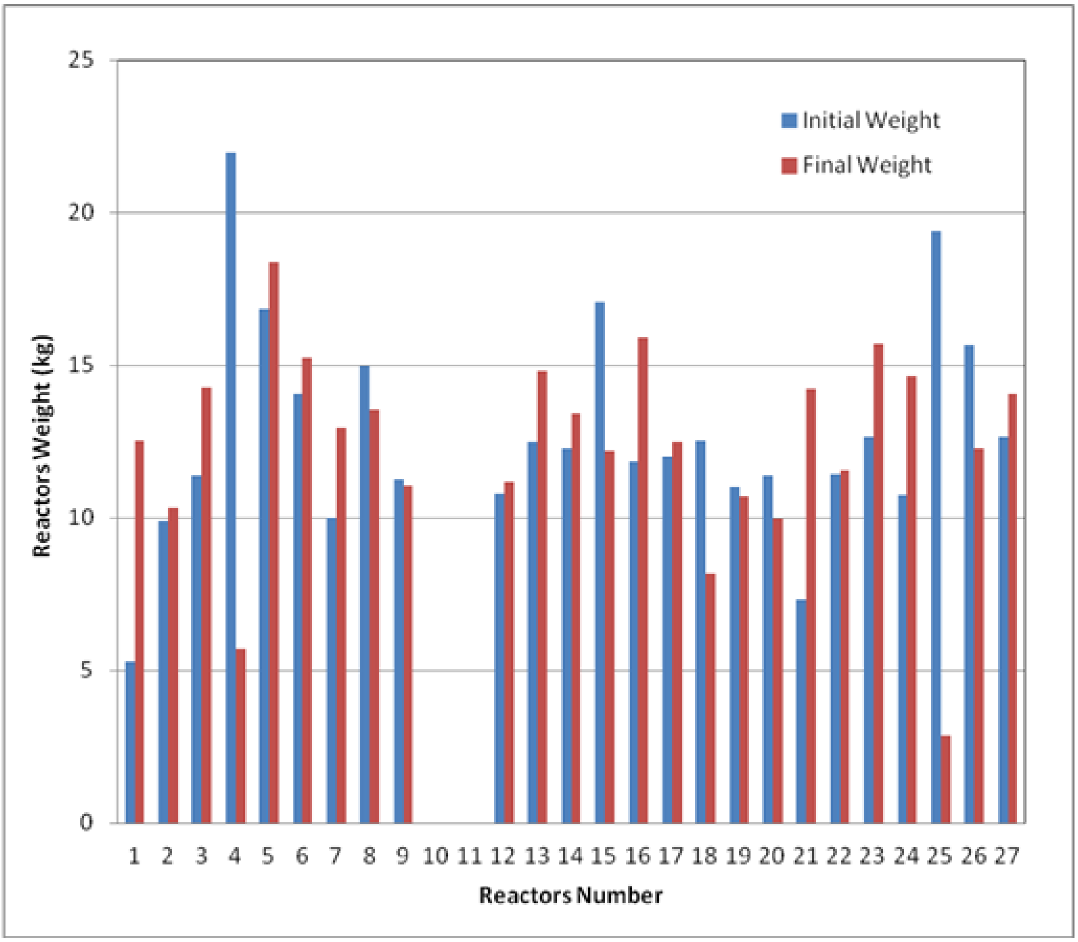


Figure 4.9 Change in Reactors Weight at the end of Operation

4.7 Leachate Color Variability

A wide variation in the concentrations of the leachate parameters was demonstrated. The higher concentrations of each leachate quality parameter were associated with early or fresh leachate. The fresh leachate sample can be considered as an indicator of the acidic decomposition phase. The lower concentration of leachate parameters suggests lower leachate strength, indicating a stable degradation phase of the reactor's life. Also, it was interesting to observe color variability in leachate samples from different reactors. Figure 4.10 shows leachate color from all reactors. The variability in leachate color depends on the waste composition of a reactor. The darker color leachate is mostly associated with reactors having higher percentages of food or yard wastes, while light color leachate is associated with reactors having mostly paper or textile wastes.

Figure 4.10 Variety of Leachate Color

CHAPTER 5

STATISTICAL ANALYSIS AND MODEL DEVELOPMENT

5.1 Introduction

Multiple Linear Regression (MLR) is a statistical method that utilizes the relation between two or more quantitative variables so that a response variable can be predicted from other predictor variables. MLR analysis is useful to investigate a number of predictor variables simultaneously because mostly more than one predictor variable influence the single response variable. The first-order multiple linear model with p-1 predictor variables is expressed as:

$$Y_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \cdots + \beta_{p-1} X_{i,p-1} + \varepsilon_i \quad (5.1)$$

Where:

$\beta_0, \beta_1, \ldots, \beta_{p-1}$ = unknown model parameters

$X_{i1}, \ldots\ldots\ldots, X_{i,p-1}$ = predictor variables

ε_i = random error term

i = 1….. n

Assuming that $E\{\varepsilon_i\} = 0,$ the response function for the above regression model is:

$$E\{Y\} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_{p-1} X_{p-1} \quad (5.2)$$

The response function is a hyperplane in more than two dimensions and it is not possible to picture this response surface. The parameters β_0 and β_1 are called regression coefficients. The parameter β_0 is the Y intercept of the regression line. β_1 indicates the change in the mean response $E\{Y\}$ per unit increase in X_1 when all other predictor variables are held constant and so on. The error term is assumed to be independent and normally distributed with expected mean of zero and constant variance.

5.2 Multiple Linear Regression (MLR) Model Building Process

There are four phases of model development process as described below.

1. **Data Collection and Preparation:** Select the response variable of interest and relevant predictors. Then proceed with the data collection. After the data is being collected then fit the preliminary model via following steps.
    - Check scatterplots and correlations.
    - Check following model assumptions and perform any necessary transformations.
        - Current MLR model form is reasonable
        - Residuals have constant variance
        - Residuals are normally distributed
        - Residuals are uncorrelated
        - No outliers
        - Predictors are not highly correlated with each other
    - Check model diagnostics
        - Outliers
        - Influence
        - Multicolinearity
    - Explore possibility of interactions between predictor variables.
2. **Model Search:** Find potentially best models using backward deletion, best subsets selection, and stepwise regression methods.
3. **Model Refinement and Selection:** Verify above listed model assumptions and check model diagnostics for all potentially best models.
4. **Model Validation:** Collect a new dataset and perform the following steps.
    - Re-estimate parameters in the best model: if new least squares estimates are similar to b, then model is validated.

- Fit a model (phases 1, 2, and 3) to the new dataset: if new model is same form as $\hat{Y}$ then model is validated.
- Compute mean square prediction error (MSPR): if MSPR is close to mean squared error (MSE), then model is validated.

5.3 Data Collection

In this study, ten leachate parameters: biochemical oxygen demand (BOD), chemical oxygen demand (COD), total alkalinity as $CaCO_3$, pH, conductivity, total dissolved solids (TDS), total suspended solids (TSS), volatile suspended solid (VSS), ammonia-nitrogen (NH_3-N), and chloride (Cl^-) were measured over time from total 25 (2 reactors; R-10 and R-11 failed) simulated laboratory-scale landfills operated in anaerobic environment by varying five types of waste (food, paper, yard, textile, inorganics) percentages (0-100%), rainfall rates (2, 6 & 12 mm/day), and temperature (70, 85 & 100 °F).

Total ten statistical models will be developed for the above listed leachate parameters, as response variables. The predictor variables are food, paper, yard, textile, leachate volume, rainfall, and temperature. An inorganic predictor variable was removed during the regression analysis as sum of all five types of waste components is 100%; so inorganics will be automatically determined from other four waste components. Also, inorganics did not show a trend in scatter plots (Log Alkalinity), so it was safe to remove inorganics from the analysis.

5.4 MLR Model Development for Total Alkalinity as $CaCO_3$

The Statistical Analysis Software (SAS), version 9.3 was used for the data analysis. The regression analysis was begun to develop model equation for total alkalinity as $CaCO_3$ (mg/l) as a response variable and used its experience to guide the model development for other response variables.

5.4.1 Raw Data Scatter Plots

Scatter plots are useful for the preliminary evaluation of suitability of MLR for the given dataset. Scatter plots provide a basic idea of nonlinearity of the regression function. It is useful to plot the response variable versus each predictor variable and a predictor variable versus other predictor variables. Figure 5.1 presents the matrix plot scatter plots of the alkalinity (response variable) vs. predictor variables as well as predictor vs. predictor plots.

5.4.1.1 Response-Predictor Scatter Plots

From figure 5.1, there is a downward trend observed for alkalinity vs. time, alkalinity vs. leachate volume, alkalinity vs. yard. There is an upward trend for alkalinity vs. food. Further, quadratic curvature is observed for alkalinity vs. textile and paper. There is a slight curvature for alkalinity vs. rain and temperature. No outliers are observed.

5.4.1.2 Predictor-Predictor Scatter Plots

Table 5.1 presents the summary of any observed trends between predictor-predictor variables. No outliers are observed for predictor-predictor plots.

Table 5.1 Summary of Observed Trends for Predictor-Predictor Variables

Variable Names	**Observed Trends**
Time vs. Leachate Volume	Downward trend
Time vs. Food	No trend
Time vs. Textile	No trend
Time vs. Paper	No trend
Time vs. Yard	No trend
Time vs. Rain	Quadratic curvature
Time vs. Temperature	Quadratic curvature
Leachate Volume vs. Food	Slightly downward trend
Leachate Volume vs. Textile	No trend
Leachate Volume vs. Paper	No trend
Leachate Volume vs. Yard	No trend
Leachate Volume vs. Rain	Upward trend
Leachate Volume vs. Temperature	Quadratic curvature
Food vs. Textile	Downward trend
Food vs. Paper	Downward trend
Food vs. Yard	Downward trend
Food vs. Rain	Quadratic curvature
Food vs. Temperature	No trend
Textile vs. Paper	Downward trend
Textile vs. Yard	Downward trend
Textile vs. Rain	No trend
Textile vs. Temperature	No trend
Paper vs. Yard	Downward trend
Paper vs. Rain	No trend
Paper vs. Temperature	No trend
Yard vs. Rain	No trend
Yard vs. Temperature	No trend
Rain vs. Temperature	No trend

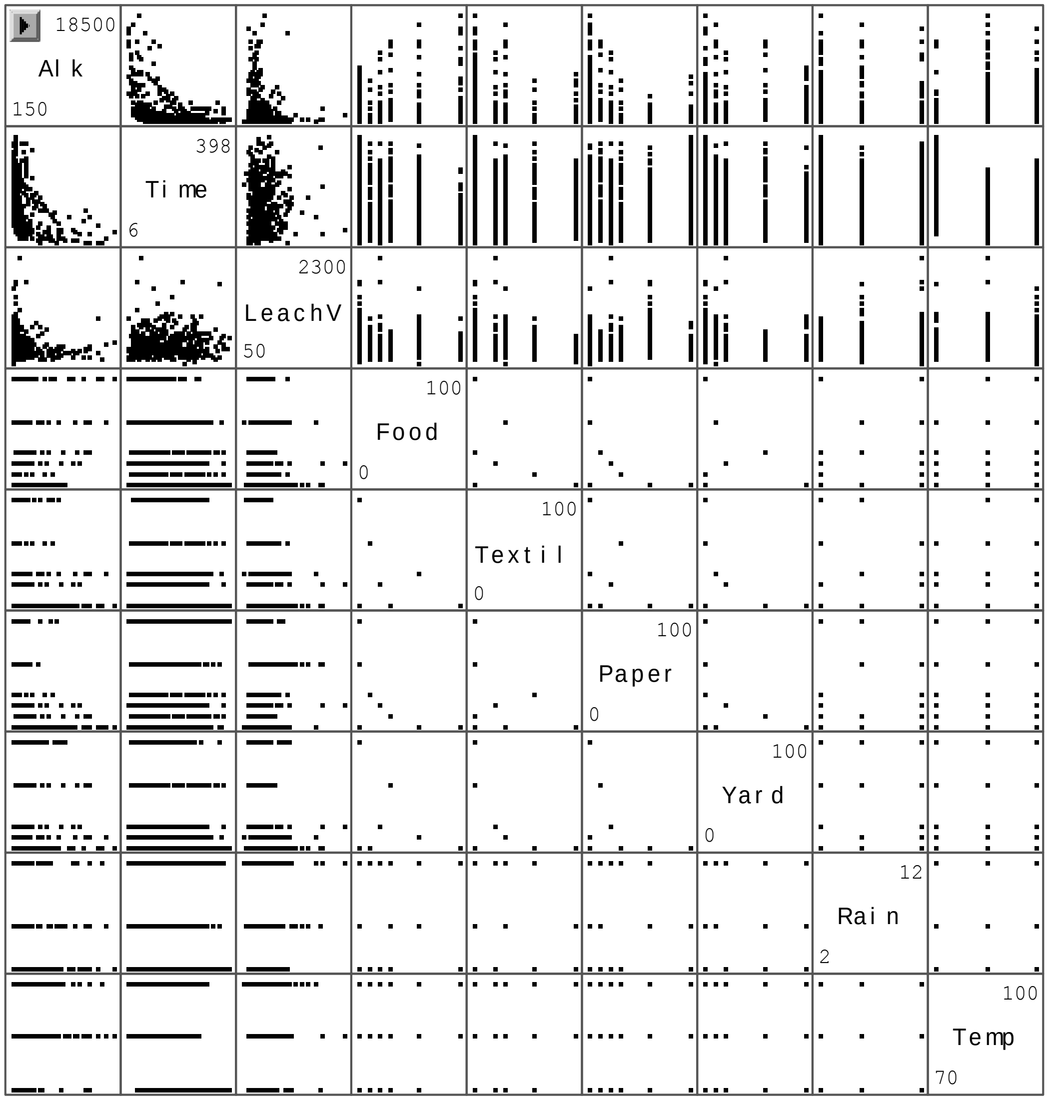


Figure 5.1 Matrix Scatter Plot of Response and Predictor Variables

5.4.2 Checking Model Assumptions

We need to check whether the current MLR model form is reasonable or not. As discussed above there is no linear relationship observed between response-predictor and predictor-predictor variables (Figure 5.1). This indicates that current MLR model form is not adequate and it requires transformation before taking any further steps.

5.4.2.1 Transformations on Predictor Variables (1/Time & 1/Leachate volume)

Since the curvature is observed for alkalinity vs. time and leachate volume (Figure 5.1), it is necessary to straighten the relationship via some form of x transformation. Besides, textile and paper showed some quadratic curvature, but since their trends are mostly linear, it was left untransformed and will be accessed later via residual analysis.

To straighten the relationship between alkalinity vs. time and leachate volume, transformation of 1/time and 1/leachate volume was performed.

5.4.2.2 Residual Plots

To verify the adequacy of the current MLR model form, the plots of the residuals vs. predictor variables are checked for any curvature after 1/time and 1/leachate volume transformation. The residual plots are presented in Figure 5.2. The inverse transformation on time and leachate volume resolved the curvature issue, however, curvature is observed for residual plots of textile and paper.

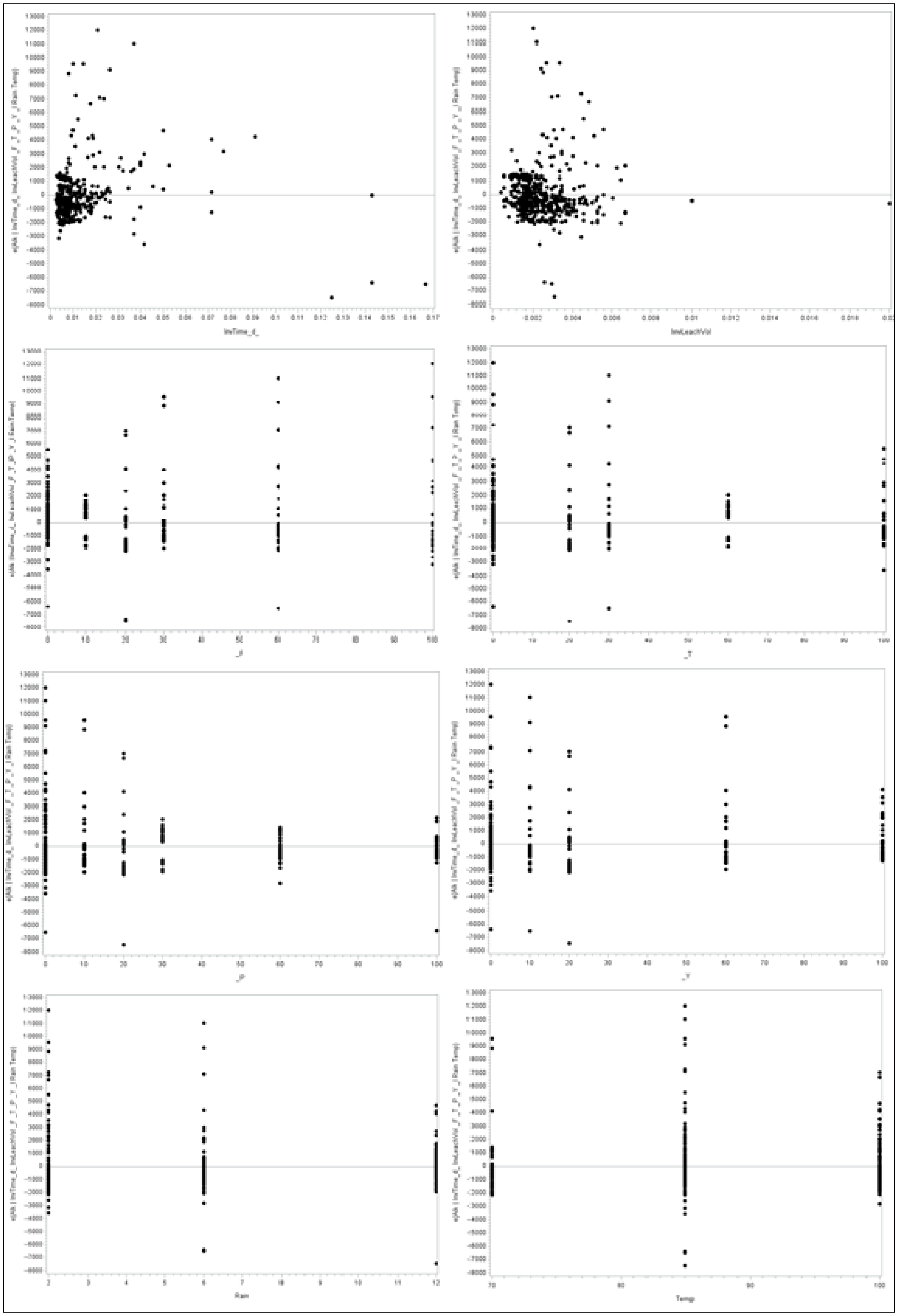


Figure 5.2 Residual Plots vs. Predictor Variables (After transformation)

5.4.2.3 Constant Variance

To verify the constant variance assumption, the plot of residual vs. predicted value of alkalinity is checked for a funnel shape. The figure 5.3 presents the residual vs. predicted value ($\hat{Y}$) of alkalinity. The plot clearly shows the funnel shape. Therefore, constant variance assumption is not satisfied which warrants variance stabilizing transformation on alkalinity (Y variable). The constant variance assumption will be checked again after performing a transformation to correct funnel shape.

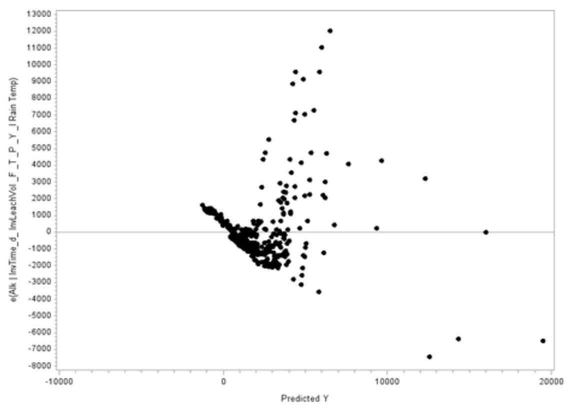


Figure 5.3 Plot of Residual vs. Predicted Value ($\hat{Y}$)

5.4.2.4 Normality

The normality of the error terms is check using a normal probability plot. In a normal probability plot, each residual is plotted against its expected value under normality. A plot that is nearly linear indicates normality is satisfied, while a plot which departs substantially from linearity indicates that the error distribution is not normal. The normal probability plot after the transformation is presented in Figure 5.4. It is observed that the normal probability plot is not straight. It has shorter tails on both sides. Hence, normality assumption is not satisfied after performing the inverse transformation on time and leachate volume. The residuals are not normally distributed.

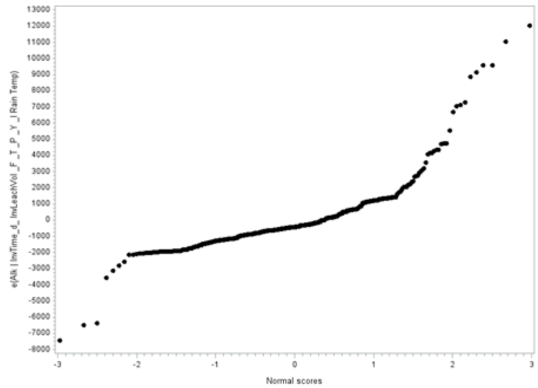


Figure 5.4 Normal Probability Plot (NPP)

5.4.3 Re-checking Model Assumptions

5.4.3.1 Transformation on Response Variable (Log Y)

The funnel shape is observed in residual vs. predicted value of alkalinity (Y) plot indicating non constant variance (Figure 5.3). This requires variance stabilizing transformation on Y. Therefore, a logarithmic (base 10) transformation was performed on alkalinity. This transformation will affect all predictor variables. The residual plots for response-predictor variables after log transformation on Y are presented in Figure 5.5. The curvature is observed for rain and temperature.

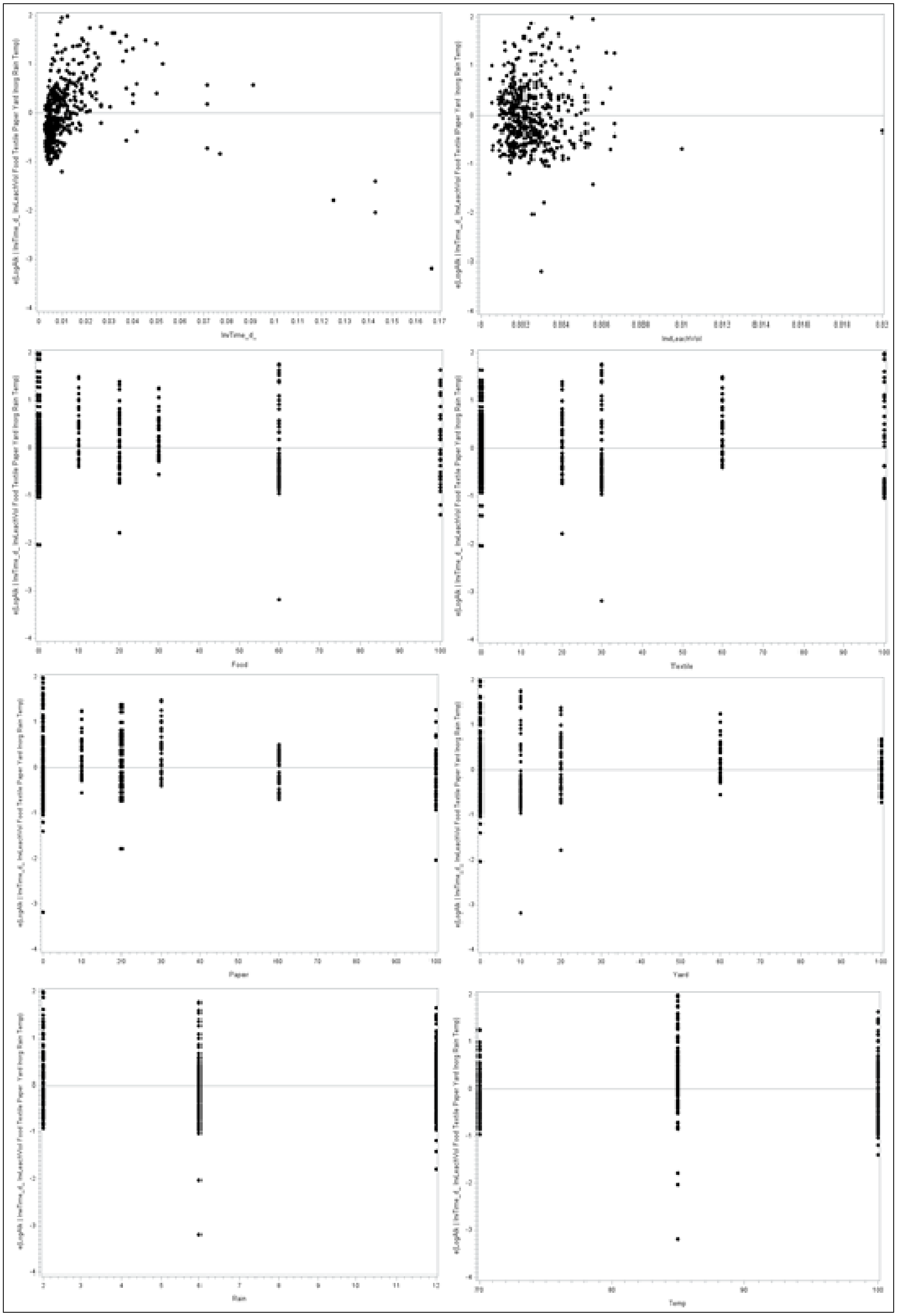


Figure 5.5 Residual Plots of Predictor Variables (After LogY Transformation)

5.4.3.2 Constant Variance

To verify the constant variance assumption, the plot of residual vs. predicted value of log alkalinity is checked for a funnel shape. The figure 5.6 presents the residual vs. predicted value ($\hat{Y}$) of log alkalinity. The plot does not show clear funnel shape. However, there seems to be a possible nonconstant variance issue due to the wider spread of points for higher predicted values of log alkalinity.

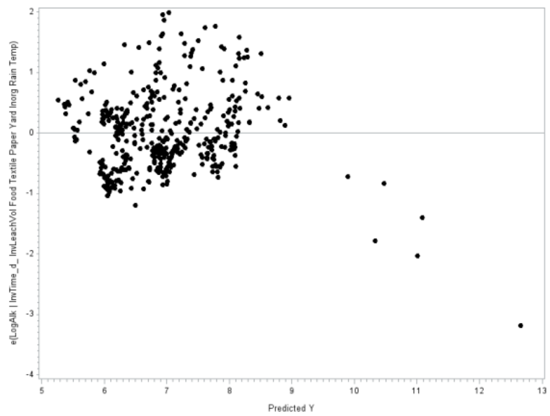


Figure 5.6 Plot of Residual vs. Predicted Value ($\widehat{Log\ Y}$)

5.4.3.3 Normality

The normal probability plot after the transformation is presented in Figure 5.7. It is observed that the normal probability plot is not straight. It has shorter tails on both sides. Hence, normality assumption is not satisfied after performing the inverse transformation on time and leachate volume. The residuals are not normally distributed.

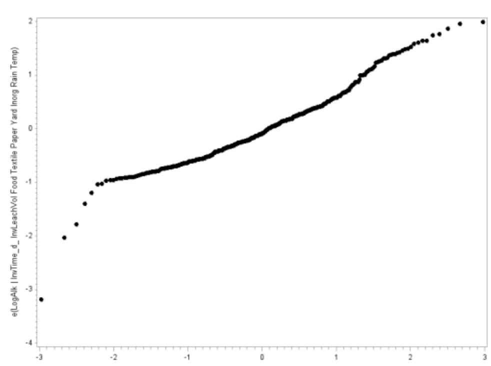


Figure 5.7 Normal Probability Plot (After $\widehat{Log\ Y}$ transformation)

5.5 Summary of Transformations for Total Alkalinity (as $CaCO_3$)

After performing the above tranformations on response variable (alkalinity) and predictor variables (time and leachate volume), numerous attempts were made step-by-step to satisfy the constant variance assumption (to get rid of the curvature in e vs. $\hat{Y}$ plot) via various transformations on response and predictor variables.

The next transformation attempted was log Y, log (time), log (leachate volume). In this case curvature was apparent, so there was non constant variance issue. Then susequent attempts were made; however, none of the transformations were able to remove the curvature in e vs. $\hat{Y}$ plot. Therefore, it was concluded that for modeling alkalinity, a basic MLR procedure is insufficient. The summary of various transformations attempts for total alkalinity (as $CaCO_3$) is provided in Table 5.2.

Table 5.2 Summary of Transformations for Total Alkalinity (as $CaCO_3$)

Steps	Transformations									Normal Probability Plot (NPP)	e vs. Yhat	comments
	Y variable	X variables										
	Alkalinity	Time (t)	Leachate Volume (L)	Food (F)	Paper (P)	Textile (Tx)	Yard (Ya)	Rain (R)	Temperature (T)			
1	Y	1/t	1/L	F	P	Tx	Ya	R	T	Not Ok as shorter tails on both sides	Funnel shape	In scatter plots curvature is apparent for time and leachate volume, so x transformation is required. Also, normality is not satisfied and funnel shape is observed which warrants variance stabilizing transformation (on Y).
2	Log(Y)	1/t	1/L	F	P	Tx	Ya	R	T	Longer tail on left side so normality is not ok.	No clear funnel shape	Non constant variance due to curvature wider spread of residuals for higher values of predicted Log Y.
3	Log(Y)	Log(t)	Log(L)	F	P	Tx	Ya	R	T	Ok	Curvature exists, so non constant variance	Curvature is observed in e vs. Rain and Temperature plot
4	Log(Y)	Log(t)	Log(L)	F	P	Tx	Ya	R & Std $(R)^2$	T & Std $(T)^2$	Ok	Curvature exists, so non constant variance	Curvature is observed in e vs. time plot
5	$1/\sqrt{Y}$	t	Log(L)	F	P	Tx	Ya	R & Std $(R)^2$	T & Std $(T)^2$	Ok	Curvature exists, so non constant variance	Curvature is observed in e vs. time plot
6	$1/\sqrt{Y}$	$\sqrt{t}$	Log(L)	F	P	Tx	Ya	R & Std $(R)^2$	T & Std $(T)^2$	Ok	Curvature exists, so non constant variance	Curvature is observed in e vs. time plot

Table 5.2 – *Continued*

7	$1/\sqrt{Y}$	Log(t)	Log(L)	F	P	Tx	Ya	R & Std $(R)^2$	T & Std $(T)^2$	Ok	Curvature exists, so non constant variance	Curvature is observed in e vs. time plot
8	$1/\sqrt{Y}$	$\frac{1}{\sqrt{t}}$	Log(L)	F	P	Tx	Ya	R & Std $(R)^2$	T & Std $(T)^2$	Ok	Curvature exists, so non constant variance	Curvature is observed in e vs. time plot
9	Log(Y)	$\frac{1}{\sqrt{t}}$	Log(L)	F	P	Tx	Ya	R & Std $(R)^2$	T & Std $(T)^2$	Ok	Curvature exists, so non constant variance	Curvature is observed in e vs. time plot
10	$\sqrt{Y}$	t & $Std(t)^2$	Log(L)	F	P	Tx	Ya	R & Std $(R)^2$	T & Std $(T)^2$	Ok	Curvature exists, so non constant variance	Curvature is observed in e vs. time plot
11	Log(Y)	t & $Std(t)^2$	Log(L)	F	P	Tx	Ya	R & Std $(R)^2$	T & Std $(T)^2$	Ok	Curvature exists, so non constant variance	Curvature is observed in e vs. time plot
12	1/Y	t & $Std(t)^2$	Log(L)	F	P	Tx	Ya	R & Std $(R)^2$	T & Std $(T)^2$	Ok	Curvature exists, so non constant variance	Curvature is observed in e vs. time plot
13	$1/\sqrt{Y}$	t & $Std(t)^2$	Log(L)	F	P	Tx	Ya	R & Std $(R)^2$	T & Std $(T)^2$	Ok	Curvature exists, so non constant variance	Modified-Levene Test concluded non constant variance
14	$1/\sqrt{Y}$	$\sqrt{1+t}$	Log(L)	F	P	Tx	Ya	R & Std (R)2	T & Std (T)2	Ok	Curvature exists, so non constant variance	Curvature is observed in e vs. time plot

Table 5.2 – *Continued*

15	$1/\sqrt{Y}$	Log(1 + t)	Log(L)	F	P	Tx	Ya	R & Std $(R)^2$	T & Std $(T)^2$	Ok	Curvature exists, so non constant variance	Curvature is observed in e vs. time plot
16	Log(Y)	t & $\sqrt{t}$	Log(L)	F	P	Tx	Ya	R & Std $(R)^2$	T & Std $(T)^2$	Ok	Curvature exists, so non constant variance	Curvature is apparent for e vs. time plot
17	$\sqrt{Y}$	t & $\sqrt{t}$	Log(L)	F	P	Tx	Ya	R & Std $(R)^2$	T & Std $(T)^2$	Not OK	Curvature exists, so non constant variance	Curvature is observed in e vs. time plot
18	Log(Y)	$\sqrt{t}$ & Std$(\sqrt{t})^2$	Log(L)	F	P	Tx	Ya	R & Std $(R)^2$	T & Std $(T)^2$	OK	Curvature exists, so non constant variance	Curvature is apparent for e vs. Food, Paper and Yard plots
19	$\sqrt{Y}$	$\sqrt{t}$ & Std$(\sqrt{t})^2$	Log(L)	F	P	Tx	Ya	R & Std $(R)^2$	T & Std $(T)^2$	Not OK	Curvature exists, so non constant variance	Curvature is observed in e vs. time plot
20	Log(Y)	$\sqrt{t}$ & Std$(\sqrt{t})^2$	Log(L)	F & Std $(F)^2$	P & Std $(P)^2$	Tx	Ya & Std $(Ya)^2$	R & Std $(R)^2$	T & Std $(T)^2$	OK	curvature so non constant variance	Curvature is observed in e vs. time plot
21	Log(Y)	$\sqrt{t}$ & Std$(\sqrt{t})^2$	Log(L)	F^2	P^2	Tx	Ya^2	R & Std $(R)^2$	T & Std $(T)^2$	OK	curvature so non constant variance	Curvature is observed in e vs. time plot

The e vs. $\hat{Y}$ plot and e vs. time plots for steps 4-21 (Table 5.2); and also e vs. $\hat{Y}$, e vs. rain, and e vs. temperature plots for step 3 are provided in Appendix.

5.6 Multivariate Adaptive Regression Splines (MARS) Analysis

The basic multiple linear regression method was insufficient for the data analysis due to nonlinearity between response and predictor variables, as discussed earlier. Therefore, a more sophisticated modeling approach of regression splines was used for the model development of all leachate parameters (pH, BOD, COD, total alkalinity as $CaCO_3$, conductivity, TDS, TSS, VSS, Cl^-, and NH_3-N), considering that the response may have a piecewise behavior over domain. MARS was run using Salford Predictive Modeler (SPM) Builder, version 6.6.

MARS was developed by Standford physicist and statistician, Jerome Friedman (1991). MARS is a modern nonparametric regression analysis method used in many studies (Walker 1990; Moore et al., 1991; White and Sifneos, 1997). MARS enables a rapid search through many candidate models to quickly identify a good model. The optimal model is selected in a two-stage process. In the first stage, MARS constructs an overly large model by adding basis functions. In the second stage, basis functions are deleted based on improvement in model fit until the model fit cannot be improved.

5.6.1 Model Fitting

Prior to building the model, it is important to define and explain a few terms that need to be understood when running MARS.

- Knots: When one regression line does not fit well to the data, then several regression lines (piecewise) are used to describe the overall behavior over the entire domain of the independent variable. A key concept underlying the spline is the knot. The value of the independent variable where the slope of a line changes is called a knot. A knot defines the end of one region of data and the beginning of another. Between knots, the model could be global (e.g. linear regression).
- Basis Functions: Basis functions are formed using truncated linear or “hinge” functions that are combined in a linear model to approximate the relationship between a response

variable and multiple predictor variables. Further, interaction basis functions are products of truncated linear functions involving different predictor variables.

For example, a univariate basis function (BF_1) on the variable temperature is defined by MARS as:

$$BF_1 = \max(0, \text{temperature} - 80) \qquad (5.3)$$

This truncated linear function truncates to zero all the values of temperature that fall below 80 °F.

- Fitting a Model: The initial model begins with a constant only (C_0), then adds a basis function (initially, univariate terms and later interaction terms) to build up a MARS model until the maximum number of basis functions, which is specified by the user, has been reached.

$$Y = C_0 + C_i * BF_i + \text{error} \quad (\text{where } i = 1,\ldots.n) \qquad (5.4)$$

Where Y is the response variable, C_0 is a constant and C_i is a coefficient for the i-th basis function.

- Model Validation: With large sample sizes, the data are split into training (e.g., 90% of the data) and test sets (e.g., 10% of the data). The training data set is used for model building and the test data set is used to validate the fitted model. For smaller samples, cross validation (CV) is the best method to use for validation (Hastie et al., 2001). In CV, one observation is left out and training is done on n-1 observations. The CV is the mean sum square of the differences between the Y_i's and their predicted values $\hat{Y}_i$ where an observation is excluded.
- Predictive Squared Error (PSE): It is the prediction error based on actual cross validation (CV).

5.6.2 Model Input and Optimal Model Selection Process for All Leachate Parameters

Various input options in Salford MARS specified to run the modeling are addressed below.

- Variable Selection: Target (Response) variable and predictor variables were selected accordingly.
- Maximum Basis Functions (Max BFs): Several runs were made with different max BFs. Analysis was started using the default value of 15 max BFs and then progressively added more max BFs until the best model was found based on the lowest mean Predictive Squared Error (PSE).
- Maximum Interactions: 2-way interaction was selected.
- Model to Compute: Best model option was selected.
- V-fold Cross Validation (CV): The default 10-fold CV option was selected.
- Other GUI (Graphical User Interface) options in the model input were selected as default to run the analysis.

Different models can be generated with different options in GUI and a model was chosen where PSE and adjusted-R^2 values were leveled off.

5.7 MARS Modeling for Total Alkalinity (as $CaCO_3$)

To run the analysis, a log transformation on alkalinity (Y-variable) was performed based on the prior regression analysis. Although MARS does not require specific model assumptions, such as constant variance or normality, to be satisfied, model fitting is easier when the error variance is more stable. The input options were selected as discussed above. Several runs were made with various max BFs to come up with the final model which has PSE and adjusted R^2 value leveled off. Table 5.3 provides the summary of the PSE and adj. R^2 values for various max BFs. The PSE and adj. R^2 values are also represented in graphs as Figures 5.8 and 5.9, respectively.

Table 5.3 Summary of PSE Values for Different Models – Total Alkalinity

Max Basis Functions	Optimal Model Nr (# of terms in the final model)	Predictive Squared Error (PSE) for Best Model Option	Adj. R^2
10	10	0.043	0.86519
15	8	0.03338	0.87356
18	18	0.02966	0.91448
20	18	0.02515	0.92485
22	19	0.02292	0.93073
25	15	0.02355	0.92315
29	29	0.02366	0.94294
30	30	0.02294	0.94416
32	32	0.02319	0.94607
33	33	0.02308	0.94649
35	35	0.02283	0.94757
37	34	0.02176	0.94996
40	39	0.02162	0.95406
42	34	0.02162	0.95615
44	41	0.01992	0.95846
46	45	0.01979	0.95908
48	40	0.0197	0.96026
50	37	0.01981	0.96126
52	46	0.01954	0.96288
54	44	0.01876	0.96389
56	44	0.01938	0.96442
58	51	0.01955	0.96475
60	57	0.01968	0.96494
62	42	0.02022	0.96491
64	55	0.02124	0.96574

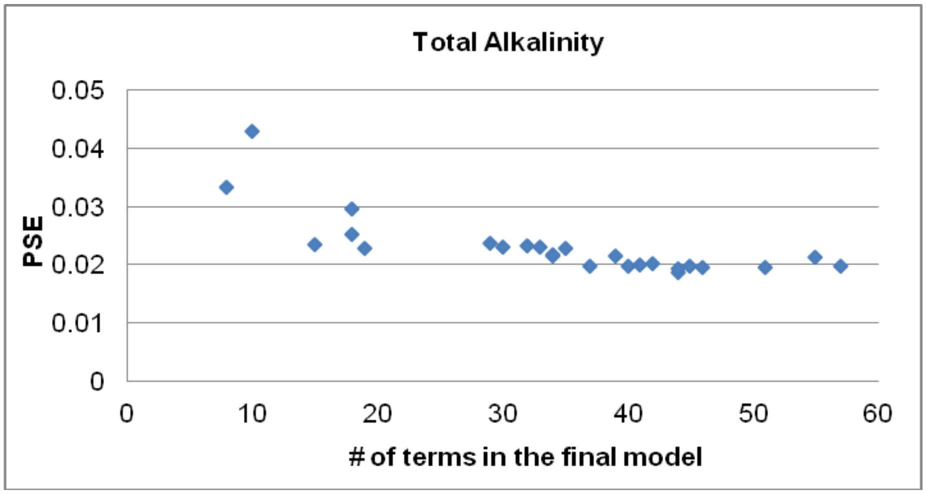


Figure 5.8 PSE Values for Various Models (Total Alkalinity)

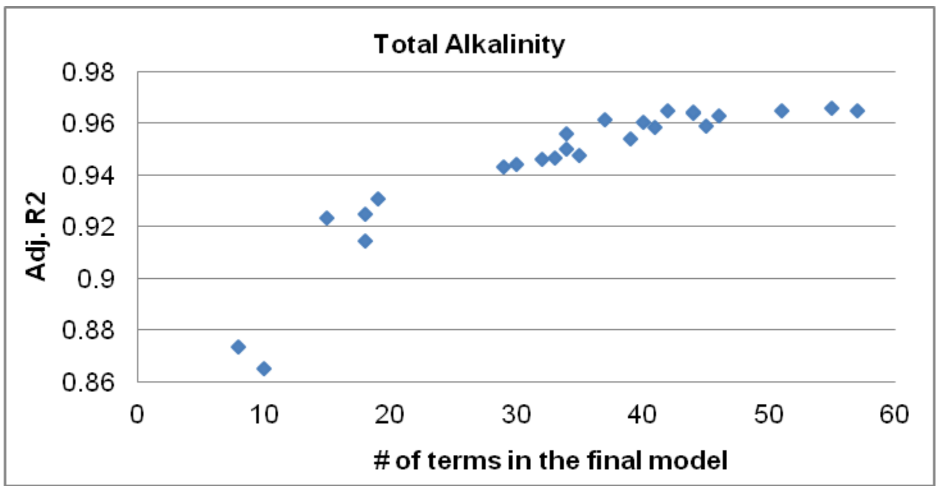


Figure 5.9 Adjusted-R^2 Values for Various Models (Total Alkalinity)

Looking at both graphs (Figure 5.8 and 5.9), the final model with lower PSE value of 0.01981 and adj. R^2 of 0.96126 was selected for total alkalinity.

5.7.1 Final Model for Total Alkalinity

The MARS text output includes final model using backward stepwise elimination method, ANOVA decomposition table, relative variable importance table, and regression information on the training data. The MARS model output for total alkalinity is provided in Appendix.

The ANOVA decomposition table for the final total alkalinity model with 50 max BF is provided in Table 5.4. In this table, the heading function is indexing different basis functions, standard deviation is a measure of variability for these BFs, -gcv (generalized cross-validation) is the reduction lack-of-fit (or the improvement of fit), #bsfns is the number of BFs with this structure, and #efprms is the number of effective parameters. In Table 5.4, the primary interest columns are #bsfns and variable. The variable column represents which parameters are appearing as main effect and which parameters appearing as interaction terms in the final model equation. The #bsfns column represents how many times a particular basis function is included in the final model equation.

Table 5.4 ANOVA Decomposition for Total Alkalinity

ANOVA Decomposition on 37 Basis Functions

fun	std. dev.	-gcv	#bsfns	#efprms	variable
1	0.35065	0.02696	3	8.28261	TIME
2	0.25388	0.02730	1	2.76087	RAIN
3	0.04158	0.01465	1	2.76087	YARD
4	0.16143	0.01954	2	5.52174	TEXTILE
5	0.09910	0.01967	2	5.52174	YARD TEMP
6	0.13607	0.02073	2	5.52174	TIME FOOD
7	0.22270	0.02902	2	5.52174	PAPER RAIN
8	0.09555	0.02082	6	16.56522	TIME RAIN
9	0.10229	0.01732	4	11.04348	YARD RAIN
10	0.18199	0.01850	2	5.52174	TIME TEXTILE
11	0.06733	0.01584	2	5.52174	TEXTILE TEMP
12	0.08409	0.01566	2	5.52174	PAPER YARD
13	0.03117	0.01517	1	2.76087	TIME LEACHVOL
14	0.06426	0.01546	2	5.52174	TIME PAPER
15	0.04334	0.01518	2	5.52174	TIME TEMP
16	0.02494	0.01440	2	5.52174	LEACHVOL TEXTILE
17	0.04840	0.01487	1	2.76087	TIME YARD

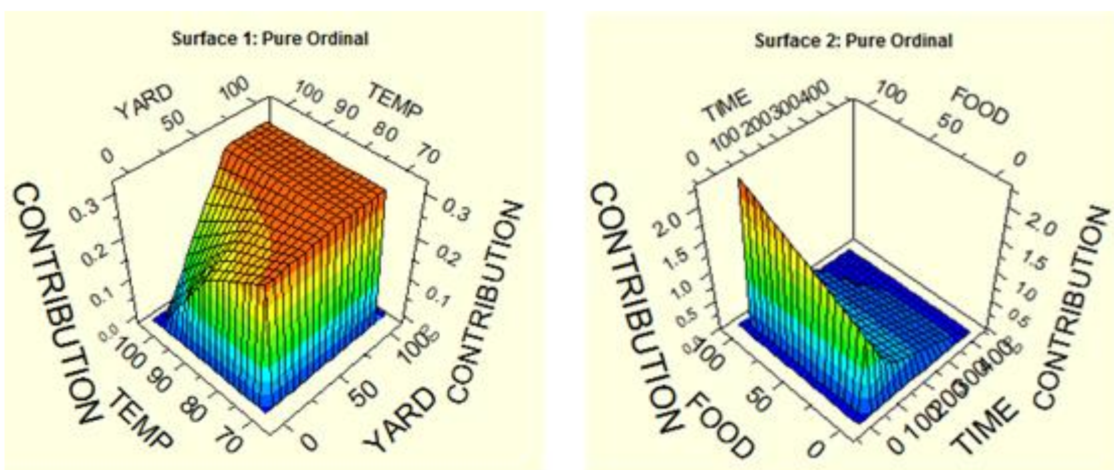
Variable importance for the total alkalinity model is provided in Table 5.5. The variable importance scores are calculated relative to the most important variable, which is always given a score of 100 (Hastie et al., 2001). In this table, TIME is given highest importance and RAIN second; while, LEACHVOL is given the least importance in predicting total alkalinity.

Table 5.5 Relative Variable Importance for Total Alkalinity

Variable	Importance	-gcv
TIME	100.00000	0.13997
RAIN	76.32967	0.08763
PAPER	42.35207	0.03706
YARD	40.12404	0.03476
TEXTILE	31.74441	0.02720
TEMP	24.53185	0.02211
FOOD	22.16418	0.02073
LEACHVOL	6.68754	0.01513

5.7.1.1 Curves for Final Model (Total Alkalinity)

MARS outputs the three-dimensional (3-D) plots which depict the relationship between a pair of predictor variables and the target variable. The 3-D plots and their explanation are provided in this section.



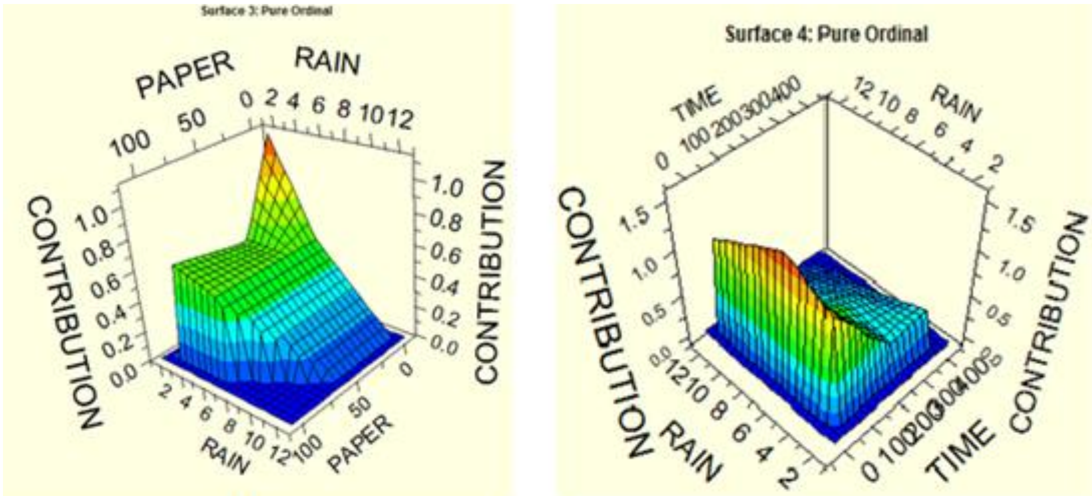
(a) (b)

Figure 5.10 3-D Interaction Plots (a) Yard-Temp and (b) Time-Food

In Figure 5.10 (a), as temperature increases and % Yard decreases, alkalinity concentration is lowest. With higher % yard and lower temperature range, alkalinity concentration increases.

In Figure 5.10 (b), alkalinity concentration decreases with time due to all food has degraded. When time is approx. between 0 to 50 days and %food is increasing from 0 to 100%

then alkalinity concentration gradually increases. This is due to food degrades quickly, which means initial high alkalinity in the leachate.



(a) (b)

Figure 5.11 3-D Interaction Plots (a) Rain-Paper and (b) Rain-Time

In Figure 5.11 (a), when %paper is between 0-30 and rainfall intensity is between 2 to 6 mm/d, alkalinity concentration is higher. There is a decrease in alkalinity as %paper or rainfall increases. Perhaps, increased rainfall dilutes the leachate. There is no data available for 100% paper and more than 6 mm/d rainfall, as there is no reactor available in the experimental design with this combination.

In Figure 5.11 (b), with the beginning of time and when rainfall goes from 2 to 6 mm/d, alkalinity concentration increases. However, when rainfall increases from 6 to 12 mm/d, there is a gradual drop in the alkalinity concentration. The drop could be due to waste already having been degraded or washed out.

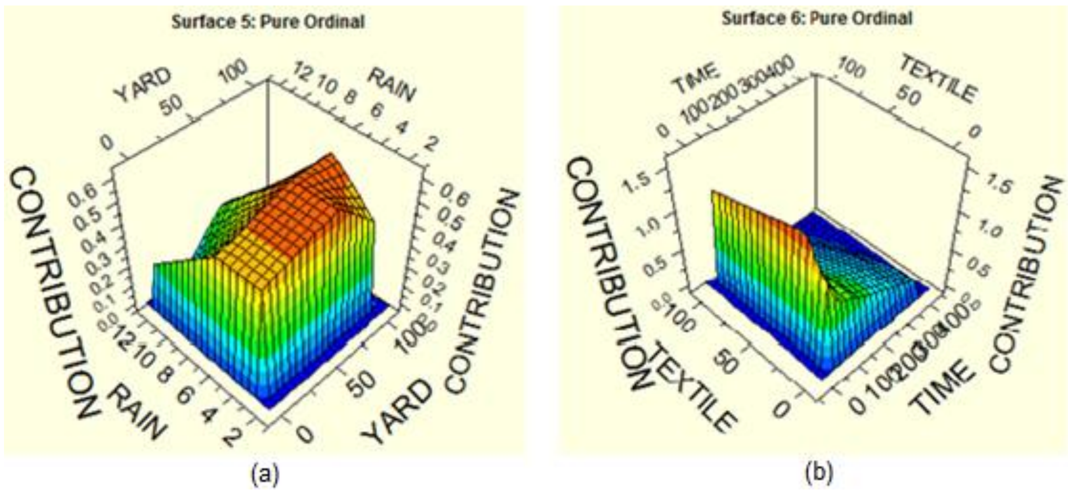


Figure 5.12 3-D Interaction Plots (a) Rain-Yard and (b) Textile-Time

In Figure 5.12 (a), when %yard increases from 0 to 60 and rainfall is between 2-6 mm/d, alkalinity concentration increases. However, when %yard increases beyond 60 and rainfall is beyond 6 mm/d, alkalinity decreases. Higher rainfall might be diluting the leachate concentrations. Also, when %yard is more, microbes might not be able to degrade the yard waste completely due to inhibitory effect of lignin component.

In Figure 5.12 (b), initially with time and when %textile increases from 0-25, alkalinity concentration increases. However, as time increases and %textile increases beyond 25, there is a decrease in alkalinity. When %textile is higher, microbes have to degrade polyester components which may take years.

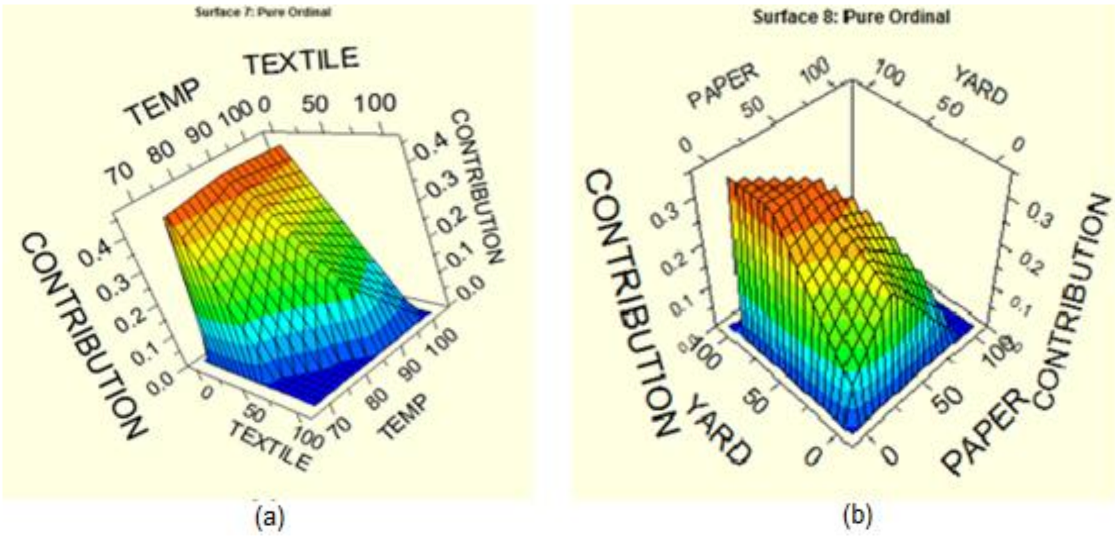


Figure 5.13 3-D Interaction Plots (a) Temp-Textile and (b) Paper-Yard

In Figure 5.13 (a), when %textile is between 0-20 and temperature is between 70-100 °F, alkalinity concentration is highest. Looking at the graph temperature effect remains approximately constant. When %textile increases beyond 20, there is a gradual decrease in alkalinity, while temp has minimum or no effect. The flat area in the plot is due to lack of data.

In Figure 5.13 (b), when paper is between 0-30% and yard is between 0-60% then there is a gradual increase in alkalinity concentration. Also, when paper is between 0-30% and yard is above 60% then alkalinity seems to level off. When %paper is above 60, alkalinity decreases which might be due to inhibitory effect of lignin.

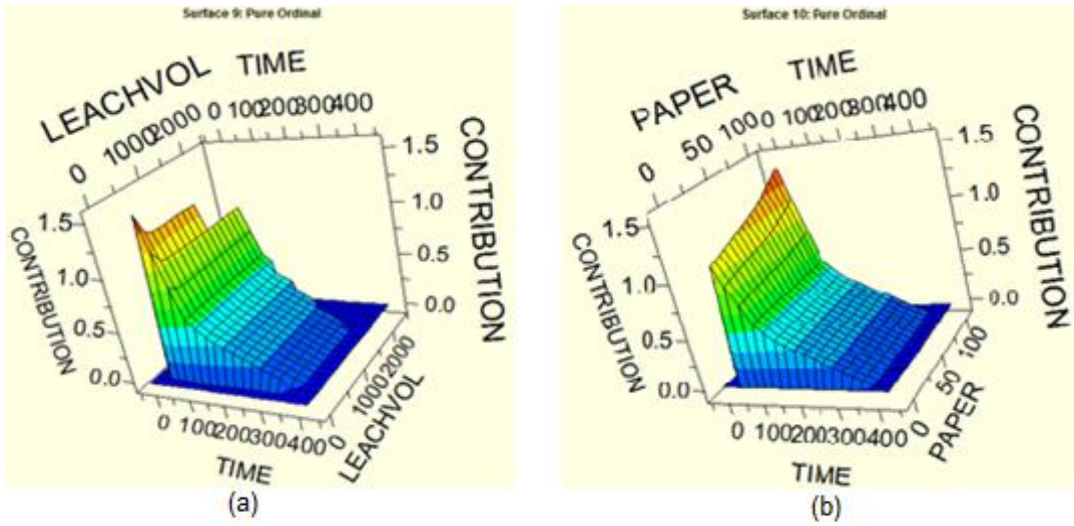


Figure 5.14 3-D Interaction Plots (a) Time-Leachate Volume and (b) Time-Paper

In Figure 5.14 (a), initially with time and when leachate generation is less, alkalinity concentration is higher. However, when time and leachate generation increases, then alkalinity concentration is significantly low which is due to waste has already degraded.

In Figure 5.14 (b), when time is between 0-50 days and %paper is 100 then alkalinity concentration is highest. As time increases, alkalinity concentration decreases and %paper effect is negligible.

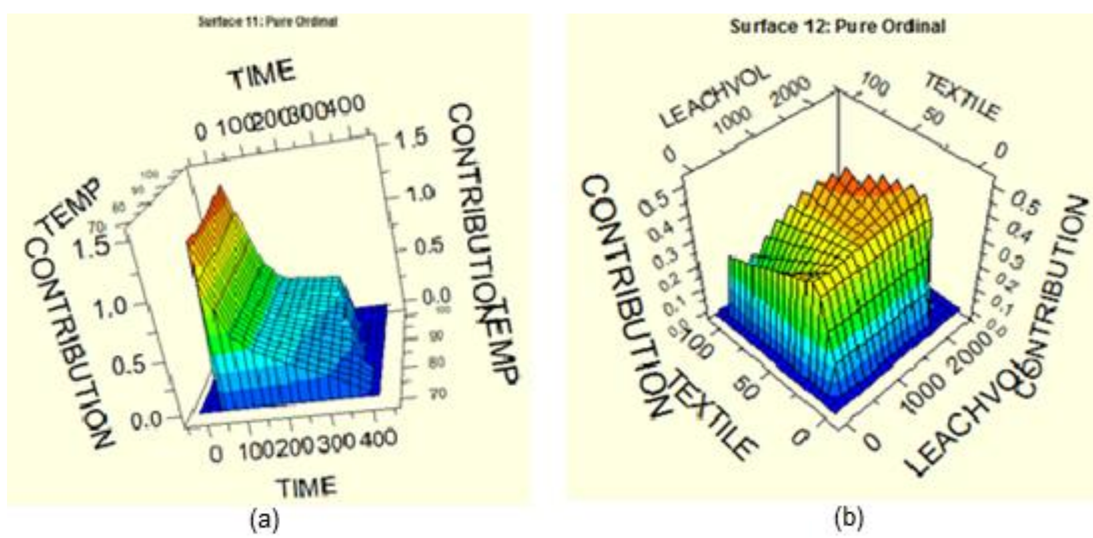
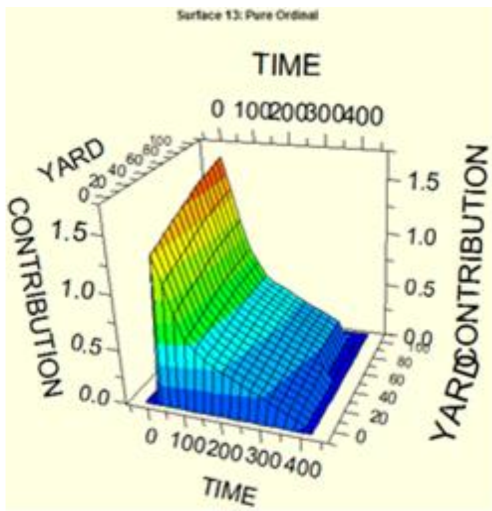


Figure 5.15 3-D Interaction Plots (a) Time-Temperature and (b) Textile-Leachate Volume

In Figure 5.15 (a), as time increases, alkalinity concentration decreases and temperature is having no or minimal effect.

In Figure 5.15 (b), when textile is up to 25% and for any given volume of leachate, alkalinity concentration increases and then above 25% textile, alkalinity concentration drops slowly. This drop is because when %textile is high, microbes are having difficult time to degrade polyester and non-biodegradable portion of the textile which takes years.



(a)

Figure 5.16 3-D Interaction Plots (a) Time-Yard

In Figure 5.16 (a), when time is between 0-50 days and yard increases from 0 to 100%, alkalinity concentration increases. However, as time increases, alkalinity concentration decreases and yard is having significantly less or no effect. Perhaps in the beginning microbes can degrade the easily accessible yard waste, so with higher %yard, alkalinity increases. As time goes on, microbes are having inhibitory effect due to lignin which is hard to degrade, meaning degradation/alkalinity decreases.

5.8 MARS Modeling for Conductivity

To run the analysis, log transformation on conductivity (Y-variable) was performed as it was necessary to scatter the data points. The input options were selected as discussed in Section 5.6.2. Several runs were made with various max BFs to come up with the final model which has PSE and adjusted R^2 value leveled off. Table 5.6 provides the summary of the PSE and adj. R^2 values for various max BFs. The PSE and adj. R^2 values are also represented in graphs as Figures 5.17 and 5.18, respectively.

Table 5.6 Summary of PSE Values for Different Models – Conductivity

Max Basis Functions	**Optimal Model Nr (# of terms in the model)**	**Predictive Squared Error (PSE) for Best Model Option**	**Adj. R^2**
15	15	0.0253	0.90787
16	15	0.02455	0.91601
18	18	0.0232	0.92468
20	16	0.02079	0.93201
22	21	0.01874	0.93789
24	23	0.01829	0.9418
26	25	0.01782	0.94443
28	27	0.01728	0.94649
30	28	0.01615	0.94841
32	28	0.01703	0.94899
34	27	0.01718	0.95144
36	29	0.01708	0.95469
38	28	0.01721	0.95562
40	35	0.01691	0.95819
42	36	0.01668	0.95958
44	38	0.01654	0.96062
46	34	0.01613	0.96092
48	42	0.01636	0.96331
50	31	0.01518	0.95799
52	33	0.01645	0.96078
54	38	0.01665	0.9655

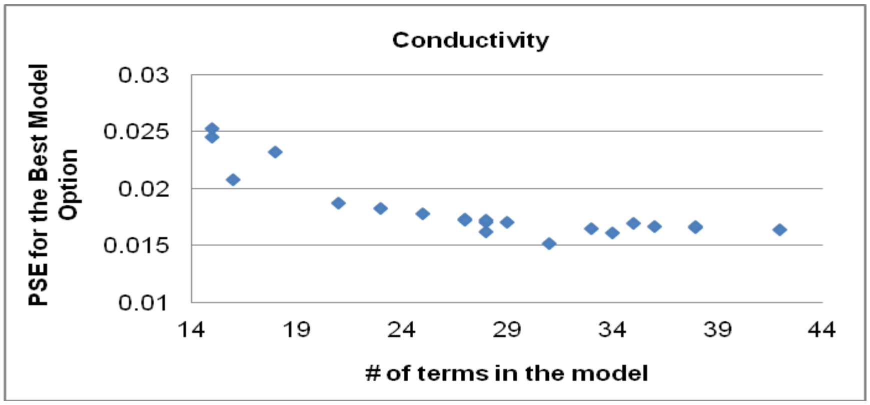


Figure 5.17 PSE Values for Various Models (Conductivity)

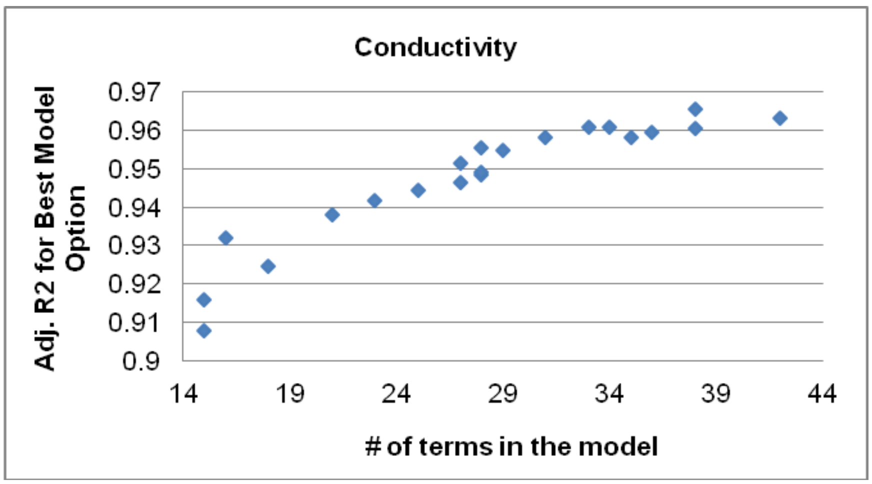


Figure 5.18 Adjusted-R^2 Values for Various Models (Conductivity)

Looking at both graphs (Figure 5.17 and 5.18), the final model with lower PSE value of 0.01518 and adj. R^2 of 0.95799 was selected for conductivity.

5.8.1 Final Model for Conductivity

The MARS text output includes final model using backward stepwise elimination method, ANOVA decomposition table, relative variable importance table, and regression information on the training data. The MARS model output for conductivity is provided in Appendix.

The ANOVA decomposition table for the final conductivity model with 50 max BF is provided in Table 5.7. In this table, the heading function is indexing different basis functions, standard deviation is a measure of variability for these BFs, -gcv (generalized cross-validation) is the reduction lack-of-fit (or the improvement of fit), #bsfns is the number of BFs with this structure, and #efprms is the number of effective parameters. In Table 5.7, the primary interest columns are #bsfns and variable. The variable column represents which parameters are appearing as main effect and which parameters appearing as interaction terms in the final model equation. The #bsfns column represents how many times a particular basis function is included in the final model equation.

Table 5.7 ANOVA Decomposition for Conductivity

ANOVA Decomposition on 30 Basis Functions

fun	std. dev.	-gcv	#bsfns	#efprms	variable
1	0.40464	0.02427	2	5.12500	TIME
2	0.20990	0.01600	1	2.56250	RAIN
3	0.10244	0.01586	2	5.12500	YARD
4	0.23284	0.01904	2	5.12500	FOOD
5	0.26638	0.02604	4	10.25000	PAPER RAIN
6	0.14065	0.02190	4	10.25000	TIME FOOD
7	0.13666	0.01544	2	5.12500	YARD TEMP
8	0.16803	0.01668	1	2.56250	TEXTILE YARD
9	0.12483	0.01818	5	12.81250	TIME RAIN
10	0.13308	0.01319	1	2.56250	PAPER YARD
11	0.33552	0.01532	2	5.12500	TEXTILE RAIN
12	0.03264	0.01294	1	2.56250	TIME LEACHVOL
13	0.05622	0.01274	1	2.56250	TIME TEXTILE
14	0.04449	0.01266	2	5.12500	TIME TEMP

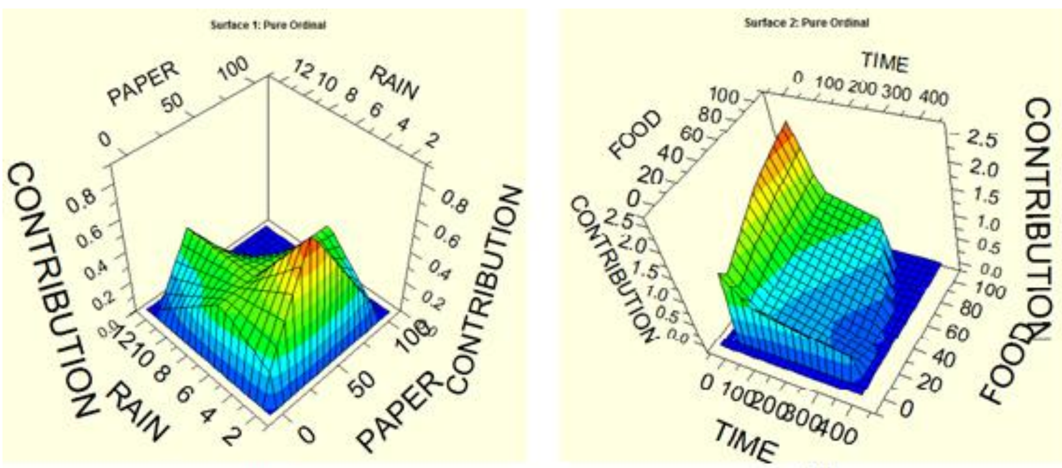
Variable importance for the conductivity model is provided in Table 5.8. The variable importance scores are calculated relative to the most important variable, which is always given a score of 100 (Hastie et al., 2001). In this table, TIME is given highest importance and RAIN second; while, LEACHVOL is given the least importance in predicting conductivity.

Table 5.8 Relative Variable Importance for Conductivity

Variable	Importance	-gcv
TIME	100.00000	0.11253
RAIN	89.75130	0.09302
YARD	58.12185	0.04610
PAPER	44.66276	0.03222
FOOD	41.87233	0.02980
TEXTILE	24.85653	0.01841
TEMP	18.18761	0.01553
LEACHVOL	8.55359	0.01294

5.8.1.1 Curves for Final Model (Conductivity)

MARS outputs the three-dimensional (3-D) plots which depict the relationship between a pair of predictor variables and the target variable. The 3-D plots and their explanation are provided in this section for the final conductivity model.

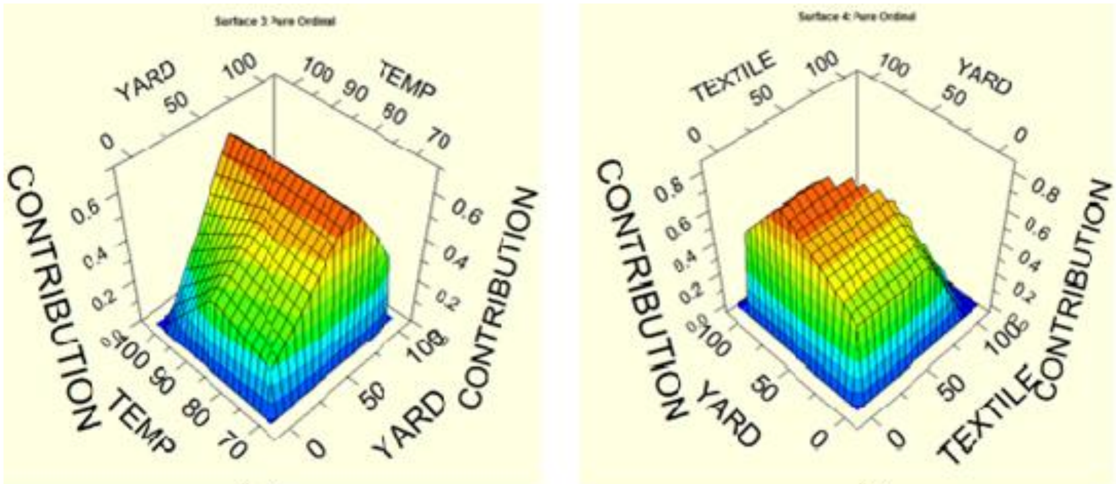


(a) (b)

Figure 5.19 3-D Interaction Plots (a) Rain-Paper and (b) Time-Food

In Figure 5.19 (a), for paper up to 30% and 2 mm/d rainfall, there is a gradual increase in conductivity concentration. Above 30% paper and at 2 mm/d rainfall, conductivity concentration decreases which might be due to inhibitory effect of lignin component. When rainfall increases from 6 to 12 mm/d, conductivity concentration decreases due to washout.

In Figure 5.19 (b), initially with time, as the %food increases, conductivity concentration increases gradually. However, as time goes on; conductivity concentration decreases due to food waste has already decomposed.

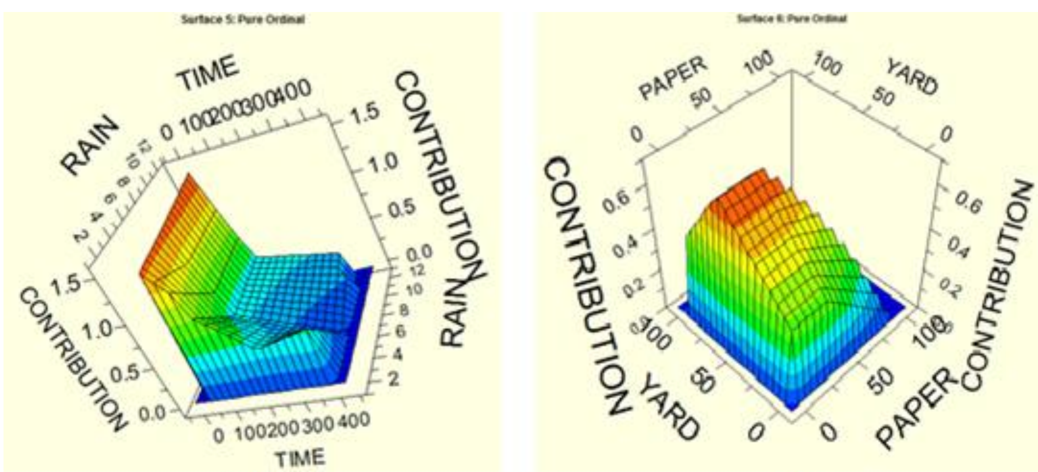


(a) (b)

Figure 5.20 3-D Interaction Plots (a) Yard-Temperature and (b) Yard-Textile

In Figure 5.20 (a), when yard increases up to 60% there is an increase in conductivity concentration for any given temperature, and then it drops beyond 60% yard. Perhaps, with high %yard there could be lignin effect. Also, when %yard is low and temperature increases up to 85 °F; there is an increase in conductivity and then it drops with increasing temperature.

In Figure 5.20 (b), for yard up to 60% and any range of textile, conductivity concentration increases and above 60% yard it decreases. Textile seems to have no effect towards conductivity.

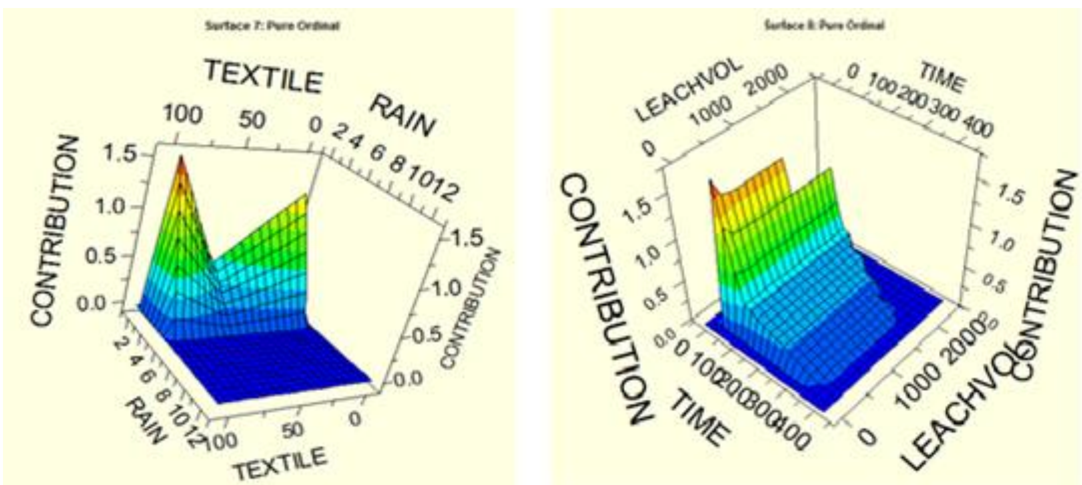


(a) (b)

Figure 5.21 3-D Interaction Plots (a) Time-Rain and (b) Yard-Paper

In Figure 5.21 (a), initially with time, conductivity concentration is higher with high rainfall. Over time, conductivity concentration decreases as most of the waste has been degraded.

In Figure 5.21 (b), when yard is up to 60%, there is an increase in conductivity concentration. However, beyond 60% yard there is a gradual decrease in conductivity. For paper up to 30%, conductivity concentration doesn't change but beyond this range, concentration decreases. Perhaps, there is an inhibitory effect of lignin for yard and paper waste.



(a) (b)

Figure 5.22 3-D Interaction Plots (a) Textile-Rain and (b) Time-Leachate Volume

In Figure 5.22 (a), for lowest rainfall and when textile increases from 60-100%, conductivity concentration increases. Also, as textile increases from 0-60% and rainfall increases, conductivity concentration decreases. The trend in this graph might be misleading as there is no data available for 12 mm/d rainfall with 100% textile.

In Figure 5.22 (b), over time, conductivity concentration decreases because more waste has already degraded. Also, as leachate volume increases, the drop is observed in conductivity concentration. Perhaps, higher rainfall generates higher volume of diluted leachate which decreases the concentration.

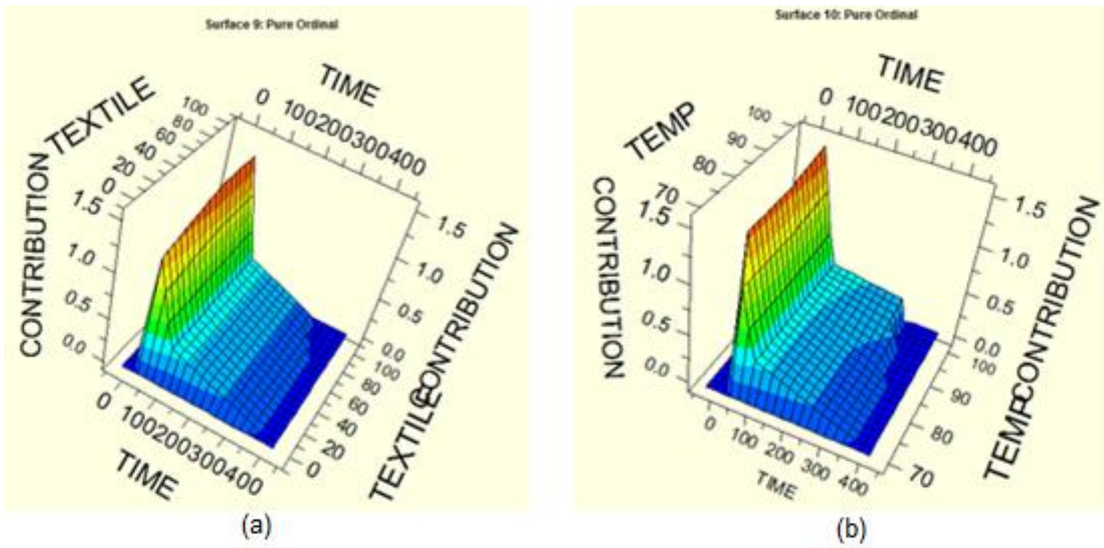


Figure 5.23 3-D Interaction Plots (a) Textile-Time and (b) Time-Temperature

In Figure 5.23 (a), initially with time, as %textile increases, conductivity concentration increases. As time increases, conductivity concentration decreases and %textile seems to have little effect. However, other graphs show that high %textile tends to inhibit degradation or has lower leachate concentration.

In Figure 5.23 (b), as temperature increases in the beginning with time, conductivity concentration increases. Higher temperatures tend to degrade the waste faster which increases the concentration in the beginning. Also, when temperature decreases with time; conductivity concentration decreases as most of the waste has been degraded.

5.9 MARS Modeling for Total Dissolved Solids (TDS)

To run the analysis, log transformation on TDS (Y-variable) was performed as it was necessary to scatter the data points. The input options were selected as discussed in Section 5.6.2. Several runs were made with various max BFs to come up with the final model which has PSE and adjusted R^2 value leveled off. Table 5.9 provides the summary of the PSE and adj. R^2 values for various max BFs. The PSE and adj. R^2 values are also represented in graphs as Figures 5.24 and 5.25, respectively.

Table 5.9 Summary of PSE Values for Different Models – TDS

Max Basis Functions	Optimal Model Nr (# of terms in the model)	Predictive Squared Error (PSE) for Best Model Option	Adj. R^2
15	10	0.03111	0.87879
16	11	0.0296	0.8857
18	14	0.02793	0.89864
20	16	0.02865	0.9046
22	20	0.02702	0.91178
24	21	0.02429	0.91795
26	21	0.02334	0.92194
28	27	0.0229	0.92562
30	27	0.023	0.92854
32	26	0.02286	0.93241
34	33	0.02238	0.93405
36	33	0.02207	0.93597
38	31	0.02174	0.938
40	32	0.02201	0.94009
42	34	0.02229	0.94176
44	37	0.02211	0.9425
46	38	0.02143	0.944
48	36	0.02227	0.94369
50	33	0.02162	0.94269
52	39	0.02146	0.94633
54	35	0.02035	0.9447
56	37	0.02104	0.94554

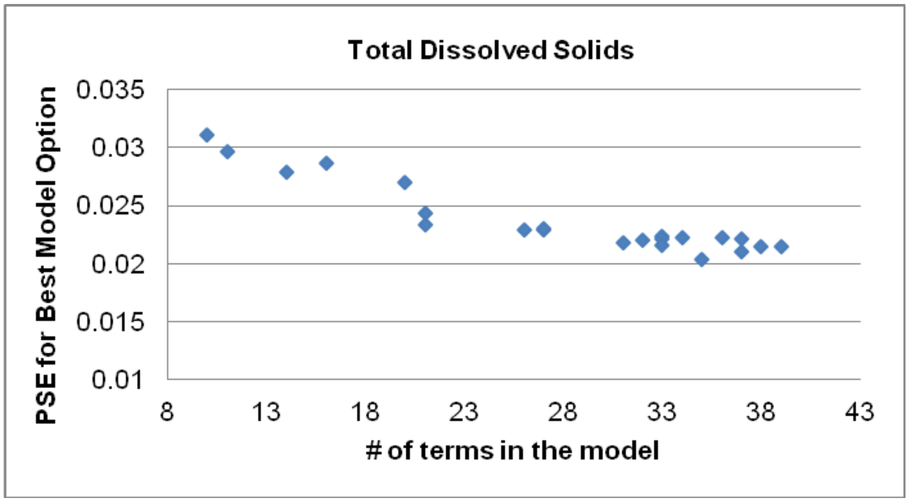


Figure 5.24 PSE Values for Various Models (TDS)

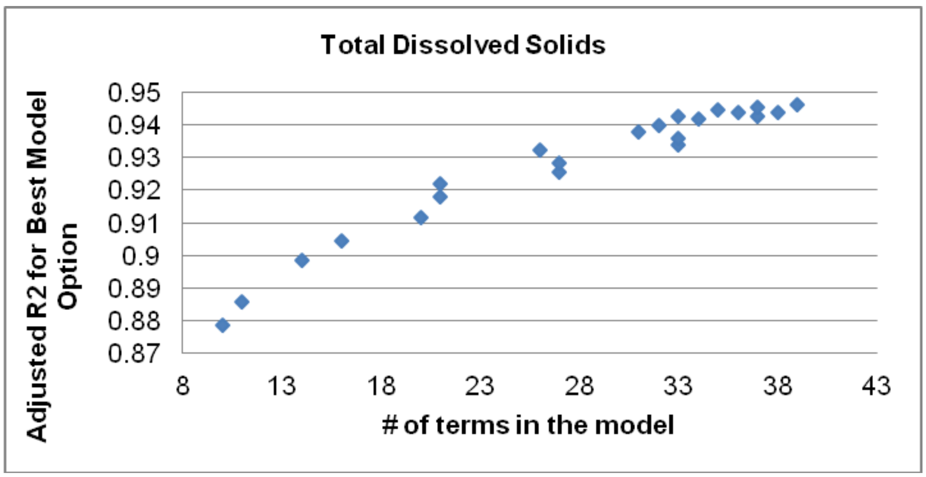


Figure 5.25 Adjusted-R^2 Values for Various Models (TDS)

Looking at both graphs (Figure 5.24 and 5.25), the final model with lower PSE value of 0.02162 and adj. R^2 of 0.94269 was selected for TDS.

5.9.1 Final Model for Total Dissolved Solids (TDS)

The MARS text output includes final model using backward stepwise elimination method, ANOVA decomposition table, relative variable importance table, and regression information on the training data. The MARS model output for TDS is provided in Appendix.

The ANOVA decomposition table for the final TDS model with 50 max BF is provided in Table 5.10. In this table, the heading function is indexing different basis functions, standard deviation is a measure of variability for these BFs, -gcv (generalized cross-validation) is the reduction lack-of-fit (or the improvement of fit), #bsfns is the number of BFs with this structure, and #efprms is the number of effective parameters. In Table 5.10, the primary interest columns are #bsfns and variable. The variable column represents which parameters are appearing as main effect and which parameters appearing as interaction terms in the final model equation. The #bsfns column represents how many times a particular basis function is included in the final model equation.

Table 5.10 ANOVA Decomposition for TDS

ANOVA Decomposition on 33 Basis Functions

fun	std. dev.	-gcv	#bsfns	#efprms	variable
1	0.65750	0.02207	4	10.89362	TIME
2	0.27352	0.03984	1	2.72340	RAIN
3	0.08208	0.02395	1	2.72340	YARD
4	0.07736	0.02088	1	2.72340	PAPER
5	0.15867	0.02517	1	2.72340	PAPER RAIN
6	0.48280	0.02974	5	13.61702	TIME FOOD
7	0.13557	0.02751	1	2.72340	TEXTILE YARD
8	0.13688	0.02537	5	13.61702	TIME RAIN
9	0.07112	0.02122	3	8.17021	TIME PAPER
10	0.16360	0.02601	3	8.17021	TEXTILE RAIN
11	0.03079	0.02001	1	2.72340	TIME LEACHVOL
12	0.04575	0.01974	1	2.72340	TIME TEXTILE
13	0.24502	0.02280	4	10.89362	TIME TEMP
14	0.06573	0.02078	2	5.44681	PAPER TEMP

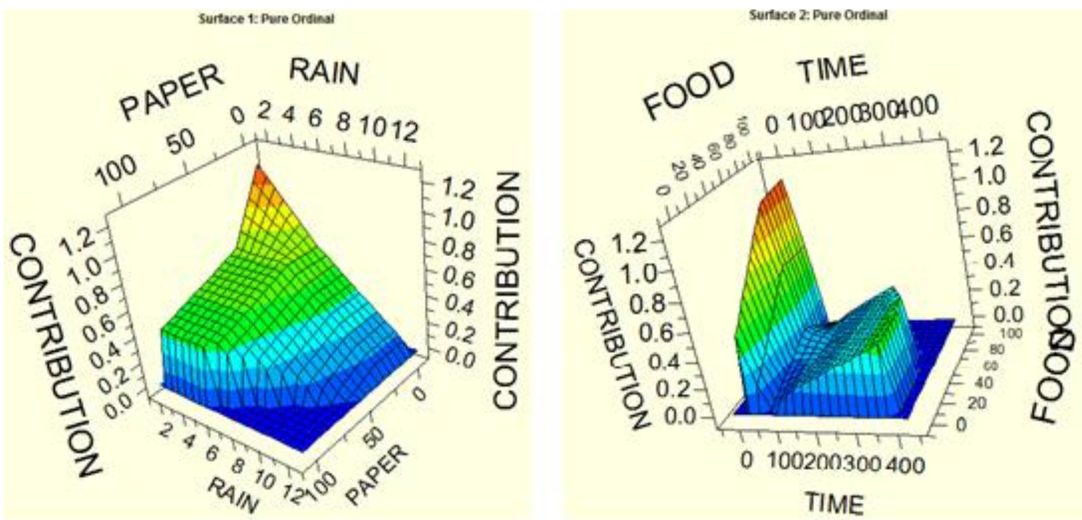
Variable importance for the TDS model is provided in Table 5.11. The variable importance scores are calculated relative to the most important variable, which is always given a score of 100 (Hastie et al., 2001). In this table, RAIN is given highest importance and TIME second; while, LEACHVOL is given the least importance in predicting TDS.

Table 5.11 Relative Variable Importance for TDS

Variable	Importance	-gcv
RAIN	100.00000	0.13454
TIME	94.22755	0.12165
PAPER	43.34694	0.04118
YARD	42.55708	0.04040
FOOD	29.72369	0.02974
TEXTILE	29.60074	0.02965
TEMP	20.97094	0.02463
LEACHVOL	6.13271	0.02001

5.9.1.1 Curves for Final Model (TDS)

MARS outputs the three-dimensional (3-D) plots which depict the relationship between a pair of predictor variables and the target variable. The 3-D plots and their explanation are provided in this section for the final TDS model.



(a) (b)

Figure 5.26 3-D Interaction Plots (a) Paper-Rain and (b) Time-Food

In Figure 5.26 (a), as %paper and rainfall intensity increase, total dissolved solids (TDS) concentration decreases. It is observed that with 2 mm/d rainfall and low %paper, TDS concentration is maximum. Higher rain decreases concentrations due to washout. Decreased concentrations with high %paper could be due to the lignin effect (microbe difficulty in degrading waste with high lignin content).

In Figure 5.26 (b), in the beginning with time, when %food is increasing, TDS concentration increases and reaches the peak. This may be due to more food particles washing out and increasing TDS with higher food content. However, when time is about 100 days, there is a significant drop in TDS and then again it increases gradually with time. The initial TDS peak may be due to washout; the second peak may be due to degradation products. A long lag time was observed in the food reactors before substantial waste degradation began, due to acid accumulation.

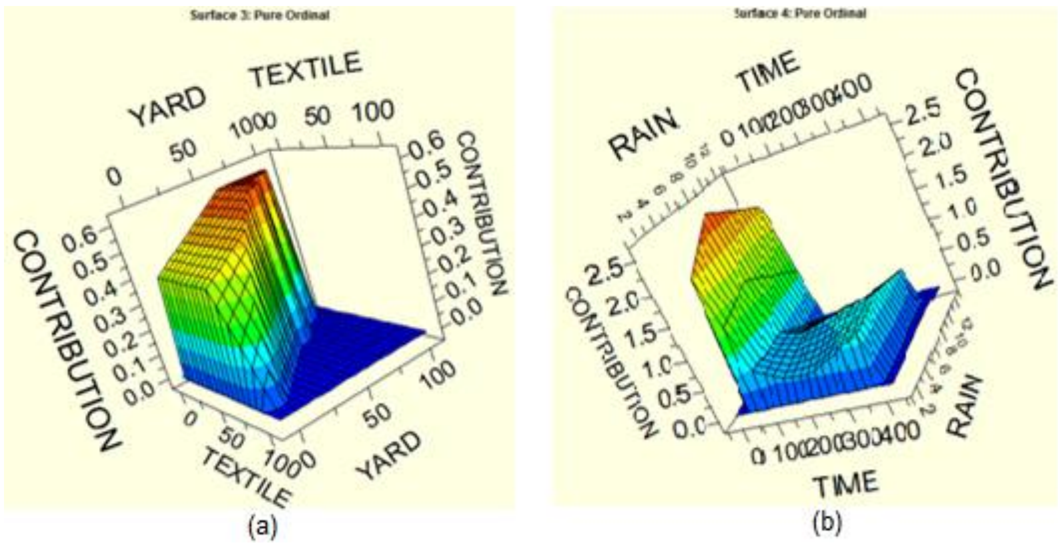


Figure 5.27 3-D Interaction Plots (a) Yard-Textile and (b) Time-Rain

In Figure 5.27 (a), when %textile is lowest and %yard is highest, TDS concentration is highest. As %textile increases and %yard decreases, TDS concentration decreases. This perhaps shows that yard is generally more degradable than textile. Upon dismantling reactors having textile waste, it was also observed that most of the textile waste remained unchanged. This could be the reason that increase in %textile does not contribute to high TDS concentration.

In Figure 5.27 (b), at t=0, TDS increases with rainfall up to 8 mm/d, and then decreases. At low values of rainfall, waste moisture content could be too low to promote substantial waste degradation. At high values of rainfall, the dilution effect might lower TDS concentrations. This would mean that TDS concentrations would peak at intermediate rainfall values. Also, with time, TDS concentration generally decreases, as most of the waste would have been degraded.

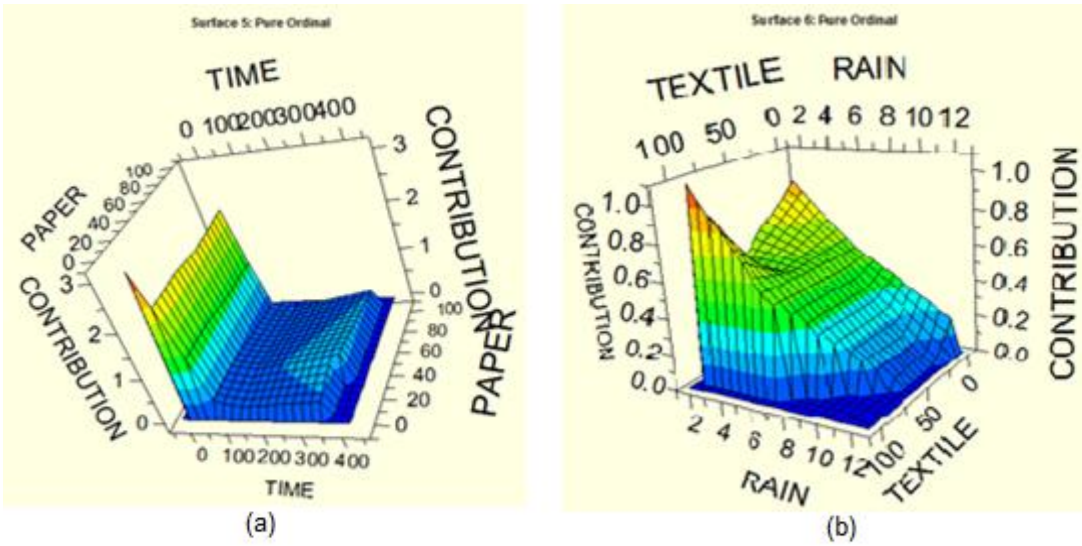


Figure 5.28 3-D Interaction Plots (a) Time-Paper and (b) Textile-Rain

In Figure 5.28 (a), at initial values of time, TDS concentration is highest and %paper seems to have no effect on TDS. However, TDS decreases significantly over time, as waste would have been degraded. Even at later values of time, % paper seems to have little effect on TDS. This could be due to the lignin effect described above.

In Figure 5.28 (b), when rainfall is low, TDS concentration is high due to less washout. As rainfall increases, TDS concentration decreases due to dilution effect. With the exception of 2 mm/day rainfall, %textile has little impact on the TDS concentration. This is likely due to non-degradable textile waste. This was confirmed while dismantling reactors having textile waste, where textile was unchanged. There is no data available for 12 mm/d rainfall and 100% textile.

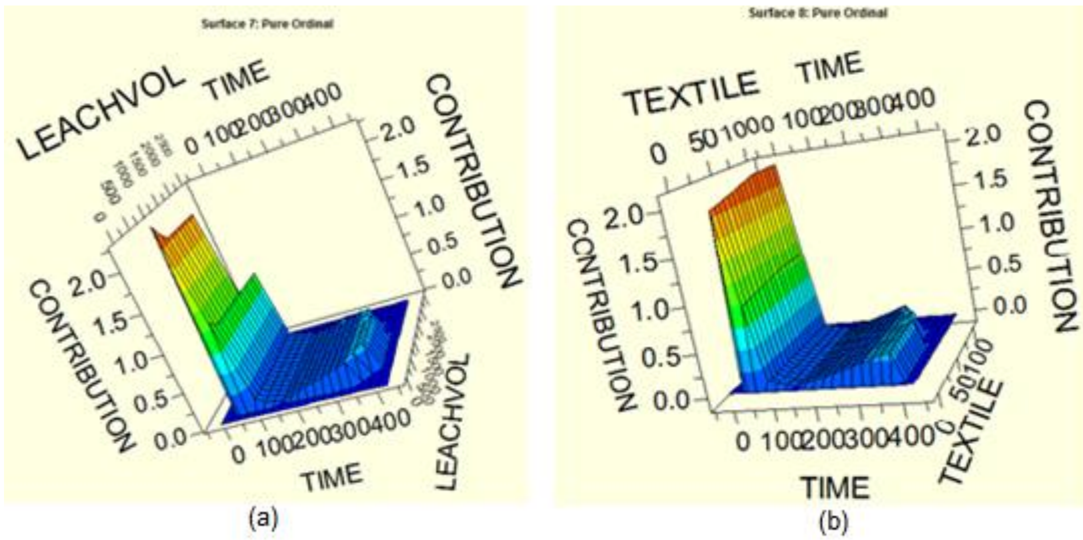


Figure 5.29 3-D Interaction Plots (a) Time-Leachate Volume and (b) Textile-Time

In Figure 5.29 (a), at initial values of time, when leachate volume is less, TDS is at peak due to less dilution. As time and leachate volume increase, TDS concentration drops significantly due to waste having been degraded over time and more dilution

In Figure 5.29 (b), at initial values of time, TDS is at peak due to more waste degradation occurring in the beginning. %textile seems to little or no effect on TDS. Upon dismantling reactors having textile waste, it was also observed that most of the textile waste remained unchanged. This could be the reason that increase in %textile does not contribute to high TDS concentration.

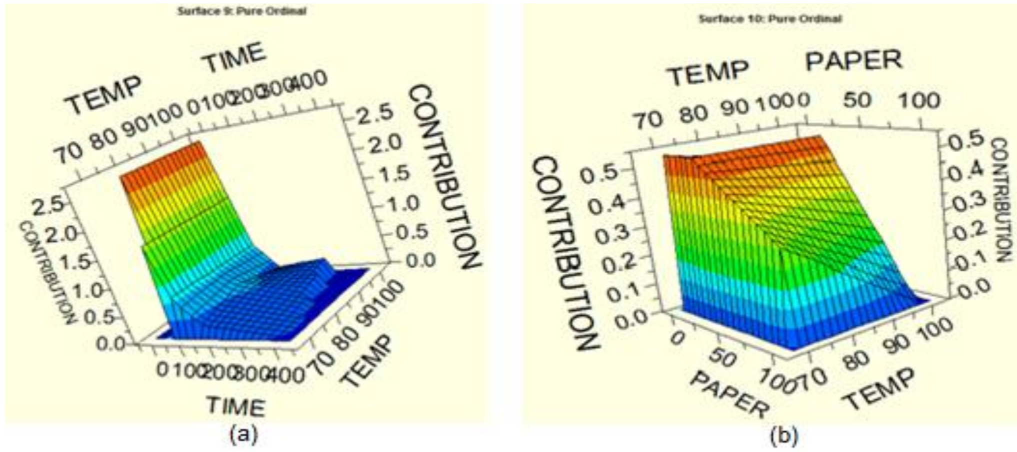


Figure 5.30 3-D Interaction Plots (a) Time-Temperature and (b) Paper-Temperature

In Figure 5.30 (a), initially with time, TDS concentration is at peak. As time increases, TDS drops due to waste degradation having already occurred. Temperature seems to have little or no effect on TDS concentration.

In Figure 5.30 (b), When temperature is lowest and %paper increases up to 30%, TDS concentration is at peak. As %paper and temperature increase, TDS concentration decreases. This is due to more degradation having been accomplished over time, which decreases concentration. Also, high %paper would not be easily degradable due to the lignin effect, and this leads to a decrease in TDS.

5.10 MARS Modeling for Total Suspended Solids (TSS)

To run the analysis, log transformation on TSS (Y-variable) was performed as it was necessary to scatter the data points. The input options were selected as discussed in Section 5.6.2. Several runs were made with various max BFs to come up with the final model which has PSE and adjusted R^2 value leveled off. Table 5.12 provides the summary of the PSE and adj. R^2 values for various max BFs. The PSE and adj. R^2 values are also represented in graphs as Figures 5.31 and 5.32, respectively. The graphs in Figures 5.31 and 5.32 are plotted up to 38 max BFs (Table 5.12), because beyond this range it can be observed that by increasing max BFs doesn't improve number of terms in the model and it starts behaving peculiar (highlighted in light gray).

Table 5.12 Summary of PSE Values for Different Models – TSS

Max Basis Functions	Optimal Model Nr (# of terms in the model)	Predictive Squared Error (PSE) for Best Model Option	Adj. R^2
15	6	0.07802	0.62579
16	6	0.07724	0.62579
18	14	0.07823	0.69615
20	17	0.07445	0.70415
22	22	0.07095	0.71141
24	20	0.07035	0.72089
26	22	0.07128	0.72645
28	20	0.06926	0.72406
30	28	0.0697	0.73355
32	28	0.06961	0.74062
34	34	0.07011	0.74928
36	35	0.07132	0.75308
38	31	0.07297	0.75837
40	22	0.07284	0.73558
42	20	0.07255	0.72835
44	33	0.07499	0.7647
46	29	0.07312	0.75902
48	36	0.07326	0.76918
50	35	0.0743	0.76888
52	23	0.07486	0.7432
54	19	0.07554	0.7274
56	19	0.07367	0.71705
58	16	0.07488	0.71705
60	41	0.07561	0.79067
62	35	0.07435	0.77729
64	40	0.07737	0.78027
66	36	0.07751	0.78027
72	33	0.07495	0.77367
78	33	0.07728	0.74687
84	22	0.07829	0.71119

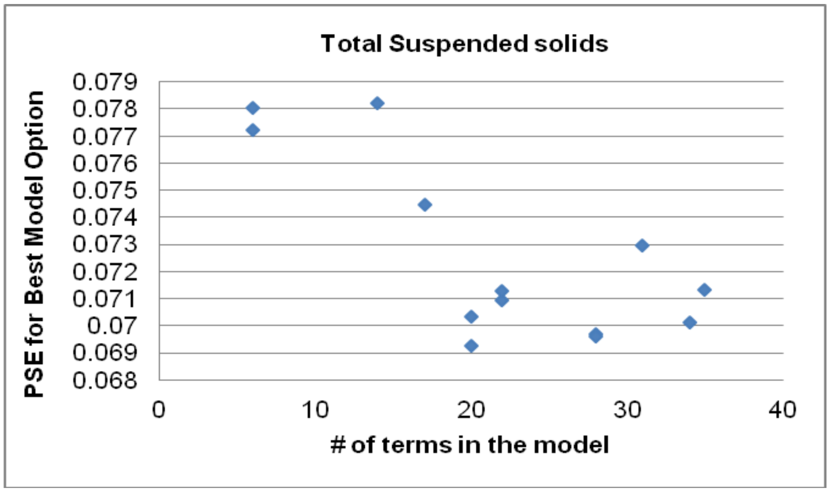


Figure 5.31 PSE Values for Various Models (TSS)

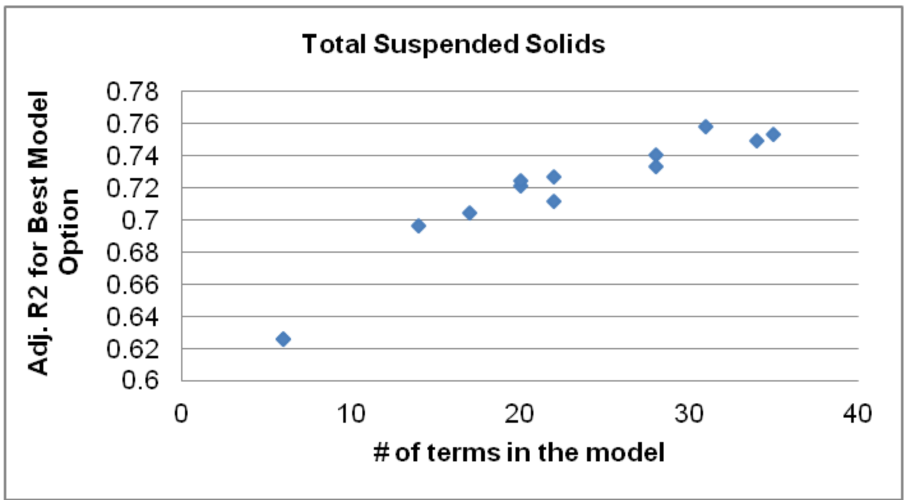


Figure 5.32 Adjusted-R^2 Values for Various Models (TSS)

Looking at both graphs (Figure 5.31 and 5.32), the final model with lower PSE value of 0.06926 and adj. R^2 of 0.72406 was selected for TSS.

5.10.1 Final Model for Total Suspended Solids (TSS)

The MARS text output includes final model using backward stepwise elimination method, ANOVA decomposition table, relative variable importance table, and regression information on the training data. The MARS model output for TSS is provided in Appendix.

The ANOVA decomposition table for the final TSS model with 28 max BF is provided in Table 5.13. In this table, the heading function is indexing different basis functions, standard deviation is a measure of variability for these BFs, -gcv (generalized cross-validation) is the reduction lack-of-fit (or the improvement of fit), #bsfns is the number of BFs with this structure, and #efprms is the number of effective parameters. In Table 5.13, the primary interest columns are #bsfns and variable. The variable column represents which parameters are appearing as main effect and which parameters appearing as interaction terms in the final model equation. The #bsfns column represents how many times a particular basis function is included in the final model equation.

Table 5.13 ANOVA Decomposition for TSS

ANOVA Decomposition on 20 Basis Functions

fun	std. dev.	-gcv	#bsfns	#efprms	variable
1	0.41315	0.11314	2	5.77778	RAIN
2	0.14447	0.07687	2	5.77778	TIME
3	0.11795	0.07130	2	5.77778	LEACHVOL
4	0.09679	0.07159	1	2.88889	RAIN TEMP
5	0.15826	0.07661	2	5.77778	PAPER RAIN
6	0.07544	0.07269	1	2.88889	TIME YARD
7	0.03480	0.06853	1	2.88889	TIME RAIN
8	0.05694	0.06962	1	2.88889	TIME FOOD
9	0.17477	0.07862	3	8.66667	FOOD RAIN
10	0.16311	0.07082	3	8.66667	TIME LEACHVOL
11	0.09131	0.06981	1	2.88889	LEACHVOL FOOD
12	0.09307	0.07288	1	2.88889	FOOD TEMP

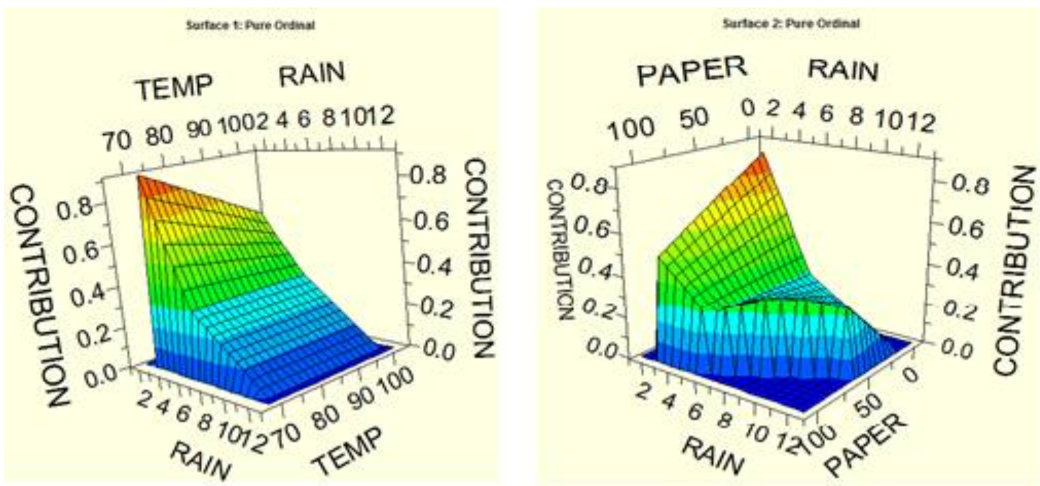
Variable importance for the TSS model is provided in Table 5.14. The variable importance scores are calculated relative to the most important variable, which is always given a score of 100 (Hastie et al., 2001). In this table, RAIN is given highest importance and TIME second; while, LEACHVOL is given the least importance in predicting TSS.

Table 5.14 Relative Variable Importance for TSS

Variable	Importance	-gcv
RAIN	100.00000	0.12862
TIME	91.16444	0.11848
FOOD	60.93209	0.09089
TEMP	46.20616	0.08142
PAPER	36.53146	0.07661
YARD	26.09216	0.07269
LEACHVOL	24.03236	0.07207

5.10.1.1 Curves for Final Model (TSS)

MARS outputs the three-dimensional (3-D) plots which depict the relationship between a pair of predictor variables and the target variable. The 3-D plots and their explanation are provided in this section for the final TSS model.



(a) (b)

Figure 5.33 3-D Interaction Plots (a) Rain-Temperature and (b) Paper-Rain

In Figure 5.33 (a), when rain and temp are lowest, contribution to TSS is highest. As the rain increases, there is more leachate dilution due to higher rainfall; therefore, TSS concentration decreases significantly. At high temperatures, degradation occurs more quickly, which would initially increase TSS and then decreases it later.

In Figure 5.33 (b), when rain and % paper are lowest, the contribution to TSS is at peak. As rain and % paper increase, TSS concentration decreases. Perhaps, due to higher rainfall there is washout effect. Also, with higher %paper, microbes are having hard time to degrade lignin component, which may take years to decompose. The experimental design doesn't have a reactor with a combination of 100% paper and 12 mm/d rainfall and due to this flat area is observed in the graph.

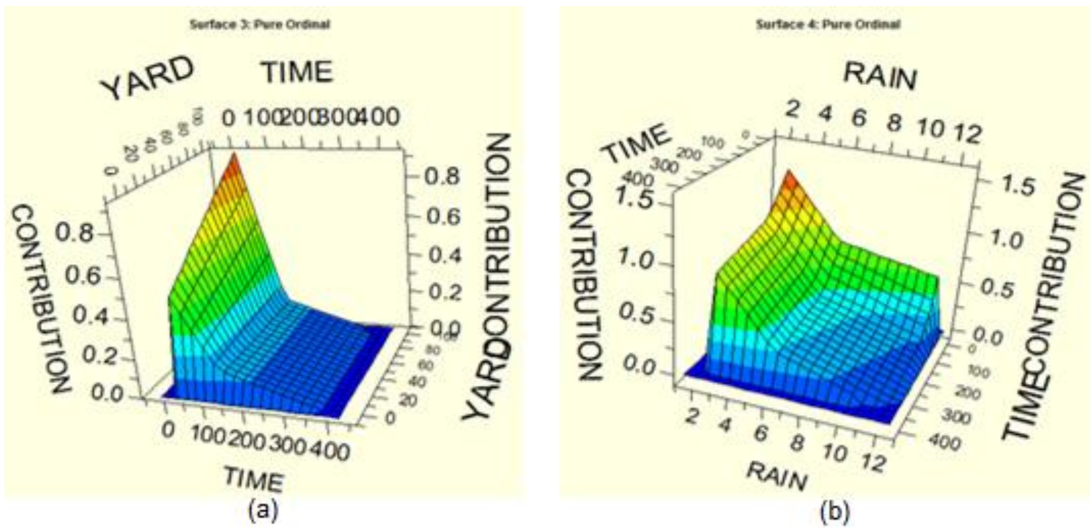


Figure 5.34 3-D Interaction Plots (a) Time-Yard and (b) Time-Rain

In Figure 5.34 (a), initially with time and when % yard is highest, TSS concentration is at peak and decreases as %yard decreases. As time increases with less % yard, TSS concentration also decreases. Perhaps in the beginning microbes can degrade the easily accessible yard waste, so with higher %yard, TSS increases. As time goes on, microbes are having inhibitory effect due to lignin which is hard to degrade, meaning TSS concentration decreases. The TSS decrease with time is expected, as waste degradation proceeds.

In Figure 5.34 (b), initially with time and lowest rainfall, TSS concentration is highest due to concentrated leachate. When time passes by with increasing rainfall, TSS concentration decreases. There may be dilution effect on leachate due to higher rainfall.

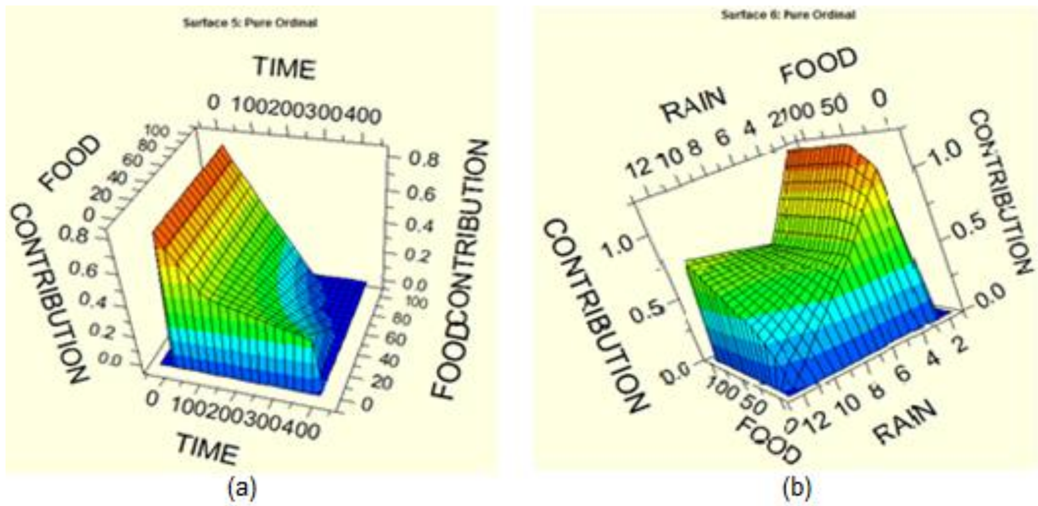


Figure 5.35 3-D Interaction Plots (a) Time-Food and (b) Rain-Food

In Figure 5.35 (a), initially with time and when %food is highest, TSS concentration is highest due to higher organic content. TSS concentration decreases gradually with time and lower % food. Perhaps, with time most of the food waste has been degraded.

In Figure 5.35 (b), with highest %food and lowest rainfall, TSS concentration is at peak. However, when rain intensity increases and %food decreases, TSS concentration decreases. This may happen because higher rainfall dilutes leachate and also with less %food, the organic content is less which decreases TSS.

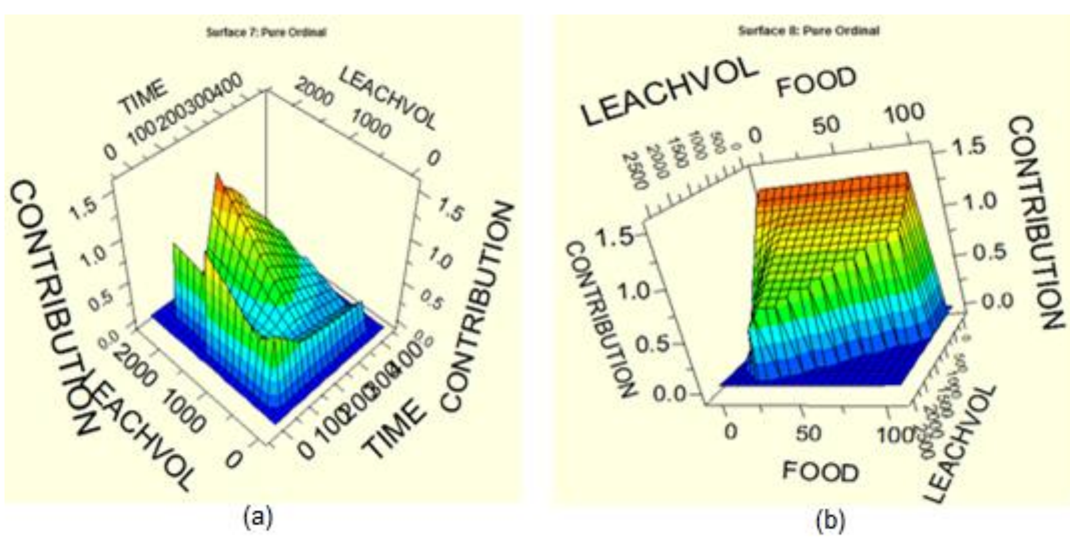
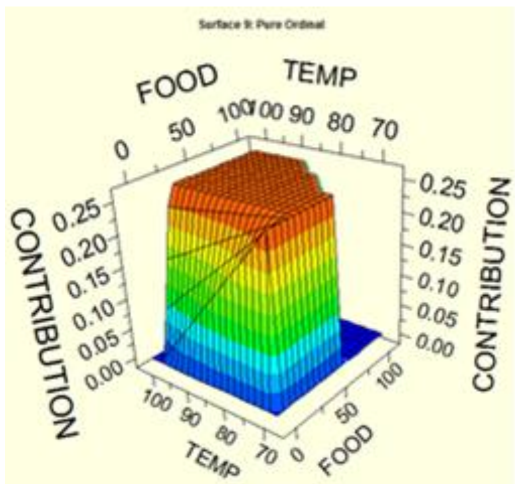


Figure 5.36 3-D Interaction Plots (a) Time-Leachate Volume and (b) Food-Leachate Volume

In Figure 5.36 (a), it is difficult to figure out the trend of TSS concentration in terms of time and leachate volume. However, the raw plots of TSS over time for various reactors (Appendix) indicate that there is a lot of fluctuation and that fluctuation is what MARS model appears to be trying to capture in terms of interaction between time and leachate volume.

In Figure 5.36 (b), when leachate volume is less, TSS concentration is at peak and % food seems to have no effect. However, as leachate volume and % food increases, TSS concentration goes down. Perhaps, this is due to washout effect.



(a)

Figure 5.37 3-D Interaction Plot (a) Food-Temperature

In Figure 5.37 (a), When temperature and %food are highest, TSS concentration is at peak. At low %food values, as temperature increases, TSS drops. For %food above about 25%, %food and temperature seem to have no effect on TSS.

5.11 MARS Modeling for Volatile Suspended Solids (VSS)

To run the analysis, log transformation on VSS (Y-variable) was performed as it was necessary to scatter the data points. The input options were selected as discussed in Section 5.6.2. Several runs were made with various max BFs to come up with the final model which has PSE and adjusted R^2 value leveled off. Table 5.15 provides the summary of the PSE and adj. R^2 values for various max BFs. The PSE and adj. R^2 values are also represented in graphs as Figures 5.38 and 5.39, respectively.

Table 5.15 Summary of PSE Values for Different Models – VSS

Max Basis Functions	Optimal Model Nr (# of terms in the model)	Predictive Squared Error (PSE) for Best Model Option	Adj. R^2
15	12	0.06443	0.73599
16	16	0.06248	0.73722
18	18	0.06194	0.74659
20	12	0.06348	0.73413
22	18	0.0636	0.76537
24	13	0.06345	0.7516
26	15	0.06006	0.76702
28	19	0.05788	0.77518
30	20	0.05857	0.77856
32	31	0.05825	0.79298
34	30	0.05625	0.79572
36	19	0.05606	0.77575
38	20	0.05525	0.77449
40	19	0.05911	0.78094
42	19	0.05728	0.77449
44	21	0.05882	0.78933
46	11	0.05866	0.72604
48	17	0.05549	0.75927
50	19	0.05838	0.77144
52	19	0.05507	0.76532
54	22	0.05976	0.78219
56	22	0.06323	0.79244
58	21	0.06182	0.78568
60	17	0.06285	0.75095
62	9	0.07129	0.70584
64	14	0.06561	0.77307

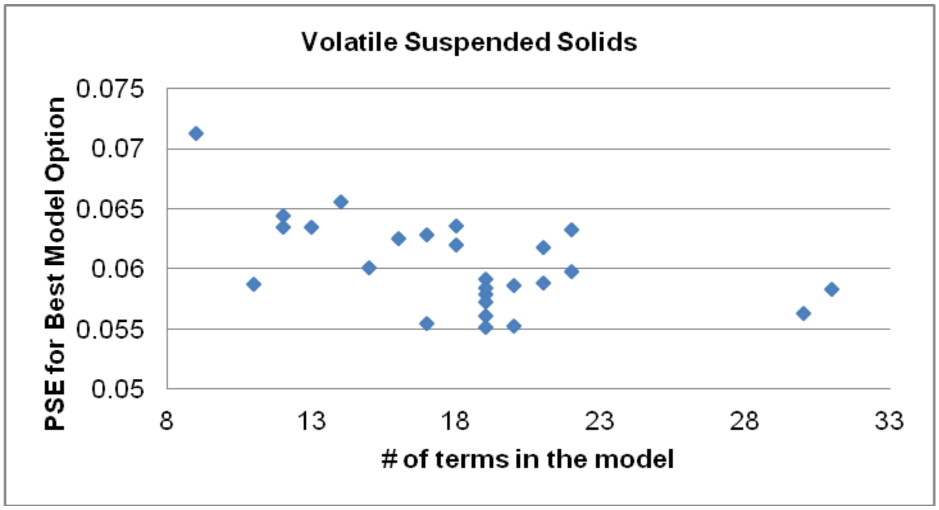


Figure 5.38 PSE Values for Various Models (VSS)

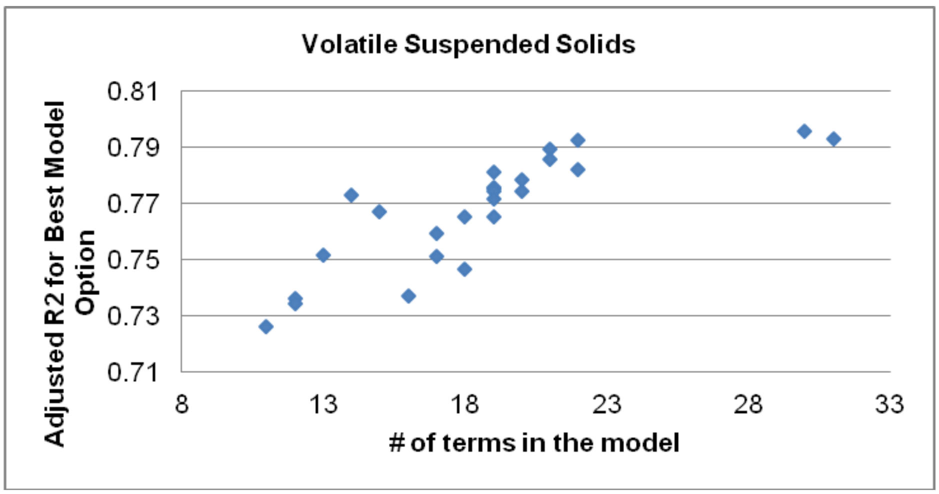


Figure 5.39 Adjusted-R^2 Values for Various Models (VSS)

Looking at both graphs (Figure 5.38 and 5.39), the final model with lower PSE value of 0.05788 and adj. R^2 of 0.77518 was selected for VSS.

5.11.1 Final Model for Volatile Suspended Solids (VSS)

The MARS text output includes final model using backward stepwise elimination method, ANOVA decomposition table, relative variable importance table, and regression information on the training data. The MARS model output for VSS is provided in Appendix.

The ANOVA decomposition table for the final VSS model with 28 max BF is provided in Table 5.16. In this table, the heading function is indexing different basis functions, standard deviation is a measure of variability for these BFs, -gcv (generalized cross-validation) is the reduction lack-of-fit (or the improvement of fit), #bsfns is the number of BFs with this structure, and #efprms is the number of effective parameters. In Table 5.16, the primary interest columns are #bsfns and variable. The variable column represents which parameters are appearing as main effect and which parameters appearing as interaction terms in the final model equation. The #bsfns column represents how many times a particular basis function is included in the final model equation.

Table 5.16 ANOVA Decomposition for VSS

ANOVA Decomposition on 19 Basis Functions

fun	std. dev.	-gcv	#bsfns	#efprms	variable
1	0.38150	0.08061	2	5.21429	TIME
2	0.31294	0.07830	2	5.21429	RAIN
3	0.12742	0.05888	1	2.60714	FOOD
4	0.10964	0.06102	2	5.21429	RAIN TEMP
5	0.06460	0.05624	1	2.60714	FOOD PAPER
6	0.05723	0.05631	1	2.60714	FOOD TEMP
7	0.11106	0.05907	1	2.60714	FOOD RAIN
8	0.12223	0.05770	4	10.42857	TIME FOOD
9	0.09951	0.05713	1	2.60714	TIME YARD
10	0.09799	0.05618	2	5.21429	TIME RAIN
11	0.07530	0.05688	1	2.60714	YARD RAIN
12	0.07648	0.05668	1	2.60714	PAPER RAIN

Variable importance for the VSS model is provided in Table 5.17. The variable importance scores are calculated relative to the most important variable, which is always given a score of 100 (Hastie et al., 2001). In this table, RAIN is given highest importance and TIME second; while, LEACHVOL is given the least importance in predicting VSS.

Table 5.17 Relative Variable Importance for VSS

Variable	Importance	-gcv
RAIN	100.00000	0.12486
TIME	93.35110	0.11586
FOOD	71.06572	0.09019
TEMP	41.14675	0.06667
PAPER	31.69315	0.06184
YARD	22.42266	0.05833

5.11.1.1 Curves for Final Model (VSS)

MARS outputs the three-dimensional (3-D) plots which depict the relationship between a pair of predictor variables and the target variable. The 3-D plots and their explanation are provided in this section for the final VSS model.

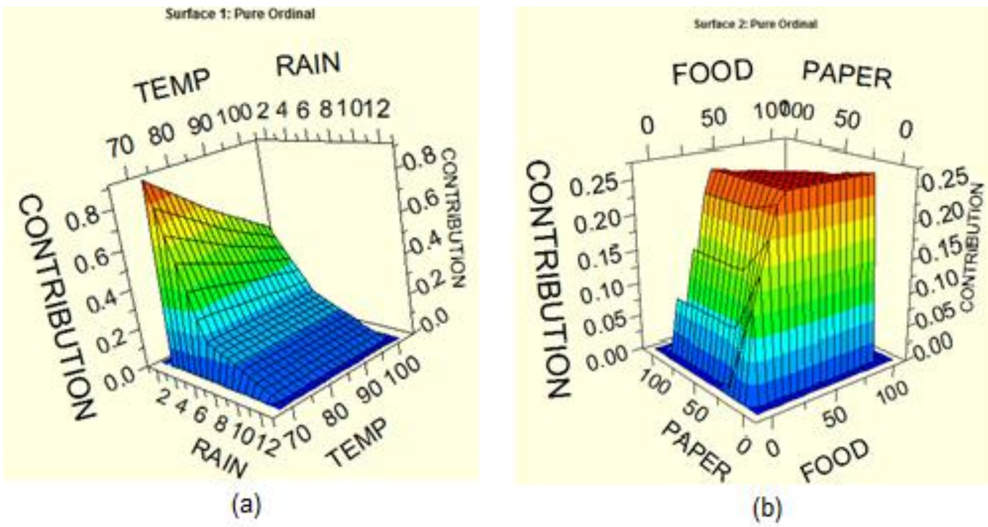


Figure 5.40 3-D Interaction Plots (a) Temperature-Rain and (b) Paper-Food

In Figure 5.40 (a), when rain and temp are lowest, contribution to VSS is highest. As the rain increases, there is more leachate dilution due to higher rainfall; therefore, VSS concentration decreases significantly. At high temperatures, degradation occurs more quickly, which would initially increase VSS and then decreases it later.

In Figure 5.40 (b), when %food increases from 0 to 25, VSS concentration increases gradually. This is due to more organic matter is there as %food increases, which increases VSS, which is a measure of organic matter present in the waste. However, beyond that range

VSS concentration remains at peak. %paper seems to have no impact on VSS, as it remains constant.

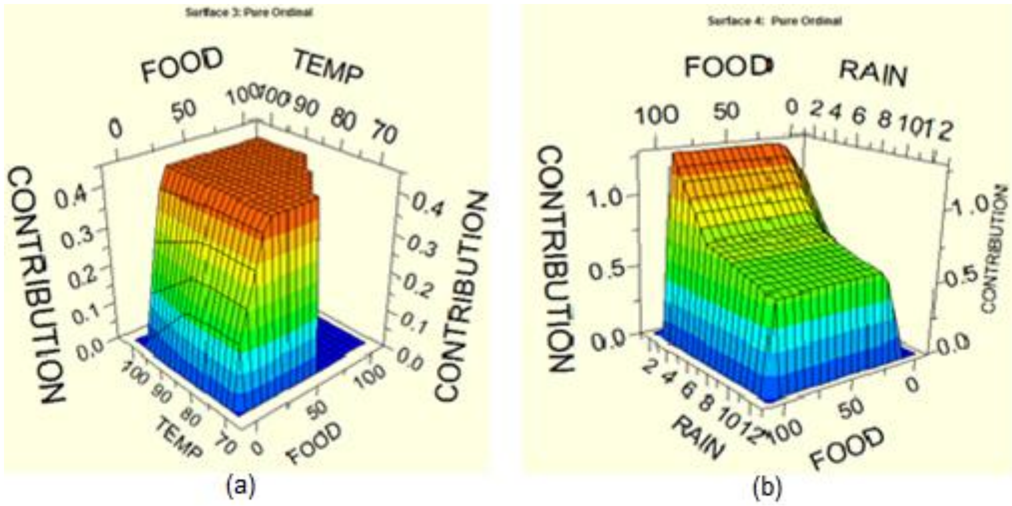


Figure 5.41 3-D Interaction Plots (a) Temperature-Food and (b) Rain-Food

In Figure 5.41 (a), when temperature increases beyond 85 °F, there is a decline in VSS concentration. Data analysis conducted elsewhere (Altouqi, 2012) indicates that the microbes may have functioned optimally at 85 °F. Also, when %food increases from 0 to 25, there is a gradual increase in VSS concentration. Perhaps, higher %food increases organic matter concentration, which increases VSS. Beyond 25% food, however, VSS concentration remains at peak.

In Figure 5.41 (b), with highest % food and lowest rainfall, VSS concentration is at peak. However, when rain intensity increases, VSS concentration decreases. When %food increases from 0 to 25, there is an increase in VSS; then it remains constant above that range. This may happen because higher rainfall dilutes leachate and also when %food is higher, the organic matter increases, which increases VSS.

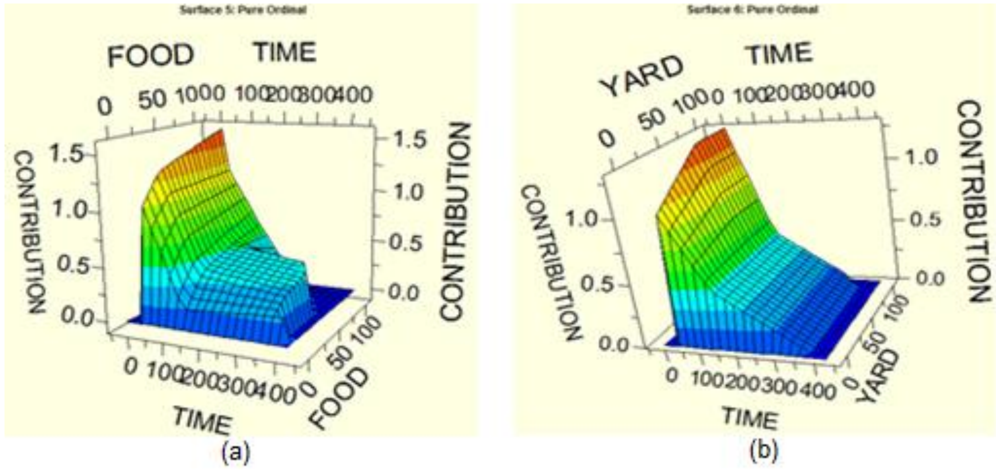


Figure 5.42 3-D Interaction Plots (a) Time-Food and (b) Yard-Time

In Figure 5.42 (a), initially with time when %food is highest, VSS concentration is highest due to higher organic content. VSS concentration decreases gradually with time and lower %food. Perhaps, with time most of the food waste has been degraded.

In Figure 5.42 (b), initially with time and when %yard is highest, VSS concentration is at peak and decreases as %yard decreases. As time increases, TSS concentration decreases for the given range of %yard. Perhaps in the beginning microbes can degrade the easily accessible yard waste, so with higher %yard, VSS increases. As time goes on, microbes are having inhibitory effect due to lignin which is hard to degrade, meaning VSS concentration decreases. Also, most of the yard waste would have degraded over time.

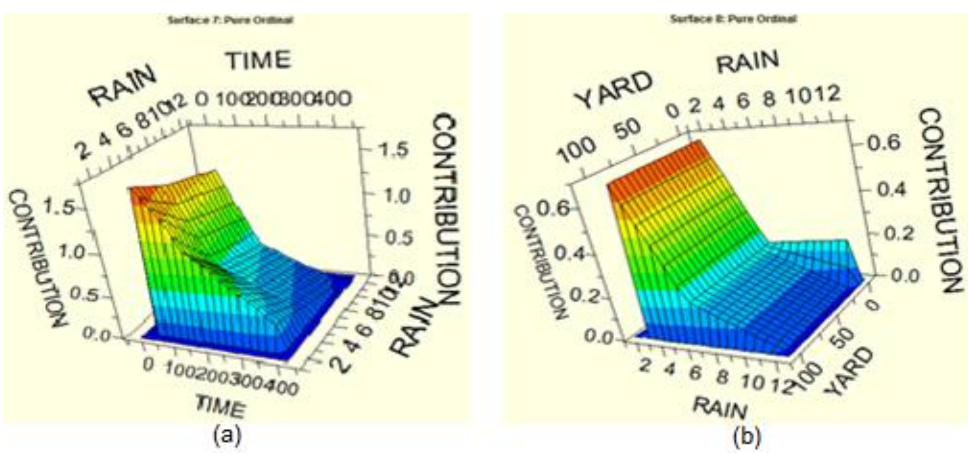


Figure 5.43 3-D Interaction Plots (a) Time-Rain and (b) Yard-Rain

In Figure 5.43 (a), initially with time and lowest rainfall, VSS concentration is highest due to concentrated leachate. When time passes by with increasing rainfall, VSS concentration decreases. There may be dilution effect on leachate due to higher rainfall. The decrease in VSS with time is anticipated, as waste degradation proceeds.

In Figure 5.43 (b), VSS concentration is at peak when rainfall is lowest. However, as rainfall increases, there is a dilution effect on leachate, which decreases VSS concentration. The effect of %yard seems to remain constant on the VSS concentration.

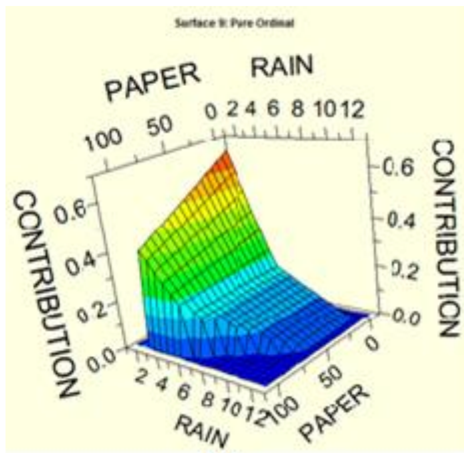


Figure 5.44 3-D Interaction Plot (a) Paper-Rain

In Figure 5.44 (a), when rain and %paper are lowest, the contribution to VSS is at peak. As rain and % paper increase, VSS concentration decreases. Perhaps, due to higher rainfall there is a washout effect. Also, with higher %paper, microbes are having hard time to degrade lignin component, which may take years to decompose. No reactor in the experimental setup for 100% paper and 12 mm/d rainfall.

<u>5.12 MARS Modeling for Biochemical Oxygen Demand (BOD)</u>

To run the analysis, log transformation on BOD (Y-variable) was performed as it was necessary to scatter the data points. The input options were selected as discussed in Section 5.6.2. Several runs were made with various max BFs to come up with the final model which has PSE and adjusted R^2 value leveled off. Table 5.18 provides the summary of the PSE and adj. R^2

values for various max BFs. The PSE and adj. R^2 values are also represented in graphs as Figures 5.45 and 5.46, respectively.

Table 5.18 Summary of PSE Values for Different Models – BOD

Max Basis Functions	**Optimal Model Nr (# of terms in the model)**	**Predictive Squared Error (PSE) for Best Model Option**	**Adj. R^2**
15	12	0.14078	0.85343
16	14	0.13773	0.8615
18	17	0.13232	0.86957
20	20	0.12797	0.88094
22	21	0.12569	0.88958
24	22	0.11611	0.8912
26	25	0.11352	0.89431
28	28	0.1173	0.89987
30	30	0.11392	0.90341
32	32	0.11046	0.90595
34	34	0.11247	0.90951
36	35	0.10965	0.91137
38	37	0.10708	0.91389
40	35	0.10267	0.91758
42	35	0.10434	0.92146
44	39	0.10608	0.92347
46	38	0.10517	0.92504
48	40	0.09941	0.92704
50	34	0.10122	0.92545
52	35	0.10085	0.92895
54	33	0.09796	0.92129
56	33	0.09626	0.92292
58	42	0.10304	0.93201
60	43	0.10101	0.9325
62	43	0.10115	0.93383
64	46	0.09894	0.93566
66	47	0.10062	0.93612
68	46	0.10304	0.93675

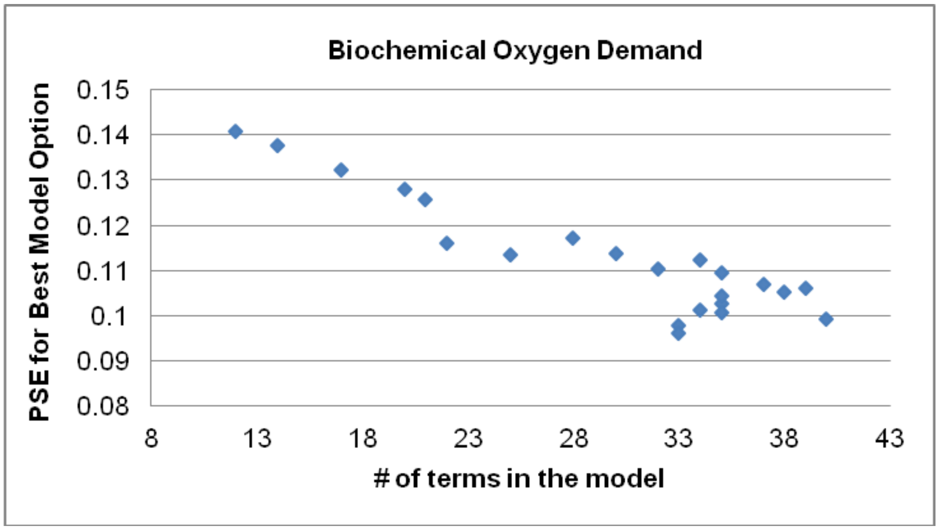


Figure 5.45 PSE Values for Various Models (BOD)

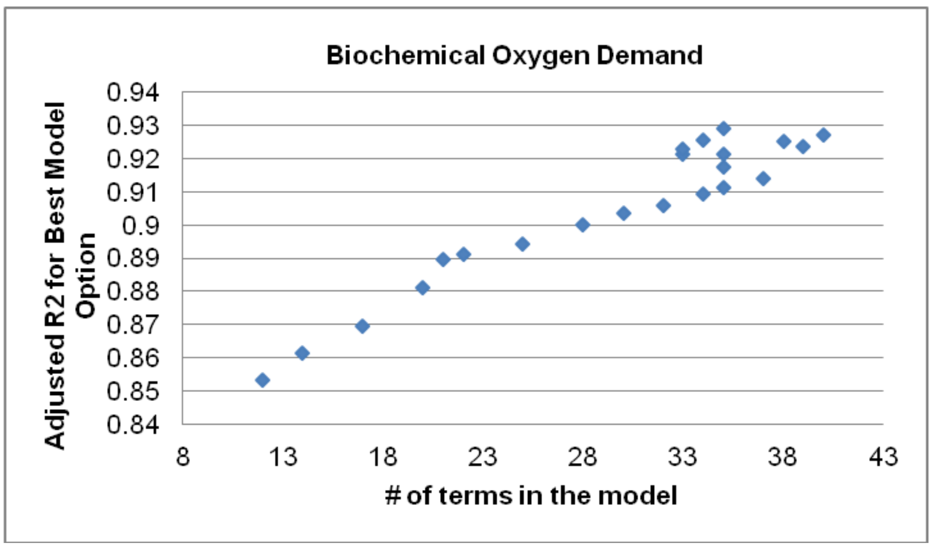


Figure 5.46 Adjusted-R^2 Values for Various Models (BOD)

Looking at both graphs (Figure 5.45 and 5.46), the final model with lower PSE value of 0.09626 and adj. R^2 of 0.92292 was selected for BOD.

5.12.1 Final Model for Biochemical Oxygen Demand (BOD)

The MARS text output includes final model using backward stepwise elimination method, ANOVA decomposition table, relative variable importance table, and regression information on the training data. The MARS model output for BOD is provided in Appendix.

The ANOVA decomposition table for the final BOD model with 56 max BF is provided in Table 5.19. In this table, the heading function is indexing different basis functions, standard deviation is a measure of variability for these BFs, -gcv (generalized cross-validation) is the reduction lack-of-fit (or the improvement of fit), #bsfns is the number of BFs with this structure, and #efprms is the number of effective parameters. In Table 5.19, the primary interest columns are #bsfns and variable. The variable column represents which parameters are appearing as main effect and which parameters appearing as interaction terms in the final model equation. The #bsfns column represents how many times a particular basis function is included in the final model equation.

Table 5.19 ANOVA Decomposition for BOD

ANOVA Decomposition on 34 Basis Functions

fun	std. dev.	-gcv	#bsfns	#efprms	variable
1	1.00428	0.38942	3	8.01923	TIME
2	1.11988	0.17534	2	5.34615	RAIN
3	1.22768	0.16696	2	5.34615	FOOD
4	0.61120	0.13728	1	2.67308	TEMP
5	1.05933	0.16459	2	5.34615	TEXTILE
6	0.10322	0.10464	1	2.67308	PAPER
7	0.27466	0.10974	2	5.34615	TIME TEMP
8	1.19765	0.15771	1	2.67308	TEXTILE RAIN
9	1.04307	0.14204	8	21.38461	TIME FOOD
10	0.26284	0.12166	2	5.34615	TIME RAIN
11	0.15852	0.10337	1	2.67308	TIME TEXTILE
12	0.63447	0.14004	2	5.34615	TEXTILE TEMP
13	0.84660	0.16006	3	8.01923	FOOD RAIN
14	0.48566	0.11250	2	5.34615	TIME YARD
15	0.23369	0.11675	2	5.34615	PAPER TEMP

Variable importance for the BOD model is provided in Table 5.20. The variable importance scores are calculated relative to the most important variable, which is always given a score of 100 (Hastie et al., 2001). In this table, TIME is given highest importance and RAIN second; while, YARD is given the least importance in predicting BOD.

Table 5.20 Relative Variable Importance for BOD

Variable	Importance	-gcv
TIME	100.00000	0.82535
RAIN	54.68585	0.31704
FOOD	43.11766	0.23499
TEMP	41.32536	0.22402
TEXTILE	29.55535	0.16352
PAPER	16.47618	0.11986
YARD	13.03944	0.11250

5.12.1.1 Curves for Final Model (BOD)

MARS outputs the three-dimensional (3-D) plots which depict the relationship between a pair of predictor variables and the target variable. The 3-D plots and their explanation are provided in this section for the final BOD model.

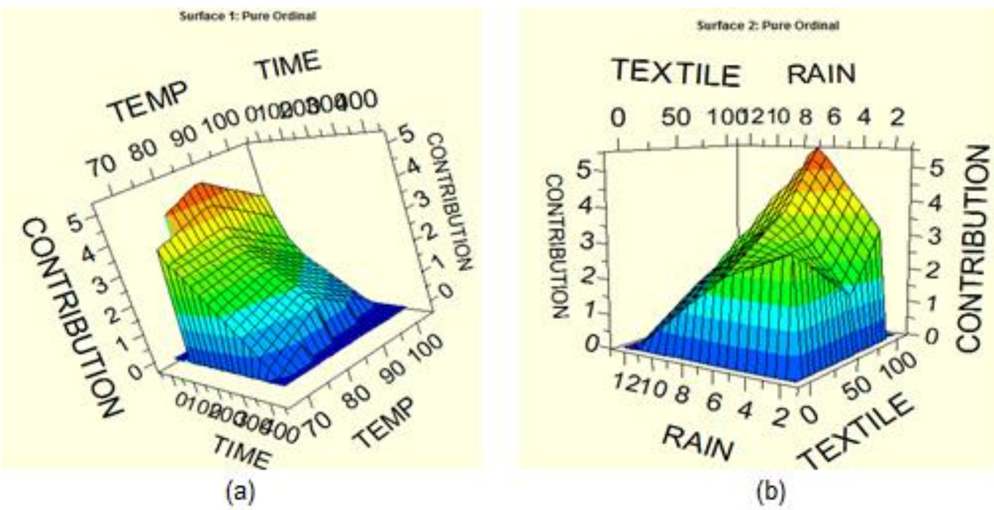


Figure 5.47 3-D Interaction Plots (a) Time-Temperature and (b) Textile-Rain

In Figure 5.47 (a), BOD concentration decreases with time, as expected as waste degradation proceeds. Initially with time and when temperature increases up to 85 °F, BOD concentration increases and reaches maximum at 85 °F. However, BOD decreases above 85 °F temperature. It seems 85 °F is the optimum temperature for the microbes to decompose waste.

In Figure 5.47 (b), BOD concentration is at peak when %textile is 100 and rainfall is 6 mm/d. This peak in BOD concentration at the intermediate rainfall value is unusual. BOD concentration decreases as % textile decreases. At 0% textile, the anticipated trend of BOD decreasing as rainfall increases (due to dilution) is observed.

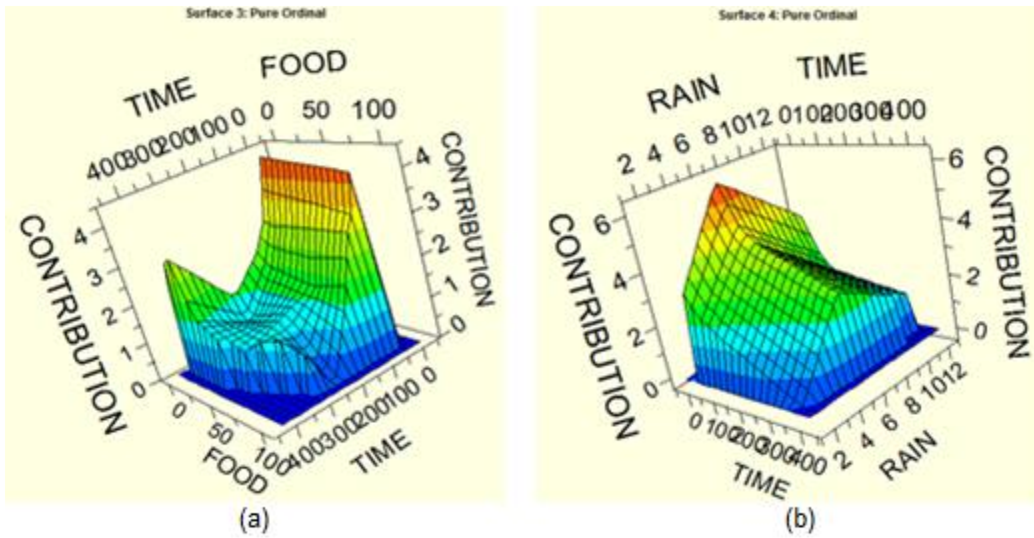


Figure 5.48 3-D Interaction Plots (a) Time-Food and (b) Time-Rain

In Figure 5.48 (a), initially with time, BOD concentration is highest. Over time, BOD concentration decreases, as most of the food waste would have been degraded. For initial times, the impact of %food on BOD is relatively constant. This is somewhat surprising since food waste is readily degradable, although sometimes a significant lag period occurs before food begins to degrade significantly. At later times, BOD is highest with smaller % food, likely because the food in reactors with high percent of food waste has already degraded.

In Figure 5.48 (b), as time increases, BOD concentration decreases, as most of the waste would have been degraded. As rain increases up to 6 mm/d, BOD concentration increases and reaches the peak and then it goes down as rainfall increases. The dilution effect on leachate as rainfall increases from 6 to 12 mm/d is anticipated. It is not clear why a similar dilution effect is not observed as rainfall increases from 2 mm/day to 6 mm/day. One reason would be that optimal moisture content for degradation occurs with a rainfall rate of 6 mm/day; however, this was not observed for other leachate parameters, such as TSS and VSS.

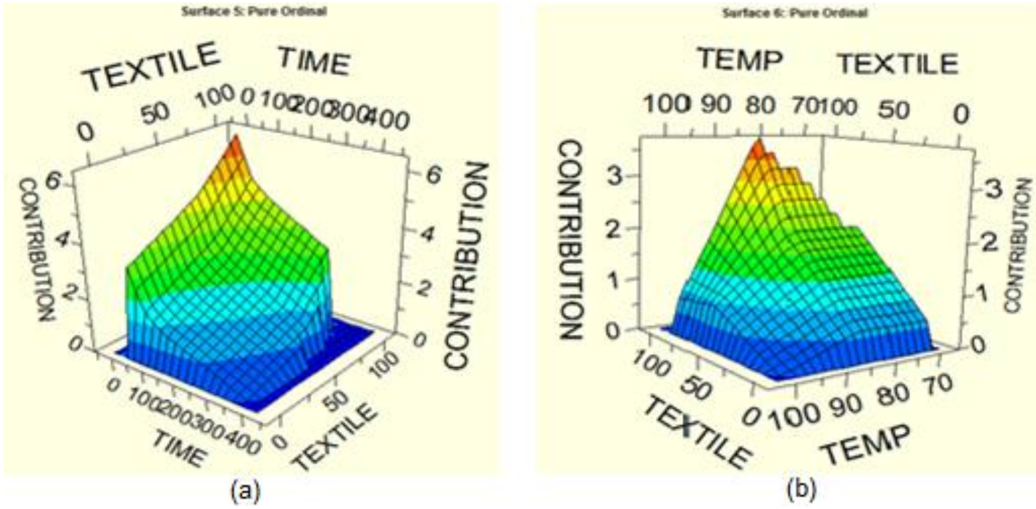


Figure 5.49 3-D Interaction Plots (a) Time-Textile and (b) Temperature-Textile

In Figure 5.49 (a), initially with time and when %textile is high, BOD concentration is at peak. As time increases and %textile decreases, BOD decreases. Most of the waste would have been degraded over time, decreasing BOD concentration.

In Figure 5.49 (b), BOD concentration is at peak when temperature is 85 °F and %textile is high. As temperature increases and %textile decreases, BOD decreases. Perhaps, due to less amount of waste, the BOD is lower. Also, with higher temperature, certain bacteria would have died.

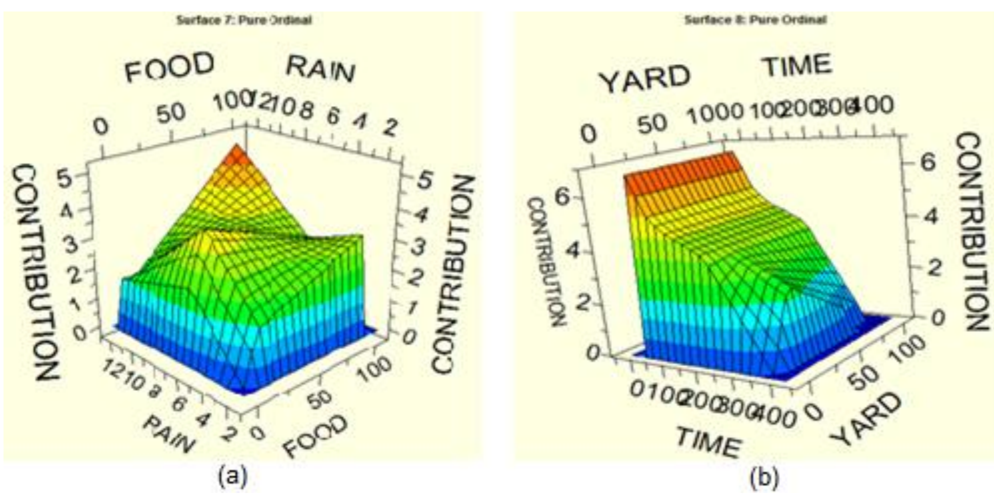
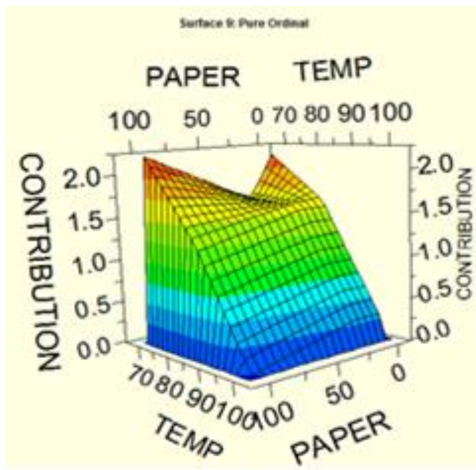


Figure 5.50 3-D Interaction Plots (a) Food-Rain and (b) Yard-Time

In Figure 5.50 (a), when %food and rainfall are highest, BOD concentration is at peak. This is due to the presence of more organic matter at higher % food. However, the high rainfall rate would be anticipated to produce low BOD concentrations due to washout. Only looking at %food, BOD increases as %food increases, which is expected, since food is very amenable to biodegradation. For low %s of food waste, BOD increases when rainfall increases up to 6 mm/d, and then BOD decreases with higher rainfall due to dilution/washout effect.

In Figure 5.50 (b), BOD decreases with time. However, %yard seems to have no effect.



(a)

Figure 5.51 3-D Interaction Plots (a) Paper-Temperature

In Figure 5.51 (a), BOD concentration is highest when temperature is low and %paper is higher. As temperature and %paper increases, BOD decreases. Perhaps, microbes are having difficult time to degrade lignin component of paper waste. The reason that BOD is highest at 70 °F rather than 85 °F (which seems to be the optimal temperature for the waste degradation) in this case is not clear.

5.13 MARS Modeling for Chemical Oxygen Demand (COD)

To run the analysis, log transformation on COD (Y-variable) was performed as it was necessary to scatter the data points. The input options were selected as discussed in Section 5.6.2. Several runs were made with various max BFs to come up with the final model which has PSE and adjusted R^2 value leveled off. Table 5.21 provides the summary of the PSE and adj. R^2

values for various max BFs. The PSE and adj. R^2 values are also represented in graphs as Figures 5.52 and 5.53, respectively.

Table 5.21 Summary of PSE Values for Different Models – COD

Max Basis Functions	**Optimal Model Nr (# of terms in the model)**	**Predictive Squared Error (PSE) for Best Model Option**	**Adj. R^2**
15	14	0.05541	0.8988
16	13	0.05539	0.8986
18	15	0.0524	0.90749
20	18	0.04938	0.91592
22	18	0.0463	0.92033
24	24	0.04419	0.92924
26	25	0.04228	0.93272
28	25	0.0398	0.9368
30	30	0.03699	0.94043
32	27	0.03699	0.94442
34	31	0.03605	0.94642
36	30	0.03556	0.94627
38	28	0.03464	0.94697
40	30	0.0342	0.9485
42	30	0.03417	0.9491
44	31	0.03384	0.94998
46	33	0.03269	0.95042
48	39	0.03427	0.95093
50	34	0.03462	0.95194
52	34	0.03501	0.95067
54	36	0.03588	0.94905
56	52	0.03666	0.95457
58	45	0.03579	0.95533
60	43	0.03618	0.95489
62	46	0.03532	0.95591
64	42	0.03684	0.95462

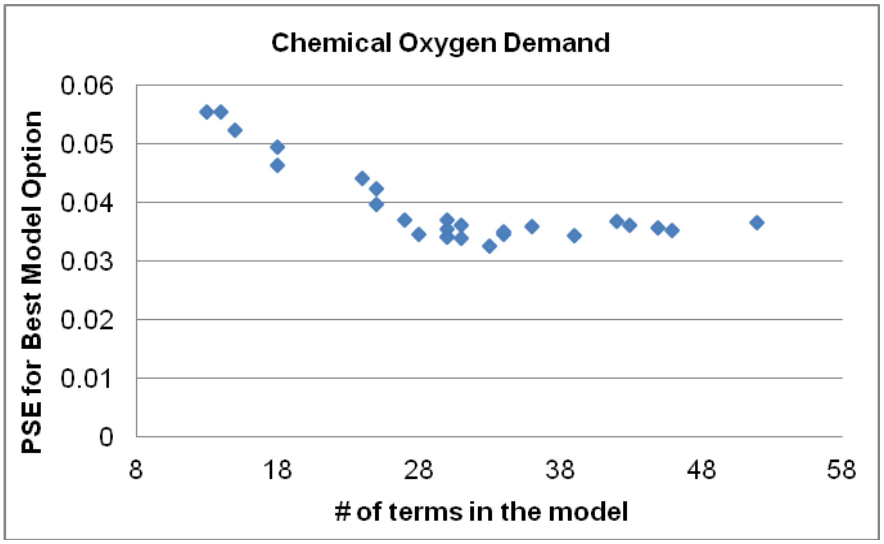


Figure 5.52 PSE Values for Various Models (COD)

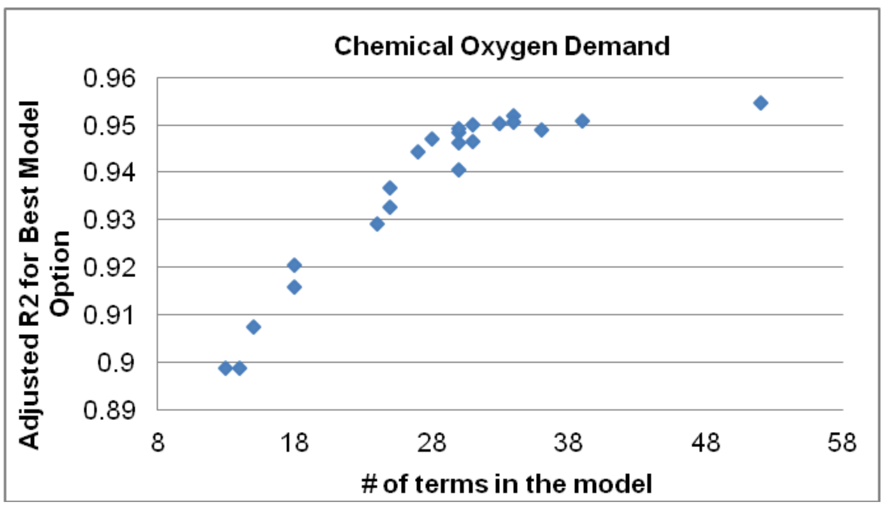


Figure 5.53 Adjusted-R^2 Values for Various Models (COD)

Looking at both graphs (Figure 5.52 and 5.53), the final model with lower PSE value of 0.03269 and adj. R^2 of 0.95042 was selected for COD.

5.13.1 Final Model for Chemical Oxygen Demand (COD)

The MARS text output includes final model using backward stepwise elimination method, ANOVA decomposition table, relative variable importance table, and regression information on the training data. The MARS model output for COD is provided in Appendix.

The ANOVA decomposition table for the final COD model with 46 max BF is provided in Table 5.22. In this table, the heading function is indexing different basis functions, standard deviation is a measure of variability for these BFs, -gcv (generalized cross-validation) is the reduction lack-of-fit (or the improvement of fit), #bsfns is the number of BFs with this structure, and #efprms is the number of effective parameters. In Table 5.22, the primary interest columns are #bsfns and variable. The variable column represents which parameters are appearing as main effect and which parameters appearing as interaction terms in the final model equation. The #bsfns column represents how many times a particular basis function is included in the final model equation.

Table 5.22 ANOVA Decomposition for COD

ANOVA Decomposition on 33 Basis Functions

fun	std. dev.	-gcv	#bsfns	#efprms	variable
1	0.56340	0.08105	2	5.42857	TIME
2	0.58260	0.06826	2	5.42857	RAIN
3	0.46631	0.05374	1	2.71429	PAPER
4	0.27598	0.04821	1	2.71429	TEMP
5	0.14156	0.03654	2	5.42857	FOOD
6	0.24708	0.05049	4	10.85714	TIME FOOD
7	0.20251	0.03879	2	5.42857	FOOD RAIN
8	0.12827	0.04663	6	16.28571	TIME RAIN
9	0.38863	0.04186	2	5.42857	YARD RAIN
10	0.13607	0.03727	2	5.42857	TIME TEMP
11	0.26487	0.04120	2	5.42857	TIME TEXTILE
12	0.19681	0.03723	2	5.42857	PAPER RAIN
13	0.23283	0.04120	2	5.42857	PAPER YARD
14	0.09463	0.03699	3	8.14286	TIME PAPER

Variable importance for the COD model is provided in Table 5.23. The variable importance scores are calculated relative to the most important variable, which is always given a score of 100 (Hastie et al., 2001). In this table, TIME is given highest importance and RAIN second; while, TEXTILE is given the least importance in predicting COD.

Table 5.23 Relative Variable Importance for COD

Variable	Importance	-gcv
TIME	100.00000	0.39962
RAIN	67.15488	0.19951
PAPER	32.06890	0.07262
TEMP	26.31967	0.06039
FOOD	21.06512	0.05131
YARD	13.65524	0.04193
TEXTILE	12.89321	0.04120

5.13.1.1 Curves for Final Model (COD)

MARS outputs the three-dimensional (3-D) plots which depict the relationship between a pair of predictor variables and the target variable. The 3-D plots and their explanation are provided in this section for the final COD model.

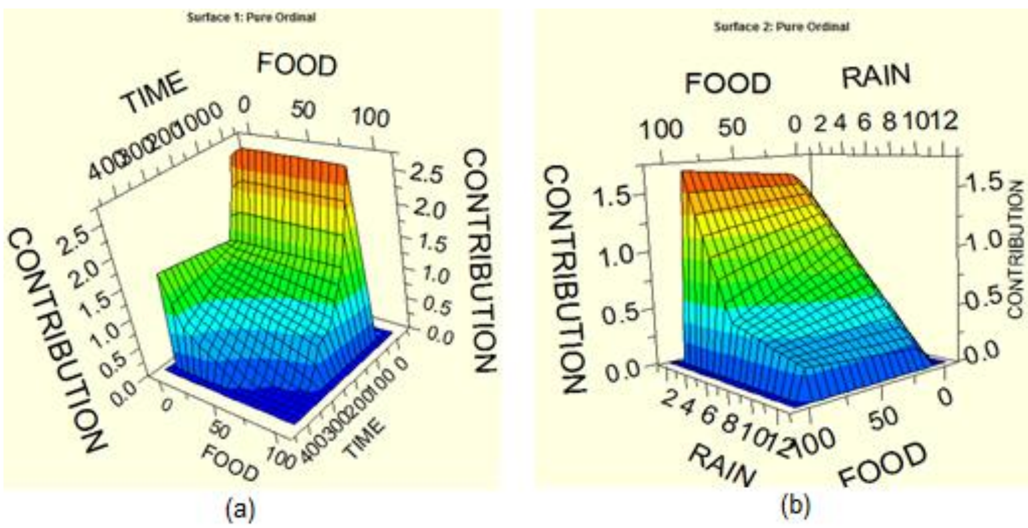


Figure 5.54 3-D Interaction Plots (a) Food-Time and (b) Rain-Food

In Figure 5.54 (a), initially with time COD is at peak for any given range of food%. COD decreases with time and as %food increases. This is due to food waste would have been degraded over time.

In Figure 5.54 (b), when %food is high and rainfall is low, COD concentration is at peak. This is due to more concentrated leachate and higher organic content. As rainfall increases, COD decreases due to dilution effect but %food seems to have no effect.

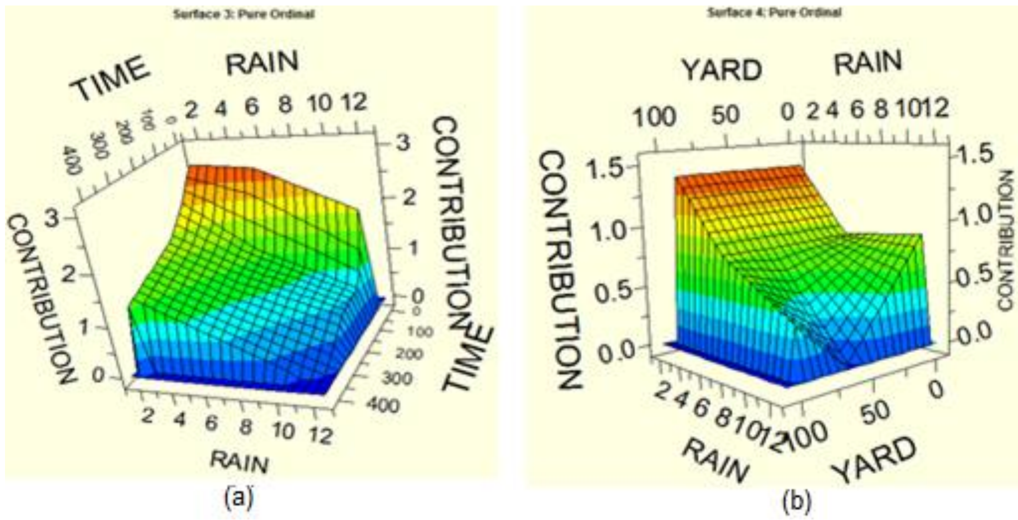


Figure 5.55 3-D Interaction Plots (a) Rain-Time and (b) Rain-Yard

In Figure 5.55 (a), when rainfall and time increase, COD decreases. Perhaps, most of the waste would have degraded and also due to dilution effect on leachate. Initially with time at lower rainfall, COD concentration is at peak. The generated leachate is concentrated.

In Figure 5.55 (b), as rainfall increases, COD concentration decreases due to dilution effect. Also at higher rainfall, when % yard increases up to 60%, there is a decrease in COD concentration and then beyond 60% yard, COD concentration gradually increases. At a 2 mm/day rainfall rate, %yard seems to have no impact.

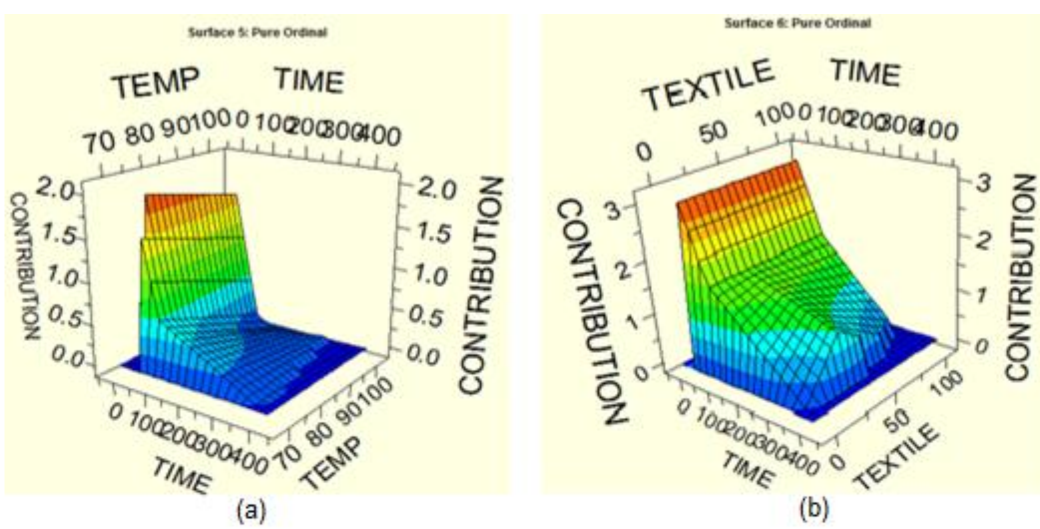
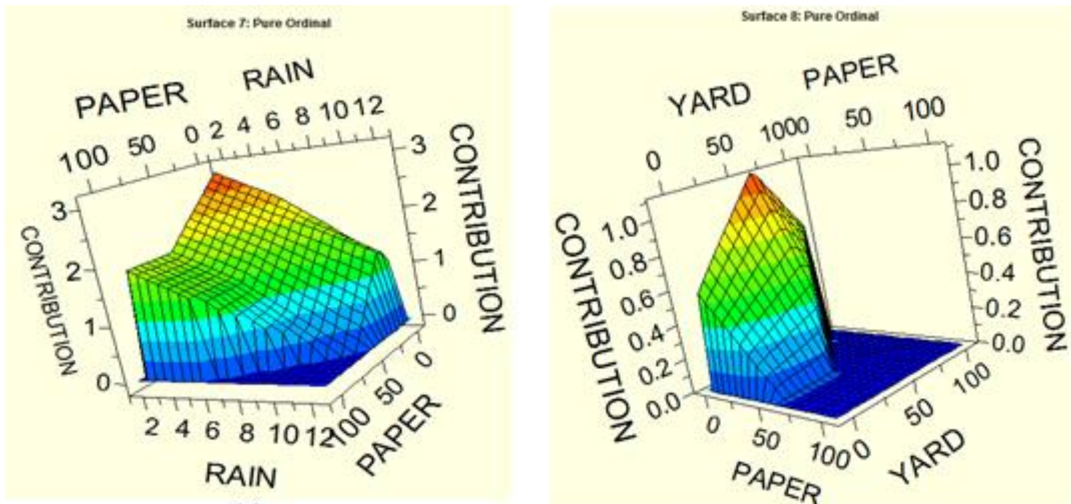


Figure 5.56 3-D Interaction Plots (a) Temperature-Time and (b) Time-Textile

In Figure 5.56 (a), it is observed that with time, COD decreases. COD decreases as temperature increases, indicating better waste degradation at 70 °F.

In Figure 5.56 (b), initially with time, COD concentration is high and %textile seems to have no effect. However, as time increases, COD decreases. Also, at maximum time, when %textile increases up to 35, COD increases and there is a decline beyond 35% textile.

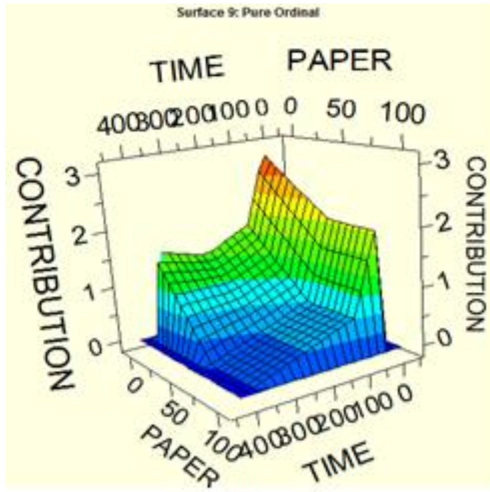


(a) (b)

Figure 5.57 3-D Interaction Plots (a) Paper-Rain and (b) Yard-Paper

In Figure 5.57 (a), when %paper and rainfall are low, COD is at peak and then decreases as %paper and rainfall increases. This is due to dilution effect at higher rainfall and also with high %paper; microbes may be having a difficult time degrading lignin.

In Figure 5.57 (b), when yard is approximately 60%, COD is at peak and then it decreases with increase in %yard. However, COD decreases as %paper increases.



(a)

Figure 5.58 3-D Interaction Plots (a) Paper-Time

In Figure 5.58 (a), initially with time and less paper%, COD concentration is maximum. As time and %paper increases, COD decreases.

5.14 MARS Modeling for Chloride

To run the analysis, log transformation on chloride (Y-variable) was performed as it was necessary to scatter the data points. The input options were selected as discussed in Section 5.6.2. Several runs were made with various max BFs to come up with the final model which has PSE and adjusted R^2 value leveled off. Table 5.24 provides the summary of the PSE and adj. R^2 values for various max BFs. The PSE and adj. R^2 values are also represented in graphs as Figures 5.59 and 5.60, respectively.

Table 5.24 Summary of PSE Values for Different Models – Chloride

Max Basis Functions	**Optimal Model nr (# of terms in the model)**	**Predictive Squared Error (PSE) for Best Model Option**	**Adj. R^2**
15	15	0.07601	0.83829
16	16	0.07331	0.84037
18	17	0.07014	0.84686
20	20	0.07084	0.8531

Table 5.24 - *Continued*

22	16	0.0684	0.85528
24	21	0.06998	0.86033
26	24	0.06844	0.86213
28	23	0.06428	0.86348
30	18	0.0651	0.86109
32	20	0.06599	0.86853
34	18	0.06466	0.8643
36	22	0.06573	0.87096
38	16	0.06745	0.85331
40	23	0.06663	0.87351
42	18	0.06993	0.86798
44	21	0.06827	0.86995
46	35	0.06872	0.88503
48	31	0.06886	0.88472
50	24	0.06585	0.87599
52	33	0.06842	0.87966
54	29	0.07164	0.88089
56	27	0.06769	0.87861
58	28	0.06768	0.8799
60	30	0.06444	0.88165
62	33	0.06973	0.88713

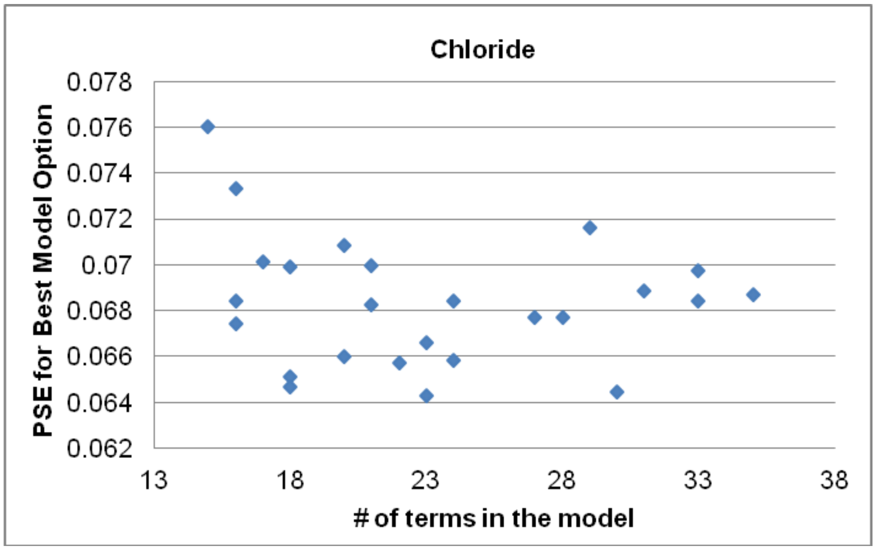


Figure 5.59 PSE Values for Various Models (Chloride)

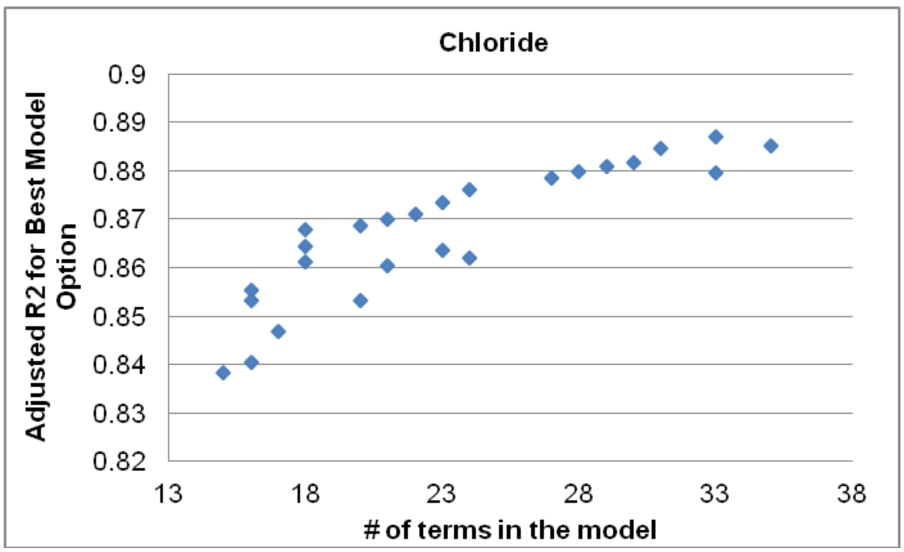


Figure 5.60 Adjusted-R^2 Values for Various Models (Chloride)

Looking at both graphs (Figure 5.59 and 5.60), the final model with lower PSE value of 0.06466 and adj. R^2 of 0.8643 was selected for chloride.

5.14.1 Final Model for Chloride

The MARS text output includes final model using backward stepwise elimination method, ANOVA decomposition table, relative variable importance table, and regression information on the training data. The MARS model output for chloride is provided in Appendix.

The ANOVA decomposition table for the final chloride model with 34 max BF is provided in Table 5.25. In this table, the heading function is indexing different basis functions, standard deviation is a measure of variability for these BFs, -gcv (generalized cross-validation) is the reduction lack-of-fit (or the improvement of fit), #bsfns is the number of BFs with this structure, and #efprms is the number of effective parameters. In Table 5.25, the primary interest columns are #bsfns and variable. The variable column represents which parameters are appearing as main effect and which parameters appearing as interaction terms in the final model equation. The #bsfns column represents how many times a particular basis function is included in the final model equation.

Table 5.25 ANOVA Decomposition for Chloride

ANOVA Decomposition on 18 Basis Functions

fun	std. dev.	-gcv	#bsfns	#efprms	variable
1	0.50237	0.09918	2	5.37500	TIME
2	0.70275	0.12639	2	5.37500	RAIN
3	0.16975	0.07538	1	2.68750	TIME PAPER
4	0.20873	0.07491	1	2.68750	YARD RAIN
5	0.09962	0.07298	2	5.37500	FOOD RAIN
6	0.07730	0.06936	1	2.68750	RAIN TEMP
7	0.24689	0.07460	5	13.43750	TIME RAIN
8	0.04672	0.06678	1	2.68750	TIME LEACHVOL
9	0.07812	0.06567	2	5.37500	TIME YARD
10	0.06804	0.06821	1	2.68750	FOOD TEMP

Variable importance for the chloride model is provided in Table 5.26. The variable importance scores are calculated relative to the most important variable, which is always given a score of 100 (Hastie et al., 2001). In this table, TIME is given highest importance and RAIN second; while, Leachate Volume is given the least importance in predicting chloride.

Table 5.26 Relative Variable Importance for Chloride

Variable	Importance	-gcv
TIME	100.00000	0.35522
RAIN	65.14143	0.18842
YARD	24.40121	0.08271
FOOD	21.93067	0.07940
PAPER	18.50021	0.07538
TEMP	16.54688	0.07339
LEACHVOL	6.74909	0.06678

5.14.1.1 Curves for Final Model (Chloride)

MARS outputs the three-dimensional (3-D) plots which depict the relationship between a pair of predictor variables and the target variable. The 3-D plots and their explanation are provided in this section for the final chloride model.

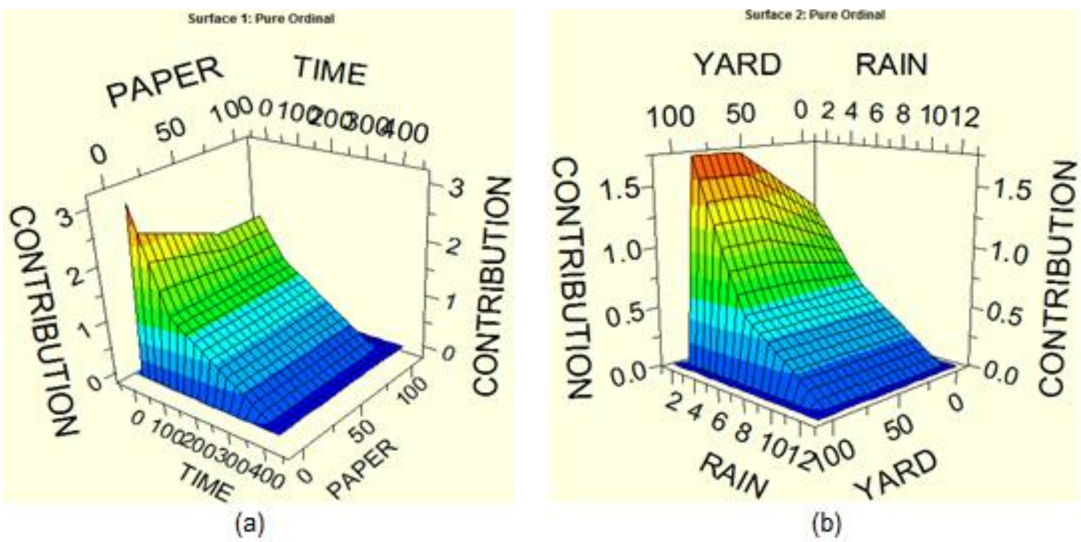


Figure 5.61 3-D Interaction Plots (a) Paper-Time and (b) Yard-Rain

In Figure 5.61 (a), at early values of time and when %paper is less, chloride concentration is at peak. However, as time passes by and with increasing %paper, chloride concentration decreases. Chloride concentrations may decrease with time due to any degradable paper already having been degraded. Chloride concentrations may decrease with %paper, at least for initial times, due to microbes not being able to readily degrade the lignin component of paper waste.

In Figure 5.61 (b), when rainfall is lower and %yard is high, chloride concentration is at peak. This might be due to concentrated leachate. With increasing rainfall, chloride concentration goes down due to wash out by the leaching. Also, as %yard decreases, chloride concentration decreases.

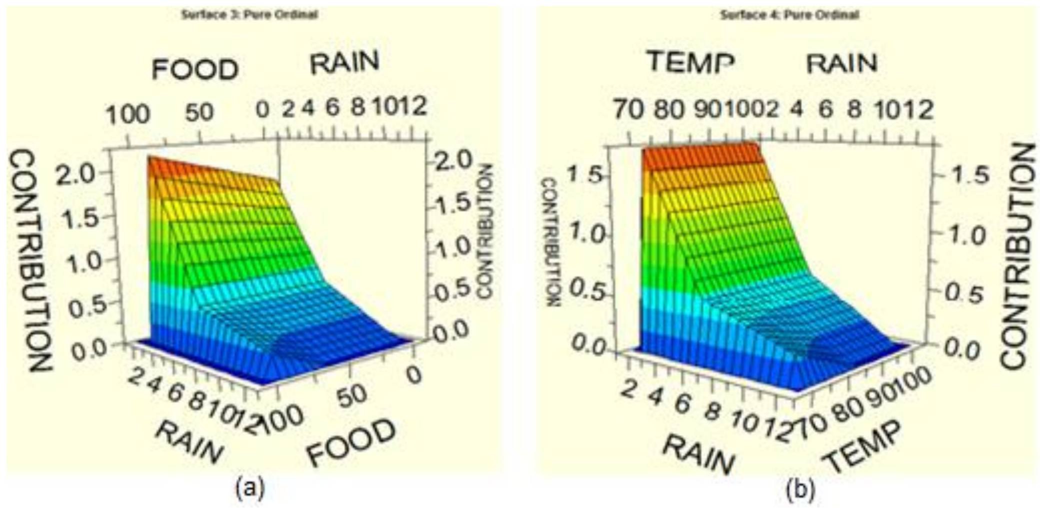
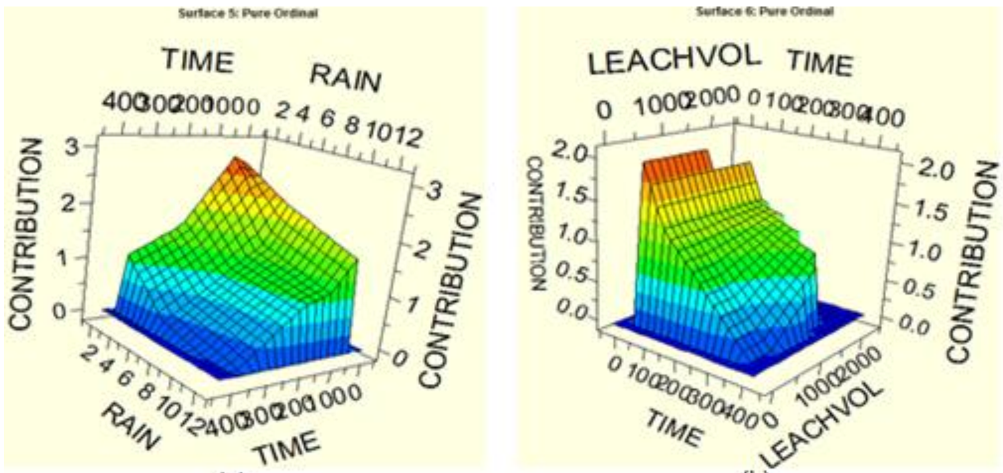


Figure 5.62 3-D Interaction Plots (a) Food-Rain and (b) Temperature-Rain

In Figure 5.62 (a), when rainfall is lower and %food is high, chloride concentration is at peak. This might be due to concentrated leachate and more amount of chloride present with higher amount of food waste. With increasing rainfall and decreasing %food, decreasing trend in concentration of chloride is observed due to wash out by the leaching, and lesser amount of food to provide chloride ions.

In Figure 5.62 (b), when rainfall is low, chloride concentration is at peak for any given range of temperature. However, as rainfall increases, decreasing trend is observed for chloride. It seems that rainfall is having a more profound effect than temperature. High rainfall increases dilution of leachate, which in turn decreases concentration of chloride.

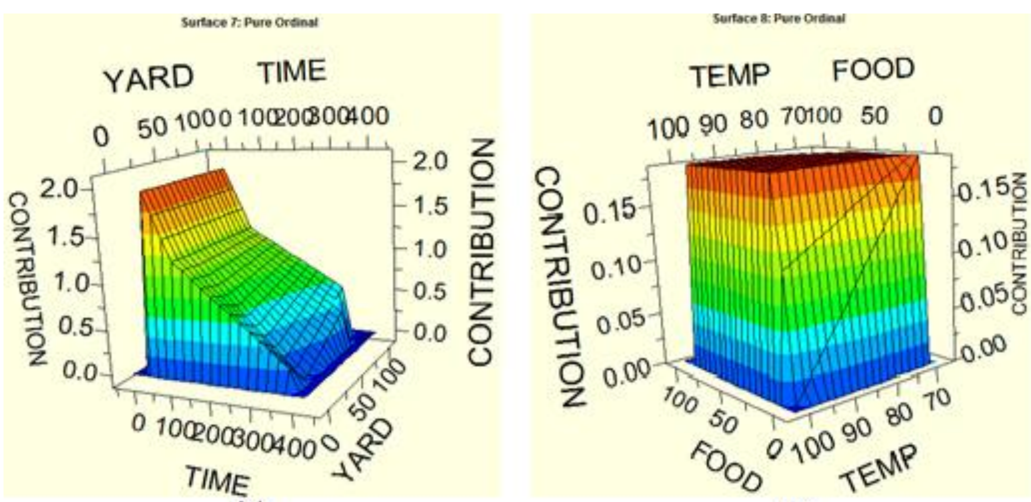


(a) (b)

Figure 5.63 3-D Interaction Plots (a) Time-Rain and (b) Time-Leachate Volume

In Figure 5.63 (a), initially with time and less rainfall, chloride concentration is at peak. A decreasing trend is observed for chloride with increasing time and rainfall. This might be due to dilution effect of leachate, and degradation of most waste at later times.

In Figure 5.63 (b), initially with time, chloride concentration is at peak due to high leachate strength. With time, chloride concentration decreases.



(a) (b)

Figure 5.64 3-D Interaction Plots (a) Time-Yard and (b) Temperature-Food

In Figure 5.64 (a), initially with time, chloride concentration is at peak and %yard seems to have no effect. With time, chloride concentration decreases. Perhaps, most of the yard waste would have been degraded.

In Figure 5.64 (b), overall, chloride concentration remains at peak for any given range of temperature and %food. It seems like change in temperature or %food wastes do not have any impact on chloride concentration. This is not consistent with the food-rain graph, which shows an influence of paper on chloride concentration.

5.15 MARS Modeling for Ammonia-Nitrogen (NH_3-N)

To run the analysis, log transformation on NH_3-N (Y-variable) was performed as it was necessary to scatter the data points. The input options were selected as discussed in Section 5.6.2. Several runs were made with various max BFs to come up with the final model which has PSE and adjusted R^2 value leveled off. Table 5.27 provides the summary of the PSE and adj. R^2 values for various max BFs. The PSE and adj. R^2 values are also represented in graphs as Figures 5.65 and 5.66, respectively.

Table 5.27 Summary of PSE Values for Different Models – NH_3-N

Max Basis Functions	**Optimal Model Nr (# of terms in the model)**	**Predictive Squared Error (PSE) for Best Model Option**	**Adj. R^2**
15	9	0.22071	0.70485
16	10	0.21555	0.71126
18	11	0.2101	0.71488
20	15	0.20801	0.73075
22	22	0.20563	0.74033
24	24	0.20519	0.74561
26	26	0.19998	0.75009
28	26	0.20094	0.75506
30	21	0.20263	0.75077
32	25	0.2091	0.75077
34	32	0.20642	0.75935

Table 5.27 - *Continued*

36	34	0.20538	0.76105
38	31	0.20154	0.76593
40	25	0.20736	0.76315
42	36	0.21006	0.76788
44	36	0.21128	0.77003
46	23	0.21861	0.7371
48	16	0.22235	0.73871
50	12	0.21714	0.71224

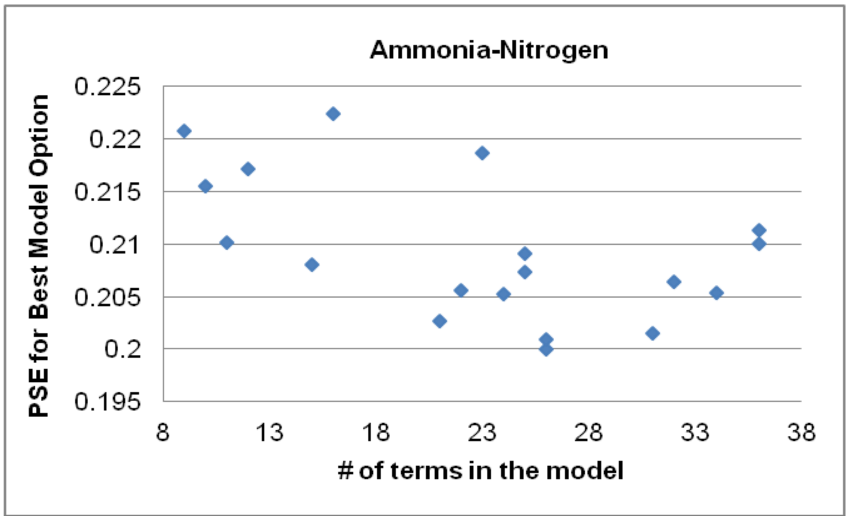


Figure 5.65 PSE Values for Various Models (NH_3-N)

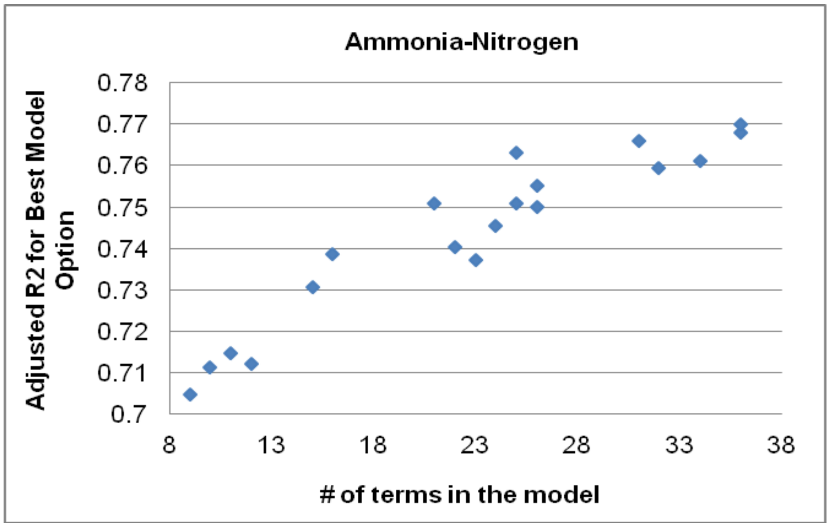


Figure 5.66 Adjusted-R^2 Values for Various Models (NH_3-N)

Looking at both graphs (Figure 5.65 and 5.66), the final model with lower PSE value of 0.19998 and adj. R^2 of 0.75009 was selected for ammonia-nitrogen.

5.15.1 Final Model for Ammonia-Nitrogen

The MARS text output includes final model using backward stepwise elimination method, ANOVA decomposition table, relative variable importance table, and regression information on the training data. The MARS model output for ammonia-nitrogen is provided in Appendix.

The ANOVA decomposition table for the final ammonia-nitrogen model with 26 max BF is provided in Table 5.28. In this table, the heading function is indexing different basis functions, standard deviation is a measure of variability for these BFs, -gcv (generalized cross-validation) is the reduction lack-of-fit (or the improvement of fit), #bsfns is the number of BFs with this structure, and #efprms is the number of effective parameters. In Table 5.28, the primary interest columns are #bsfns and variable. The variable column represents which parameters are appearing as main effect and which parameters appearing as interaction terms in the final model equation. The #bsfns column represents how many times a particular basis function is included in the final model equation.

Table 5.28 ANOVA Decomposition for NH_3-N

ANOVA Decomposition on 26 Basis Functions

fun	std. dev.	-gcv	#bsfns	#efprms	variable
1	0.37781	0.25410	2	5.69231	YARD
2	0.60359	0.27949	2	5.69231	FOOD
3	0.29607	0.24291	1	2.84615	RAIN
4	0.65333	0.31229	2	5.69231	TIME
5	0.08005	0.22421	1	2.84615	TEMP
6	0.16063	0.22557	2	5.69231	TEXTILE
7	0.41835	0.26037	2	5.69231	TIME FOOD
8	0.15016	0.22873	2	5.69231	TIME LEACHVOL
9	0.23936	0.23087	1	2.84615	FOOD TEMP
10	0.10819	0.22706	2	5.69231	TIME TEMP
11	0.11181	0.22342	1	2.84615	LEACHVOL RAIN
12	0.25211	0.23062	2	5.69231	TIME YARD
13	0.17486	0.22334	2	5.69231	TIME TEXTILE
14	0.06734	0.22240	2	5.69231	LEACHVOL YARD
15	0.08648	0.22439	1	2.84615	YARD TEMP
16	0.10783	0.22431	1	2.84615	LEACHVOL FOOD

Variable importance for the ammonia-nitrogen model is provided in Table 5.29. The variable importance scores are calculated relative to the most important variable, which is always given a score of 100 (Hastie et al., 2001). In this table, FOOD is given highest importance and YARD second; while, TEMPERATURE is given the least importance in predicting ammonia-nitrogen.

Table 5.29 Relative Variable Importance for NH_3-N

Variable	Importance	-gcv
FOOD	100.00000	0.39646
YARD	98.33926	0.39082
TIME	87.32211	0.35585
RAIN	44.70255	0.25965
TEMP	25.59730	0.23669

5.15.1.1 Curves for Final Model (Ammonia-Nitrogen)

MARS outputs the three-dimensional (3-D) plots which depict the relationship between a pair of predictor variables and the target variable. The 3-D plots and their explanation are provided in this section for the final ammonia-nitrogen model.

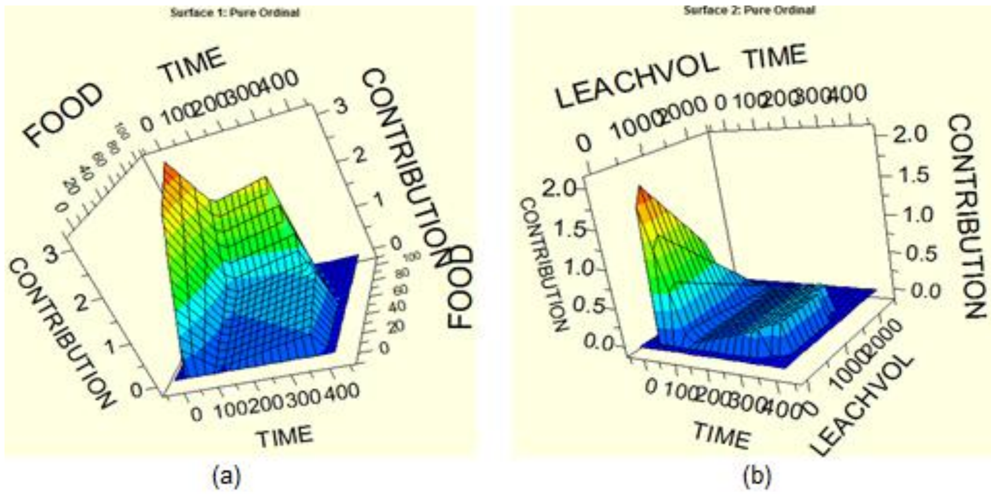


Figure 5.67 3-D Interaction Plots (a) Time-Food and (b) Time-Leachate Volume

In Figure 5.67 (a), overall, chloride concentration remains at peak for any given range of temperature and %food. It seems like change in temperature or % food wastes do not have any impact on chloride concentration. This is not consistent with the food-rain graph, which shows an influence of paper on chloride concentration.

In Figure 5.67 (b), initially with time and when leachate volume is less, NH_3-N concentration is high, and then it decreases with increasing time and leachate volume. Perhaps, at later times most of the waste would be degraded and at higher leachate volumes, there might be a dilution effect of the leachate.

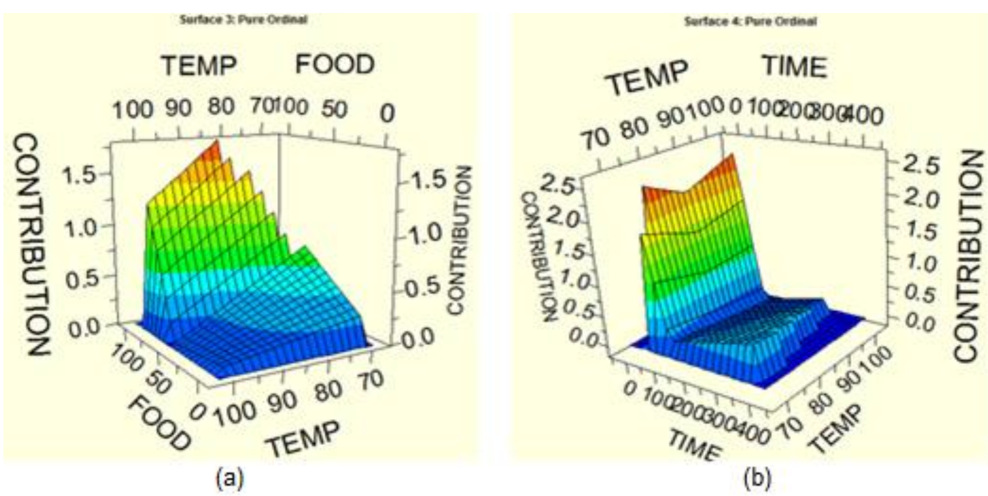


Figure 5.68 3-D Interaction Plots (a) Temperature-Food and (b) Time-Temperature

In Figure 5.68 (a), when %food is high and temperature is 85°F, NH_3-N concentration is highest. However, as temperature increases and %food decreases, NH_3-N concentration decreases. It looks like 85 °F is the optimum temperature to release NH_3-N when %food is high. This is consistent with previous analysis which identified 85 °F as the optimum temperature in this research (Altouqi, 2012). At lower %food values, however, 70 °F appears to be the optimal temperature.

In Figure 5.68 (b), initially with time, NH_3-N concentration is high and it decreases as time increases. With the exception of initial times, temperature has little influence on NH_3-N concentration. The influence of temperature on NH_3-N generated from food waste must be an exception. Overall, with time NH_3-N concentration decreases as most of the waste would have been degraded and stabilized.

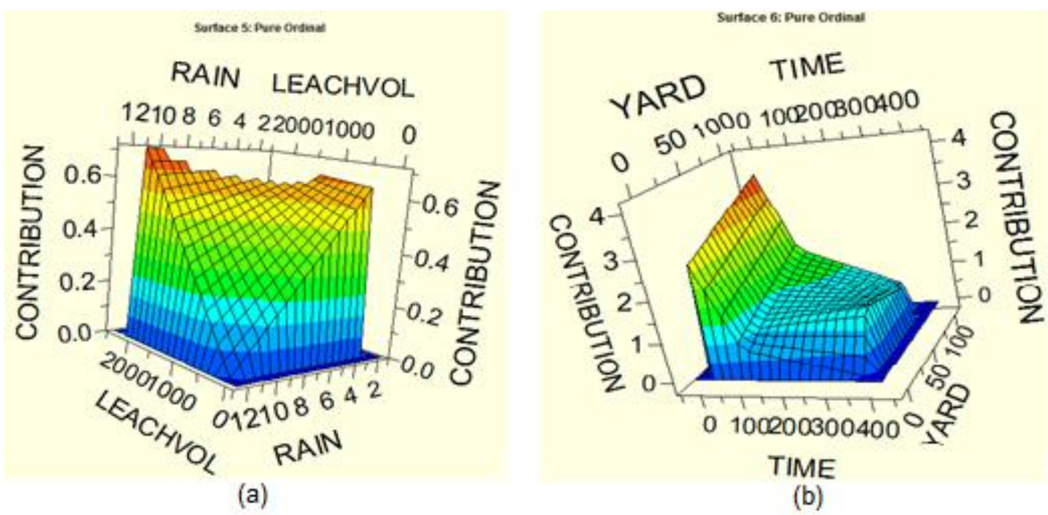


Figure 5.69 3-D Interaction Plots (a) Rain-Leachate Volume and (b) Time-Yard

In Figure 5.69 (a), as leachate volume increases, NH_3-N increases. However, as rainfall increases, NH_3-N decreases due to dilution effect. A dilution effect due to leachate volume would also have been anticipated, but is not present in this graph.

In Figure 5.69 (b), initially with time, as %yard increases, NH_3-N concentration increases gradually and reaches a peak. However, as time increases and %yard decreases, NH_3-N decreases. Perhaps, bacterial activities have gone down over time and with less %yard.

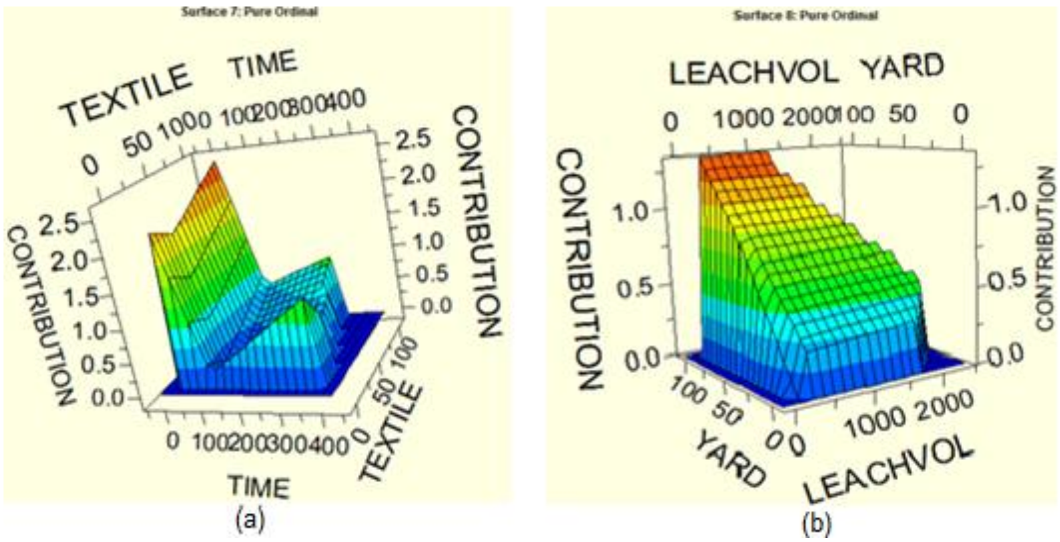
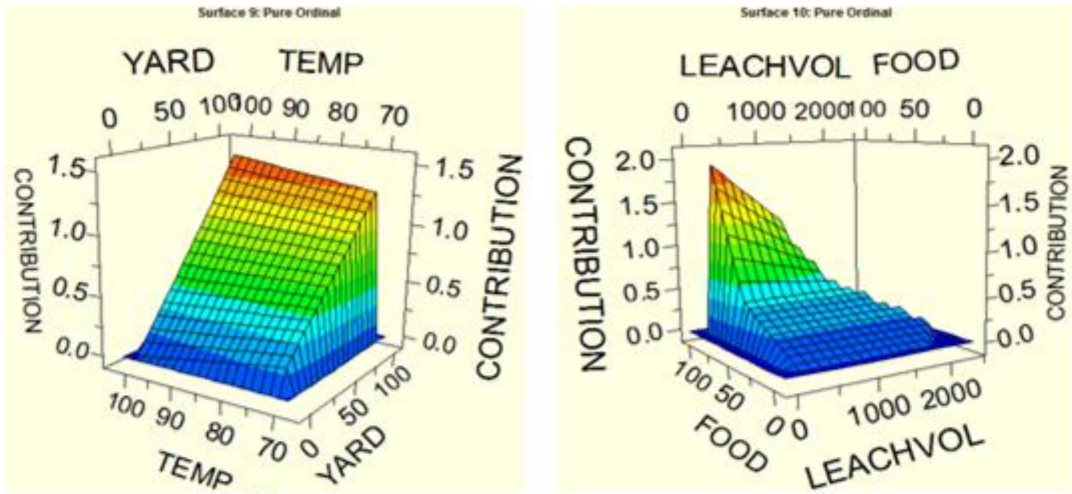


Figure 5.70 3-D Interaction Plots (a) Time-Textile and (b) Yard-Leachate Volume

In Figure 5.70 (a), in the beginning with time when %textile is high, NH_3-N concentration is at peak. However, NH_3-N decreases with decrease in %textile. As time passes by, NH_3-N decreases; however, it increases a little bit again after 125 days. Perhaps, some microbial activities trigger later in time due to microbes degrading textile of a different composition.

In Figure 5.70 (b), when %yard is high and leachate volume is less; NH_3-N concentration is at peak. Perhaps, high %yard increases microbial activities due to which there is an increase in NH_3-N releases. Also, more concentrated leachate is contributing to high concentration of NH_3-N.



(a) (b)

Figure 5.71 3-D Interaction Plots (a) Temperature-Yard and (b) Food-Leachate Volume

In Figure 5.71 (a), when %yard is high, NH_3-N concentration is at peak due to high organic matter. NH_3-N concentration goes down with decrease in %yard. Temperature seems to have little influence on yard waste degradation.

In Figure 5.71 (b), when %food is high and leachate volume is less, NH_3-N concentration is at peak. Perhaps, high organic matter and concentrated leachate are contributing to high NH_3-N. As %food decreases and leachate volume increases, NH_3-N decreases.

5.16 MARS Modeling for pH

To run the analysis, the input options were selected as discussed in Section 5.6.2. Several runs were made with various max BFs to come up with the final model which has PSE and adjusted R^2 value leveled off. Table 5.30 provides the summary of the PSE and adj. R^2 values for various max BFs. The PSE and adj. R^2 values are also represented in graphs as Figures 5.72 and 5.73, respectively. The graphs in Figures 5.72 and 5.73 are plotted up to 42 max BFs (Table 5.12), because beyond this range it can be observed that by increasing max BFs doesn't improve number of terms in the model and it starts behaving peculiar (highlighted in light gray).

Table 5.30 Summary of PSE Values for Different Models – pH

Max Basis Functions based on ** values	Optimal Model # (# of terms in the model)	PSE for Best Model Option	Adj. R^2
15	15	0.21669	0.56157
16	14	0.21227	0.57831
18	17	0.20152	0.61684
20	19	0.18418	0.64981
22	17	0.18639	0.67922
24	19	0.16552	0.67203
26	25	0.1598	0.71466
28	28	0.15906	0.72669
30	30	0.16092	0.74604
32	17	0.16327	0.71747
34	26	0.1591	0.7601
36	17	0.15756	0.71697
38	38	0.16262	0.7693
40	39	0.16428	0.77289
42	33	0.15961	0.77938
44	39	0.16339	0.7817
46	40	0.1596	0.78496
48	40	0.16553	0.78777
50	26	0.16723	0.7645
52	42	0.1777	0.79272
54	26	0.16332	0.76653
56	21	0.17463	0.72994
58	18	0.17528	0.73176
60	21	0.16744	0.72133
62	21	0.15984	0.72133
64	20	0.15559	0.72373

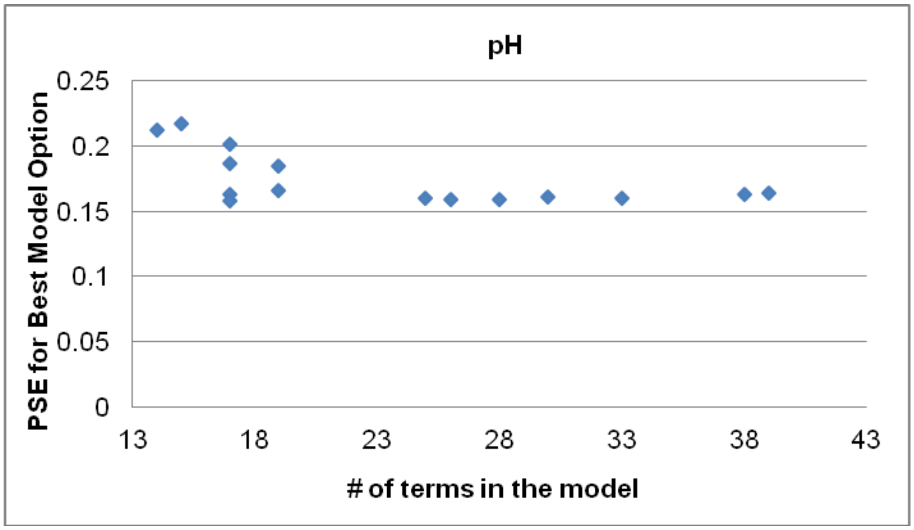


Figure 5.72 PSE Values for Various Models (pH)

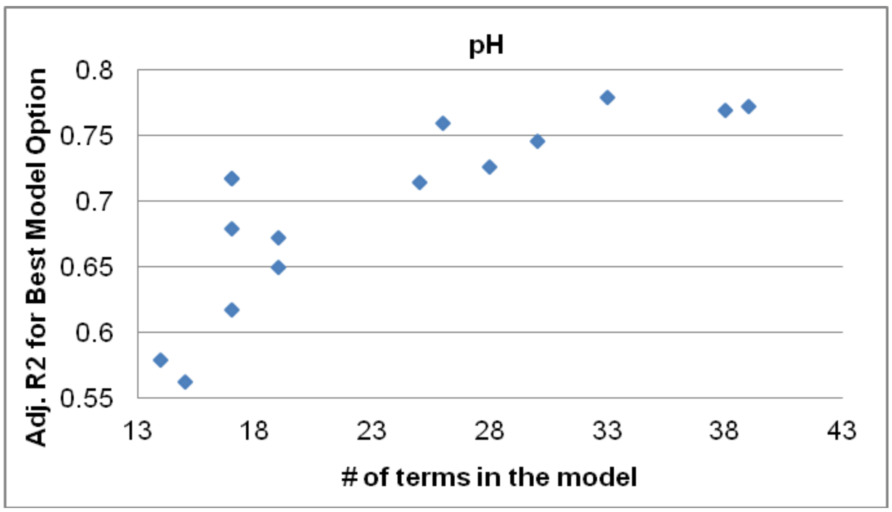


Figure 5.73 Adjusted-R^2 Values for Various Models (pH)

Looking at both graphs (Figure 5.72 and 5.73), the final model with lower PSE value of 0.1591 and adj. R^2 of 0.7601 was selected for pH.

5.16.1 Final Model for pH

The MARS text output includes final model using backward stepwise elimination method, ANOVA decomposition table, relative variable importance table, and regression information on the training data. The MARS model output for pH is provided in Appendix.

The ANOVA decomposition table for the final pH model with 34 max BF is provided in Table 5.31. In this table, the heading function is indexing different basis functions, standard deviation is a measure of variability for these BFs, -gcv (generalized cross-validation) is the reduction lack-of-fit (or the improvement of fit), #bsfns is the number of BFs with this structure, and #efprms is the number of effective parameters. In Table 5.31, the primary interest columns are #bsfns and variable. The variable column represents which parameters are appearing as main effect and which parameters appearing as interaction terms in the final model equation. The #bsfns column represents how many times a particular basis function is included in the final model equation.

Table 5.31 ANOVA Decomposition for pH

ANOVA Decomposition on 26 Basis Functions

fun	std. dev.	-gcv	#bsfns	#efprms	variable
1	0.28636	0.14084	2	5.37500	RAIN
2	0.38435	0.16357	2	5.37500	TIME
3	0.28485	0.14937	1	2.68750	TEMP
4	0.22708	0.14108	2	5.37500	FOOD
5	0.09364	0.13189	1	2.68750	LEACHVOL
6	0.17687	0.14646	1	2.68750	TIME RAIN
7	0.14780	0.14052	1	2.68750	TEXTILE TEMP
8	0.10017	0.12965	1	2.68750	FOOD TEMP
9	0.34523	0.16567	3	8.06250	TIME FOOD
10	0.46184	0.14856	2	5.37500	FOOD RAIN
11	0.30283	0.13933	3	8.06250	TIME TEMP
12	0.17413	0.14836	5	13.43750	TIME YARD
13	0.13609	0.13247	2	5.37500	TIME

Variable importance for the pH model is provided in Table 5.32. The variable importance scores are calculated relative to the most important variable, which is always given a score of 100 (Hastie et al., 2001). In this table, TIME is given highest importance and FOOD second; while, Leachate Volume is given the least importance in predicting pH.

Table 5.32 Relative Variable Importance for pH

Variable	Importance	-gcv
TIME	100.00000	0.29212
FOOD	71.20448	0.21024
RAIN	62.27167	0.19043
TEMP	57.94884	0.18180
YARD	36.66952	0.14836
TEXTILE	29.53841	0.14052
LEACHVOL	21.38526	0.13362

5.16.1.1 Curves for Final Model (pH)

MARS outputs the three-dimensional (3-D) plots which depict the relationship between a pair of predictor variables and the target variable. The 3-D plots and their explanation are provided in this section for the final pH model.

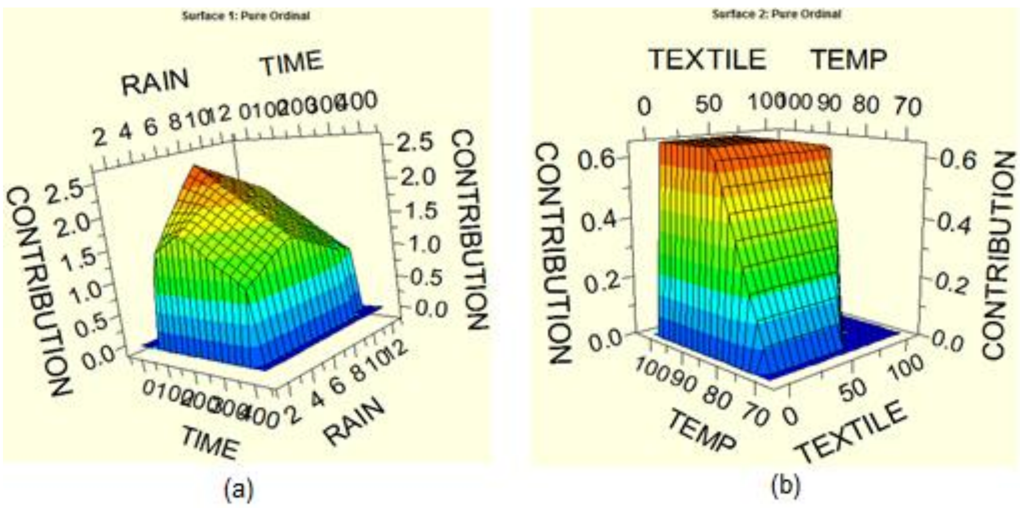


Figure 5.74 3-D Interaction Plots (a) Time-Rain and (b) Temperature-Textile

In Figure 5.74 (a), for a rainfall of 2 mm/day, in the beginning pH is more acidic and gradually increases up to 150 days and then gradually decreases and stabilizes in the methanogenic phase. For 6 mm/day and 12 mm/day, the rainfall appears to follow a similar trend, but peaks earlier. This is not what would be anticipated: one would anticipate a drop in pH during the acidogenic phase. We were adding base (KOH), however, to avoid drastic drops in pH which would kill the methanogens.

In Figure 5.74 (b), when temperature increases up to 85 °F, there is a gradual increase in pH and it reaches the peak at 85 °F. When temperature goes beyond 85 °F, then there is no change in pH and it remains constant. However, %textile seems to have no effect on pH. Perhaps, textile waste does not degrade significantly.

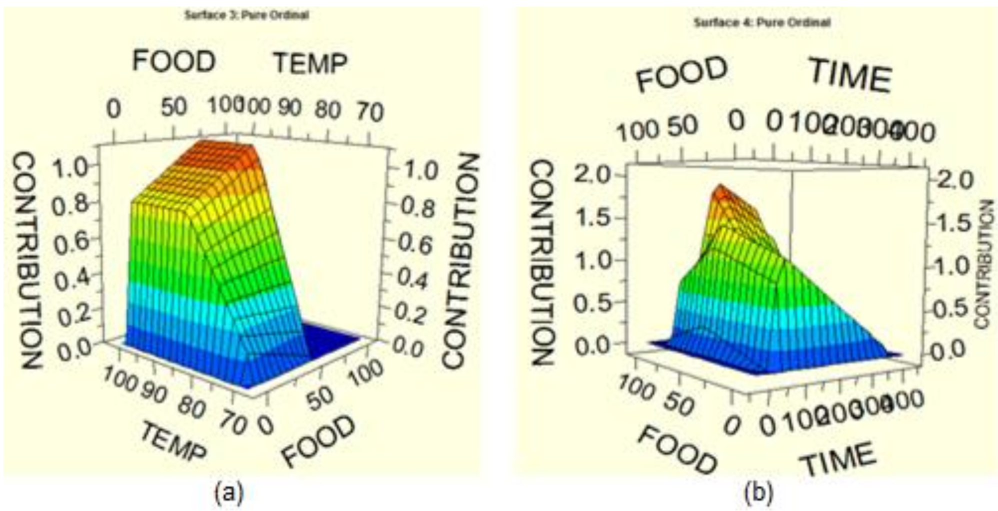


Figure 5.75 3-D Interaction Plots (a) Temperature-Food and (b) Time-Food

In Figure 5.75 (a), when temperature increases up to 85 °F and %food increases up to 60, there is an increase in pH. However, beyond 85 °F, pH stabilizes. This is somewhat surprising, since reactors with high food percentages can actually fail due to acid accumulation. Again, the base was added to stabilize the pH, which may explain this trend. There is no data available for 100% food reactor at 70 °F, as this reactor failed due to excessive acid accumulation.

In Figure 5.75 (b), when %food increases up to 60, pH gradually increases and then it decreases as %food increases. Perhaps, increases in %food, increases acidity and pH drops. Also, when time increases up to 75 days, there is an increase in pH and then it decreases as time progresses. Again, this is not what would be anticipated, given that the acidogenic phase typically shows a decrease in pH.

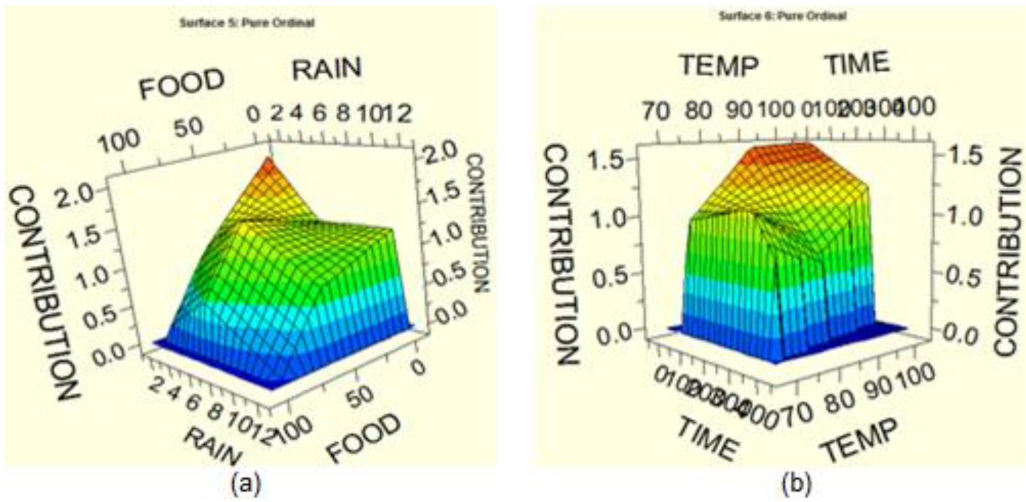
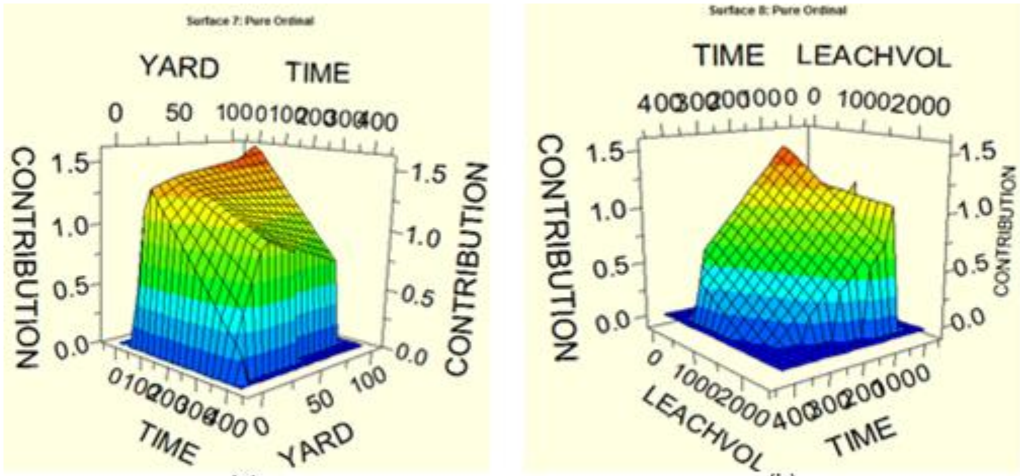


Figure 5.76 3-D Interaction Plots (a) Rain-Food and (b) Time-Temperature

In Figure 5.76 (a), when % food is low and rainfall intensity is lowest, pH is at peak. However, when % food increases, pH drops. This is due to increase in acidity due to higher amount of food. Also, pH increases with rainfall up to 6 mm/day and then pH drops as rainfall increases beyond 6 mm/d. The reason for this is unclear.

In Figure 5.76 (b), for a temperature of 70 °F, pH increases gradually with time up to 300 days and then pH drops slightly. For higher temperatures, it appears that the pH peaks earlier and then drops. At time t=0, pH increases as temperature increases up to 85 °F, and then stabilizes. For later times, pH actually decreases as temperature increases up to 85 °F, and then increases again. This happens because as temperature increases, pH will change but there is not a general relationship between temperature and pH. It depends on the composition of a liquid.



(a) (b)

Figure 5.77 3-D Interaction Plots (a) Time-Yard and (b) Time-Leachate Volume

In Figure 5.77 (a), initially with time, when %yard is high, pH is at peak. When time passes by, there is a drop in pH. At later times, pH increases when %yard increases up to 25 and then it gradually decreases.

In Figure 5.77 (b), initially with time, when leachate volume is lower, pH is at peak. As time and leachate volume increase, pH drops.

<u>5.17 Importance of Temperature</u>

Based on the MARS analysis for the leachate parameters, it was observed that the temperature variable did not have significant impact (high rank) in predicting leachate parameters in the variable importance table for the final models. Theoretically, the temperature variable was expected to be a critical variable, along with Time and Rain, in predicting leachate parameters. However, the variable ranges in this research were chosen based on real-world reasonably expected values, which resulted in rainfall varying over a much wider range (a factor of 6) compared to temperature. It was hypothesized that temperature would grow in importance if the variation in rainfall were narrowed. A number of the plots showed a larger impact of rainfall varying from 2 mm to 6 mm, compared with rainfall varying from 6 mm to 12 mm. Thus, a test case was run without 2 mm/day rainfall intensity using MARS for all leachate parameters to see if temperature variable scoring/ranking improved in the final models. To run the MARS analysis, the Max BFs from the final models for each leachate parameter were selected.

MARS analysis was also performed using SPM software on the leachate parameters without 2 mm/day rainfall intensity data. The variable importance tables for the leachate parameters were examined. It was observed that temperature variable ranking improved only for pH, BOD, and TDS. However, the ranking of temperature variable for the remaining leachate parameters (total alkalinity, conductivity, TSS, VSS, COD, chloride, ammonia-nitrogen) did not improve as expected.

The effect of temperature would likely have been greater if the temperature had been varied over a wider range. In addition, the impact of temperature in this study was lessened because of loss of two reactors (R10 & R11) at 70 °F, which reduced the amount of data the model was able to use at 70 °F.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

Leachate generation and management is recognized as one of the greatest problem associated with environmentally sound operation of the landfills. An understanding of leachate composition is critical for understanding long-term impacts of landfills due to pollution potential of leachate to ground water and surface water. Various mathematical models have been developed for estimating leachate parameters concentrations from landfills. The limiting factor of the current models is their inability to accommodate to the varying waste compositions and climatic conditions. The main objective of this research was to develop models to predict leachate parameters by varying rainfall, ambient temperature and waste composition in a lab-scale setup.

6.1 Summary and Conclusions

The major findings and facts of this research are:

1. This is the first study where a systematic approach (cyclic incomplete block experimental design) was used to study the impacts of temperature, waste composition, and rainfall, along with their interactions, on leachate composition.
2. The basic multiple linear regression (MLR) method was insufficient for the data analysis due to nonlinearity between response and predictor variables. Therefore, a more sophisticated modeling approach of regression splines was used for the model development of all leachate parameters (pH, BOD, COD, total alkalinity as $CaCO_3$, conductivity, TDS, TSS,

VSS, Cl^-, and NH_3-N), considering that the response may have a piecewise behavior over domain.

3. It was observed upon dismantling the reactors that 100% food waste reactors had maximum settlement compared to other reactors. Food waste typically the most degradable waste component in the waste streams, a considerable amount of organics would have leached faster and thereby increasing the settlement in the reactor.
4. Overall, most of the reactors had increase in their final weight at the end of operation. This is due to high amount of water absorption especially in reactors having textile waste. Also, it was observed upon dismantling the reactors having inorganic waste that they were holding lots of water in the bottles and cans which created ponding. Hence, the final weight of these reactors would have increased at the end. However, a few reactors (R4, R15, R18, R25, and R26) had significant weight loss at the end of operation. These reactors had greater percentages of the most degradable wastes, food and yard wastes. Hence, it led to faster leaching of organic matter from these reactors.
5. BOD/COD ratios provided a good indication of wastes stabilization in the reactors. Initially the ratio was high (0.5 or above) indicating acidic phase and as time progresses, this ratio decreases to 0.1 or below, indicating methanogenic phase where most of the waste would have been degraded. Thereafter, landfills would have reached to stabilization phase where leachate strength would have been decreased significantly.
6. Overall, the cumulative volume of water added is almost equal to the total amount of leachate generated from the reactors which shows the water balance in the system.
7. In general, reactors at 70 °F temperature were having lower concentrations of almost all leachate parameters than reactors at 85 °F and 100 °F, except R2 and R3. These two reactors showed a little higher concentration compared to other reactors having the same waste composition as R2 and R3. Because these two reactors were being operated at

lowest rainfall rate of 2 mm/day which would have generated high strength leachate, causing little higher concentration of leachate parameters.

8. Reactors with 100% food waste showed the highest concentrations for all the leachate parameters measured in this study. This was expected as food waste has the maximum amount of organic matter present and also it is the most biodegradable waste component. Besides, the food vs. time 3D-plots generated by Multivariate Adaptive Regression Splines (MARS) modeling showed a decreasing trend with time.
9. For all the model equations developed by MARS modeling in predicting leachate parameters, Time or Rain was the most important variable except for the model equation in predicting ammonia-nitrogen, where Food variable was given the highest importance.
10. The Paper vs. Rain 3D-plots generated by MARS for predicting Total Alkalinity and Total Dissolved Solids (TDS) showed similar trend. Total Alkalinity and TDS concentrations were decreasing with increasing rainfall and paper percentage. Perhaps, increased rainfall dilutes leachate and decreased concentrations with high amount of paper could be due to the lignin effect where microbes have difficulty in degrading waste with high lignin content.
11. Similar trend was observed in Leachate Volume vs. Time 3D-interaction plots generated by MARS for predicting Total Alkalinity, TDS, and Conductivity. In these plots, as time and leachate volume increase, the concentration of these leachate parameters decreases. This was expected as with time most of the waste would have been degraded and also an increase in leachate volume would dilute the concentrations of contaminants.
12. The Temperature vs. Rain, Paper vs. Rain, and Food vs. Temperature 3D-interaction plots generated by MARS in predicting Total Suspended Solids (TSS) and Volatile Suspended Solids (VSS) had similar trend and they were also identical. Besides, the raw data plots over time for TSS and VSS were almost similar in shape for all reactors.
13. The final model equation for Total Alkalinity had the highest adjusted R^2 value of 0.96126 and Conductivity being the second, which had adj. R^2 value of 0.95799. Also, the final

model equations for COD, TDS, and BOD had really good adj. R^2 values of 0.95042, 0.94269, and 0.92292.

14. Based on these experiments, it was observed that 85 °F was the optimum temperature for waste decomposition from the 3D-interaction plots of BOD, NH_3-N, and VSS.
15. Based on these experiments, rainfall intensity of 6 mm/d was observed as the optimum for waste decomposition from the 3D-interaction plots for Total Alkalinity, Conductivity, TDS, and BOD.

6.2 Recommendations for Future Studies

1. An attempt should be made to develop a correlation between different heights of reactors and various leachate quality parameters to facilitate scale-up of future study data from the lab to the field.
2. Experiment should be conducted with duplicate reactors to compare the leachate quality. Also, considering duplicate reactors would help to analyze the data and develop the model equations, in case a reactor fails.
3. An experiment can be conducted using complete block design instead of incomplete block design.
4. Similar experiment should be conducted on different forms of each waste component.
5. In the current study, soil cover was not considered. The future study should be conducted to include top and intermediate soil covers to simulate the actual landfill condition.
6. Conduct similar experiment to include wide range of temperatures and rainfall intensities which can cover extreme climatic conditions.
7. Develop the model equations using the “no integer” option with all predictors (without dropping any predictor variable) using the mixture design. There will be no β_0 in the model.
8. Develop MARS model for certain leachate parameters assuming monotonic downward curve.

9. Water should be added at different intervals such as once per week or once per month to better simulate the real time rainfall condition. Also, it would be interesting to consider occasional flooding event meaning continuous or heavy rainfall for many (24-48) hours.
10. Leachate recirculation should be considered to study the behavior of leachate quality parameters over time.
11. The model equations developed using Multivariate Adaptive Regression Splines (MARS) in predicting leachate parameters should be validated against field data from actual landfills.

APPENDIX A

RAW DATA

Table A.1 Raw Data

Reactor	Reactor Inception Date	Sample Date	Age (days)	pH	Conductivity (ms/cm)	TDS (mg/l)	Total Alkalinity as $CaCO_3$ (mg/l)	BOD (mg/l)	COD (mg/l)	TSS (mg/l)	VSS (mg/l)	Chloride (mg/l)	Ammonia-Nitrogen (mg/l)
R1	1/5/2011	4/20/2011	105	7.42	3.88	2021	2500	3024.37	6094.48	135	103	162.64	0
		5/11/2011	126	7.62	2.09	1128	1450	1225.26	2852.73	105	85	111.97	2
		6/8/2011	154	7.46	1.98	998	1350	1440.69	2534.12	47.5	45	68.68	13.8
		7/11/2011	187	7.79	1.44	732	950	874.6	1457.24	64	43	32.27	15.33
		8/1/2011	208	7.77	1.28	651	900	311.66	970.67	58	56	29.32	7.98
		8/16/2011	223	7.84	0.9	450	500	81.47	540.91	34	46	25.6	14.4
		9/2/2011	240	7.79	0.83	415	433.33	80.05	466.81	36	27	20.46	17.6
		9/14/2011	252	8.02	1.09	545	600	0	518.68	95	33.33	20.4	10.3
		9/27/2011	265	7.97	1.29	660	766.67	80.25	522.38	22.14	21.43	27.93	13.47
		10/12/2011	280	7.78	1	524	566.67	93.2	558.2	38	30	25.9	26.03
		10/26/2011	294	7.82	1.12	583	650	105.96	533.5	64	44	22.94	12.43
		11/8/2011	307	7.66	1.19	626	650	81.45	497.68	41	32	18.05	4.74
		11/21/2011	320	7.91	0.94	491	500	103.87	426.06	45	22.5	13.69	40.27
		12/8/2011	337	7.63	0.99	525	533.33	64.66	309.97	28	30	7.11	41.83
		12/22/2011	351	7.65	0.94	498	533.33	44.98	261.81	0	0	19.38	45.73
		1/10/2012	370	7.37	1.21	643	700	30.08	255.63	36	30	2.27	14.53
		1/24/2012	384	7.55	1.18	648	700	22.56	266.75	45	36	15.97	0
		2/7/2012	398	7.38	1.22	666	766.67	32.64	254.4	31	23	34.43	15.83
R2	1/6/2011	4/18/2011	102	5.8	24.7	14600	14000	24509.03	42605.78	426	326	1576.2	339.5
		5/11/2011	125	5.78	19.88	12210	13100	16664.25	37418.99	182.5	137.5	1804.53	680.33
		6/8/2011	153	7.56	9.15	5080	5300	5586.63	12843.48	790	700	416.57	359.33
		7/11/2011	186	7.14	6.6	3600	4100	6932.2	9978.4	340	322.5	260.02	221
		8/1/2011	207	7.85	5.22	2810	3200	1676.5	4606.36	330	287.5	201.53	187
		8/11/2011	217	8.16	4.7	2510	2600	540.08	2432.85	397.5	345	182.76	197.67
		8/29/2011	235	7.78	5.08	2730	1900	229.52	2030.26	395	217.5	99.49	184.33
		9/14/2011	251	7.96	4.81	2560	2600	0	1380.67	320	188.33	124.32	197.67
		9/28/2011	265	7.7	4.88	2590	2700	149.37	1146.03	116.67	91.67	97.69	198
		10/17/2011	284	7.69	4.62	2570	2500	173.16	983.02	103.75	78.75	102.45	404.33
		10/26/2011	293	7.59	4.55	2520	2600	164.85	960.79	160	90	88.37	163.67
		11/8/2011	306	7.83	4.55	2540	2600	166.67	889.16	103.75	76.25	94.39	188

R2		11/21/2011	319	7.88	4.43	2460	2500	163.89	876.81	143.33	93.33	93.23	189.33
		12/8/2011	336	7.83	4.16	2340	2300	129.31	792.84	143.33	78.33	52.08	210.33
		12/21/2011	349	7.51	4.33	2450	3600	115.12	727.39	57.5	41.25	70.9	203.33
		1/10/2012	369	7.39	4.2	2360	2400	107.76	658.23	45	32.5	21.56	199.67
R3	2/18/2011	4/12/2011	53	5.65	11.47	6330	8900	10043.95	22673.68	289	164	908.11	488
		5/11/2011	82	7.33	6.71	3820	5200	6174.89	13806.74	325	210	531.11	58.4
		6/8/2011	110	7.68	4.79	2560	3600	8324.76	7422.05	1542.5	542.5	228.41	10.43
		7/11/2011	143	7.83	3.15	1650	2100	1353.59	2432.85	125	101.25	70.99	6.97
		8/1/2011	164	7.96	2.16	1116	1450	235.41	1108.99	101.67	93.33	52.19	7.18
		8/16/2011	179	7.97	1.96	1000	1200	174.95	1150.97	78.75	67.5	31.28	6.98
		9/2/2011	196	7.57	2.22	1145	1300	114.66	1647.42	165	142.5	40.2	35.9
		9/14/2011	208	7.66	2.41	1240	1400	0	2089.54	245	168.33	34.2	83.77
		9/28/2011	222	7.81	2.48	1273	1400	161.44	2380.98	263.33	171.67	52.86	113.33
		10/12/2011	236	8.16	2.25	1220	1200	180.3	2499.54	300	210	28.94	141
		10/26/2011	250	7.78	2.48	1336	1300	0	2420.5	242.5	187.5	36.88	126.67
		11/7/2011	262	7.84	2.65	1550	1500	240.61	2400.74	132.5	97.5	30.98	220.67
		11/21/2011	276	7.85	3	1640	1600	238.02	2124.11	127	106	35.35	115
		12/8/2011	293	7.76	2.92	1618	1500	136.86	1768.45	185	121.67	13.83	246.33
		12/21/2011	306	7.74	3.2	1790	1700	121.69	1684.47	166.67	131.67	0	332.33
		2/21/2012	368	8.06	3.24	1820	1800	212.77	1049.71	133.33	111.67	23.95	268.33
R4	5/19/2011	6/1/2011	13	6.35	26.9	16580	15500	33989.53	60759.54	1540	1345	3191.73	224.67
		7/6/2011	48	5.85	28.3	17360	18500	46134.17	59648.09	475	345	1986.48	466
		7/27/2011	69	5.74	23.8	14220	15400	33230.42	49768.49	382.5	315	2233.58	1125
		8/16/2011	89	5.85	20.5	12100	12800	22461.68	42420.53	208.33	171.67	1695.35	548
		8/30/2011	103	5.92	17.79	10320	10100	17710.27	32911.42	260	220	808.23	585
		9/13/2011	117	6.22	13.23	7530	7500	16384.25	25069.49	195	157.5	625.33	1038.33
		9/27/2011	131	7.14	10.47	5820	5800	9281.5	16177.85	283.33	253.33	647.25	826.33
		10/10/2011	144	7.76	8.52	4830	4400	0	8372.96	416.67	370	522.63	624.67
		10/25/2011	159	8.16	7.68	4400	4100	3688.82	5347.33	200	185	220.88	578.67
		11/7/2011	172	8.09	6.65	4030	3500	850.51	2037.67	312.5	275	181.25	495
		11/21/2011	186	8	6.73	3820	3500	423.89	995.37	109	95	170.37	341
		12/12/2011	207	7.97	5.76	3250	2700	186.62	739.74	90	81	53.8	337.33
		12/30/2011	225	8	4.19	2380	2200	99.59	471.75	58.75	41.25	21.59	423.33
		1/24/2012	250	0	0	0	0	139.59	556.96	0	0	94.84	0
		2/14/2012	271	7.91	3.06	1698	1600	57.73	327.26	33.33	16.67	27.88	269.67
R5		6/6/2011	24	5.89	3.6	1974	2240	3160.58	9039.83	62.5	55	935.82	138.33
		7/5/2011	53	7.97	10.47	5690	6400	8960.15	13979.63	105	91.67	181.1	9.68

R5	5/13/2011	8/3/2011	82	8.17	13.12	7410	8300	8544.11	16054.35	173.33	171.67	320.47	20.4
		8/23/2011	102	8.29	13.2	7490	7300	4041.28	7953.08	305	275	208.03	27.13
		8/30/2011	109	8.1	12.3	6900	6800	2339.55	6792.23	240	212.5	141.34	11.3
		9/15/2011	125	8.27	9.81	5390	5000	0	3334.37	216.25	195	94.03	22.1
		9/27/2011	137	8.02	7.6	4140	3900	679.38	2778.64	116.67	93.33	175.3	26.33
		10/10/2011	150	8.17	6.1	3400	2800	0	1864.77	91.25	80	116.72	26.67
		10/25/2011	165	7.99	5.31	2980	2800	417.55	1763.51	167	145	57.18	25.5
		11/9/2011	180	7.87	4.91	2730	2500	194.07	1556.04	75	60	45.01	23.7
		11/23/2011	194	7.91	4.38	2420	2200	192.51	1363.38	44	40	50.54	25.5
		12/12/2011	213	7.82	3.56	1970	1700	135.83	1225.07	75	63.33	23.97	23.5
		12/30/2011	231	7.54	2.42	1340	1300	81.1	817.54	45	35	13.13	43.2
		1/24/2012	256	7.63	1.92	1061	1000	128.97	1190.49	77	73	25.16	0
		2/14/2012	277	7.46	1.73	940	900	106.6	1425.13	73	69	29.68	25.1
R6	5/18/2011	6/7/2011	20	5.6	9.19	5100	7200	19889.1	18129.07	176.25	137.5	1749.79	125
		7/8/2011	51	7.29	7.22	3960	5700	8803.89	13090.47	245	133.33	716.35	17.97
		8/4/2011	78	7.79	2.37	1229	1000	544.9	4001.24	197.5	180	455.32	57.83
		8/16/2011	90	7.48	2.59	1340	1500	308.72	2692.19	211.67	160	247.26	47.1
		8/30/2011	104	7.27	1.77	902	800	306.23	2655.14	120	102.5	232.45	33.33
		9/14/2011	119	7.61	2.19	1130	1200	0	2154.99	73	58	201.02	6.42
		9/27/2011	132	7.63	1.95	993	1000	83.76	1941.34	71	50	191.36	6.15
		10/10/2011	145	7.62	1.84	970	1000	0	1669.65	82.5	57.5	120.17	5.3
		11/9/2011	175	7.85	1.7	904	900	135.27	1625.19	93.75	47.5	107.35	23.47
		11/28/2011	194	7.6	1.76	942	1050	110.4	1054.65	56.67	30	85.95	5.21
		12/12/2011	208	7.58	1.38	740	700	207.9	849.65	65	35	34.17	7.05
		12/30/2011	226	7.43	1.53	827	900	76.48	786.66	42	38	21.22	7.5
		1/24/2012	251	7.69	1.36	749	800	56.85	821.24	42.5	37.5	37.76	0
		2/16/2012	274	7.22	1.41	761	750	28.01	747.14	49	51	40.31	53.43
R7	3/9/2011	4/28/2011	50	7.55	4.16	2160	2750	2816.24	6211.8	36	37	488.42	16.9
		5/23/2011	75	8.23	1.49	801	700	101.44	1117.63	44	40	319.41	14.97
		6/15/2011	98	7.73	1.18	603	700	114.31	763.2	14	11	168.02	7.16
		7/14/2011	127	8.1	0.96	480	475	58.91	477.93	16.67	15	75.24	3.29
		8/2/2011	146	8.28	0.87	436	455.33	34.23	434.7	12	14	52.3	15.9
		8/15/2011	159	8.23	0.74	383	366.67	29.67	450.78	17	13	44.74	23.6
		8/31/2011	175	8.14	0.78	389	366.67	18.46	417.41	12.5	11.5	27.17	22.07
		11/4/2011	240	8.21	0.59	328	300	40.68	308.74	24	8	22.9	14

R8	3/10/2011	4/12/2011	33	8.36	15.41	8690	8250	976.09	13498	432	345	2872.8	792.67
		4/25/2011	46	8.33	15.24	8580	8400	573.39	10768.76	127	104	1544.13	501.67
		5/9/2011	60	8.18	15.33	9050	8900	334.8	7792.53	55	37.5	1333.8	598.33
		6/9/2011	91	8.24	13.58	7750	7700	280.69	4600.19	70	43	776.21	412.67
		7/14/2011	126	8.07	11.02	6120	6200	116.47	2400.74	10	8	411.71	550.33
		8/2/2011	145	8.16	9.8	5460	5700	67.59	1911.7	18	22	347.29	353
		8/15/2011	158	8.45	8.15	4660	4700	246.17	2213.03	140	78.75	312.58	422.67
		8/31/2011	174	7.95	9.13	5020	5000	87.65	1659.77	58.33	41.67	195.13	222
		9/19/2011	193	8.22	8.19	4460	4200	108.79	1464.65	145	63.33	144	863
		11/7/2011	242	8.05	6.01	3630	3500	97.35	980.55	35	18.33	84.18	363
R9	3/14/2011	4/25/2011	42	5.87	15.63	8810	12000	18823.59	38777.43	106	87	699.71	254.33
		5/10/2011	57	7.54	14.25	8430	11000	16732.81	33467.15	255	192.5	711.28	166
		6/9/2011	87	8.36	6.19	3390	3300	926.44	3556.66	142	80	660.35	10.37
		7/14/2011	122	8.06	4.23	2230	1866	269.44	2000.62	275	88.33	505.51	22.13
		8/2/2011	141	8.06	3.46	1820	1666	74.9	1704.23	112.5	92.5	269.92	31.8
		8/15/2011	154	8.06	2.67	1460	1300	129.99	1437.48	65	57.5	211.79	23.2
		8/31/2011	170	7.93	2.81	0	1333.33	58.85	1128.74	77.5	62.5	137.2	20.4
		11/8/2011	239	8.18	1.79	954	850	32.85	577.96	0	0	52.43	37
R11	1/31/2011	3/29/2011	57	7.39	0.856	421	516.5	0	558.2	70	53	261.81	0
		4/5/2011	64	7.06	0.665	357	450	180.38	591.54	45	35	66.19	197
		4/14/2011	73	7.07	0.685	335	300	326.44	713.8	70	53	67.13	48.67
		4/28/2011	87	6.88	0.634	309	366.67	313.2	739.74	145	117.5	40.39	3.94
		5/16/2011	105	6.87	0.51	268	300	294.28	629.82	32.5	35	47.41	7.37
		6/30/2011	150	6.98	0.403	196	200	137.516	342.08	42.5	43.75	26.32	10
		7/28/2011	178	7.11	0.47	234	200	23.28	167.95	23	21	28.37	28.53
		8/24/2011	205	7.04	0.4	196.1	166.67	13.47	148.19	28.75	21.25	8.43	23.2
		1/17/2012	351	7.5	0.9	488	466.67	52.4	287.74	48	40	20.96	67.87
R12	2/16/2011	3/29/2011	41	6.65	4.47	2340	3400	-	5828.96	82	60	218.45	0
		4/1/2011	44	6.64	3.96	2065	3000	-	5100.34	101	62	216.48	59.8
		4/8/2011	51	7.04	3.19	1642	2200	2123.89	3550.48	78	57	152.86	93.67
		4/14/2011	57	7.32	2.7	1384	1900	1401.56	2500.77	93	51	132.77	1.44
		5/2/2011	75	6.91	2.19	1021	1383	579.45	1170.73	54	30	114.55	13.7
		5/24/2011	97	6.79	1.671	910	1150	478.89	970.67	63	40	72.31	5.22
		6/16/2011	120	6.59	1.44	746	944.33	171.74	464.34	64	36	42.93	12.3
		7/18/2011	152	7.23	1.21	608	722	15	121.03	44	22	45.52	5.27
		8/9/2011	174	6.67	1.09	550	666.67	21.78	143.25	41	22	32.31	12.65
		9/8/2011	204	6.86	1.06	537	600	10.59	76.57	36	19	16.42	28.17

R12	2/16/2011	9/26/2011	222	6.64	1.14	570	666.67	0	85.21	42	20	41.45	13.9
		10/20/2011	246	6.68	1.06	557	633.33	21.35	76.57	36.25	20	32.34	9.35
		11/22/2011	279	6.79	1.02	536	600	25.32	91.39	44	18	18.2	29.13
		12/14/2011	301	6.73	1.06	563	566.67	22.74	144.49	52.14	30.71	18.61	38.37
		1/12/2012	330	7.15	0.92	498	533.33	22.87	140.78	0	0	2.85	38.53
		2/7/2012	356	6.51	0.91	493	533.33	24.68	80.27	19	8	35.59	8.03
R13	5/19/2011	5/26/2011	7	5.95	9.32	5420	7950	10277.82	20524.87	68.75	58.75	792.33	8.18
		6/7/2011	19	6.25	8.65	4790	7100	9256.32	15436.88	81.67	65	968.75	6.76
		6/15/2011	27	7.04	6.58	3620	5250	6228.062	11657.93	136.67	101.67	230.87	1.85
		7/1/2011	43	7.47	2.74	1440	1866.67	1931.46	3000.93	71	59	84.51	10.43
		7/12/2011	54	7.55	1.87	960	1200	814.47	1438.72	33.75	36.25	102.87	11.97
		7/20/2011	62	7.5	1.34	680	722	361.35	545.85	52.5	45	68.52	12.3
		8/2/2011	75	7.74	1.11	560	633.33	45.95	328.5	25	25	60.38	9.21
		8/15/2011	88	7.53	1.34	720	750	47.61	265.51	20	13.75	41.76	7.66
		8/22/2011	95	7.47	1.25	631	700	50.99	266.75	40	17	28.39	14.7
		9/7/2011	111	7.09	1.37	689	800	54.3	293.92	103.33	63.33	33.73	22.4
		9/12/2011	116	7.16	1.14	574	633.63	37.73	217.35	153.75	53.75	26.28	26.5
		9/15/2011	119	7.21	1.3	634	766.67	0	275.39	127.5	42.5	28.8	3.14
		9/26/2011	130	7.41	1.29	650	733.33	33.3	219.82	13	10	39.76	4.62
		10/3/2011	137	7.13	1.23	619	700	49.08	249.46	40	17.5	41.8	17.7
		10/11/2011	145	7.54	1.29	681	800	29.6	245.76	46	29	31.39	18.87
		11/8/2011	173	7.09	1.19	625	550	46.39	301.33	48	29	87.75	0.78
		11/22/2011	187	7.52	1.15	605	600	41.31	214.88	33.75	26.25	44.21	1.83
		11/30/2011	195	7.42	1	521	500	29.5	181.54	45	15	46.59	4.89
		12/12/2011	207	7.51	1.03	547	500	17.86	170.42	25	19	22.03	2.24
		12/22/2011	217	7.42	0.99	526	533.33	26.66	177.83	21.25	11.25	34.87	11.83
		1/3/2012	229	7.21	1.15	615	633.33	16.69	202.53	28	23	6.45	43.87
		1/12/2012	238	6.95	0.97	523	533.33	28.46	212.41	31.25	16.25	6.53	1.77
		1/19/2012	245	6.93	0.87	471	466.67	28.81	197.59	27.5	22.5	5.19	68.2
		1/26/2012	252	7.09	0.85	454	466.67	26.2	200.06	23.33	33.33	23.56	11.47
		2/2/2012	259	6.9	0.96	512	533.33	18.6	135.84	25	22	28.84	28
		2/14/2012	271	7.5	0.93	495	533.33	14.31	114.85	18	16	18.85	5.3
R14	5/13/2011	5/27/2011	14	5.54	16.14	9680	9600	12361.38	30256.28	128.33	121.67	1839.33	566.67
		6/7/2011	25	6.92	13.12	7470	8300	11077.78	22908.32	420	375	2014.25	673.33
		6/20/2011	38	7.53	8.54	4700	4900	5796.5	12695.29	515	412.5	438.27	467.33
		7/1/2011	49	7.86	6.87	3760	3500	1738.52	6174.75	382.5	330	260.15	394
		7/12/2011	60	8.03	5.92	3220	3300	639.97	4025.94	215	160	340.55	426.67

R14	5/13/2011	7/20/2011	68	7.82	5.13	2760	2800	206.74	2735.41	95	85	241.44	293.33
		7/27/2011	75	7.96	4.69	2520	2600	156.95	2277.25	232.5	137.5	180.91	290.67
		8/4/2011	83	7.96	4.4	2340	2600	119.98	1862.3	85	65	139.93	261.67
		8/9/2011	88	7.71	4.21	2220	2300	74.54	1617.78	44	36	134.73	281.67
		8/17/2011	96	7.71	3.63	1923	2100	65.75	1247.3	43.33	20	91	214
		8/25/2011	104	7.56	3.87	2039	2100	47.72	512.5	15	21.25	54.11	219
		9/7/2011	117	7.29	3.66	1830	1900	48.93	892.87	66.67	55	74.6	154.67
		9/15/2011	125	7.83	3.13	1620	1900	0	1906.76	46.25	41.25	43.32	117.67
		9/21/2011	131	7.76	3.02	1570	1700	434.3	1309.05	51.67	41.67	54.97	152
		9/29/2011	139	7.7	3.34	1530	1500	195.37	1047.24	47.5	35	40.07	132
		10/4/2011	144	7.45	2.71	1420	1500	106.14	775.55	37	32	42.49	135
		10/11/2011	151	7.37	2.59	1395	1400	70.49	703.92	55	45	48.96	120.33
		10/17/2011	157	7.39	2.53	1370	1400	62.92	654.52	24	16	64.5	189.33
		10/24/2011	164	7.27	2.51	1330	1350	54.51	606.36	24	18	46.77	117.67
		10/31/2011	171	8.05	2.19	1200	1300	64.23	629.82	41.67	33.33	52.72	120.67
		12/5/2011	206	7.31	2.01	1078	1150	31.75	456.93	16.25	17.5	53.13	189.33
R15	5/20/2011	5/26/2011	6	5.73	21.45	13340	13000	21928.16	47452.95	345	265	4266.4	613.33
		6/16/2011	27	7.69	25.5	15600	17000	18021.6	28712.59	337.5	287.5	1041.68	392
		6/27/2011	38	7.61	22.4	13240	14000	16754.63	26180.94	78.75	83.75	454.27	718
		7/5/2011	46	7.56	18.55	10000	11500	13757.02	21883.31	86.67	71.67	663.54	649.67
		7/13/2011	54	7.86	13.76	7840	8400	8108.48	14646.51	65	53.33	382.13	443
		7/20/2011	61	8.1	11.23	6300	6600	4035.54	9360.92	172.5	152.5	485.38	278.67
		7/27/2011	68	8.09	8.4	4700	4800	2631.79	6150.05	107.5	87.5	304.18	223
		8/4/2011	76	8.18	6.04	3280	3400	547.41	3075.03	80	72.5	112.03	130.33
		8/9/2011	81	8.11	4.63	2460	2600	1275.15	2778.64	78	66	94.26	85.17
		8/18/2011	90	7.94	3.76	2000	1900	430.69	1599.26	86.67	81.67	59.47	49.4
		8/29/2011	101	7.88	2.83	1465	1600	142.07	1047.24	116.67	101.67	24.2	30.73
		9/9/2011	112	7.75	2.11	1090	1150	0	757.02	90	70	34.48	13.6
		9/19/2011	122	7.9	1.9	961	1000	41.09	594.01	61.67	43.33	12.33	0
		9/26/2011	129	7.65	1.79	911	1000	68.3	575.49	46.67	45	38.63	1.39
		10/3/2011	136	7.66	1.65	842	950	57.36	489.04	55	43.75	36.5	12.2
		10/10/2011	143	7.8	1.54	804	900	0	443.35	48.75	35	20.86	3.5
		10/17/2011	150	7.47	1.52	805	900	57.12	400.12	33.75	23.75	40.71	9.75
		10/24/2011	157	7.78	1.42	747	850	27.12	293.92	41	27	30.09	7.83
		10/31/2011	164	7.2	1.52	752	850	82.07	385.3	47.5	30	27.11	11.27
		11/10/2011	174	8.08	1.27	676	700	35.48	398.89	55	45	30.47	0.33
		11/15/2011	179	7.84	1.29	686	750	30.58	316.15	40	31.67	32.36	18.77

R15	5/20/2011	11/22/2011	186	7.62	1.32	688	750	33.75	311.21	41.25	32.5	22.81	0.28
		11/28/2011	192	7.61	1.27	6690	700	34.39	323.56	46.67	36.67	41.22	4.94
		1/19/2012	244	7.58	0.95	520	533.33	34.45	311.21	103.33	86.67	4.28	7.34
		2/2/2012	258	6.62	0.91	474	500	48	309.97	50	44	26.04	4.7
		2/16/2012	272	7.15	0.81	440	466.67	17.37	229.7	38	38	0	4.73
R16	3/9/2011	4/5/2011	27	6.4	3.98	2068	2200	6008.49	6878.67	63	51	835.83	396
		4/19/2011	41	6.13	2.145	1089	1100	1725.03	3927.14	65	61	323.35	147.67
		5/3/2011	55	6.46	1.308	678	850	1173.89	2692.19	42	35	181.23	82.9
		5/24/2011	76	6.79	0.612	326	400	399.83	1257.18	71.67	70	128.37	12.4
		6/9/2011	92	6.91	0.48	240	277.67	127.99	643.41	73.33	50	50.74	3.65
		6/28/2011	111	6.83	0.433	212	222	99.381	470.52	57.5	55	33.96	17
		7/8/2011	121	7	0.41	204	200	85.18	438.41	58.33	50	34.24	3.19
		7/19/2011	132	6.55	0.4	120	191.5	73.38	333.44	31	22	29.7	9.41
		7/26/2011	139	6.73	0.41	199	200	56.35	334.67	26.43	20	23.66	11.73
		8/8/2011	152	6.99	0.39	191	185	52.11	321.09	31.67	15	24.19	19.1
		8/17/2011	161	7.04	0.38	185.7	200	21.7	259.34	16	10	23.26	15.3
		9/6/2011	181	6.94	0.39	192.1	166.67	36.31	227.23	23.33	23.33	10.04	28.8
		9/13/2011	188	7.1	0.39	189	166.67	38.29	239.58	25	12.67	15.15	20
		9/20/2011	195	7.14	0.39	189	154.64	27.18	250.69	15	5	14.79	19.8
		9/28/2011	203	6.74	0.38	186	191.5	34.65	234.64	20	15	20.18	9.65
		10/4/2011	209	6.82	0.38	186	166.67	30.3	269.22	50	42.5	19	13.6
		10/11/2011	216	6.81	0.37	186	150	42.7	271.69	28	18	17.79	5.5
		10/20/2011	225	7.03	0.37	189	183.33	50.12	256.87	40	36.67	21.78	5.18
		10/25/2011	230	6.71	0.38	194	166.67	39.76	255.63	43.33	36.67	23.56	6.82
		11/4/2011	240	6.75	0.38	196	200	28.9	237.11	18.33	15	9.65	19.5
		11/10/2011	246	6.78	0.38	197	166.67	29.11	256.87	41.67	31.67	23.53	0.01
		11/15/2011	251	6.73	0.38	194	200	26.78	229.7	40	23.33	20.46	7.05
		11/23/2011	259	7	0.38	192	192.31	18.69	227.23	22	15	9.92	3.02
		11/30/2011	266	6.61	0.38	193	193	42.54	242.05	0	0	20.82	1.12
		12/13/2011	279	6.76	0.39	200	166.67	42.56	279.1	20	25	8.61	28.87
		12/22/2011	288	6.61	0.39	207	166.67	25.81	258.1	24	18	19.1	5.67
		1/3/2012	300	6.63	0.41	213	200	19.87	279.1	23.33	26.67	1.8	9.66
		1/10/2012	307	6.55	0.41	212	200	23.77	279.1	25	15	1.9	14.13

R17	3/15/2011	4/11/2011	27	7.74	2.4	1225	1466.5	1259.75	2692.19	45	44	110.73	281
		4/22/2011	38	7.19	2.34	1189	1500	575.66	1494.29	46	30	110.02	27.65
		5/10/2011	56	7.25	1.474	779	950	59.63	348.26	408	35	61.87	2.48
		6/3/2011	80	6.91	1.364	682	777.67	0	293.92	30	27.5	48.84	18.27
		6/14/2011	91	7.2	1.28	650	777.67	41.39	219.82	3	10	25.27	9.88
		6/28/2011	105	7.37	1.301	650	783	43.71	233.41	30	22	27.88	2.48
		7/6/2011	113	7.34	1.19	602	766.67	31.7	206.24	15	11	27.21	15.03
		7/13/2011	120	7.05	1.24	632	800	28.32	181.54	14	9	19.72	18.1
		7/25/2011	132	6.93	1.3	650	766.67	30.26	181.54	15	4	26.34	7.04
		8/11/2011	149	7.65	0.98	490	566.67	18.94	125.96	8	8	18.02	6.33
		9/6/2011	175	6.98	1.23	625	700	12.34	97.56	22.5	16.25	8.91	10.9
		9/13/2011	182	7.88	1.15	580	650	8.9	90.15	16	8	13.82	5.1
		9/20/2011	189	7.36	1.28	646	733.33	8.5	102.5	40	14	13.09	9.26
		1/19/2012	310	7.34	1.06	582	633.33	12.66	118.56	43	17	3.57	3.74
R18	3/14/2011	4/7/2011	24	5.44	13.92	7790	9200	14826.09	33467.15	99	92	1171.33	3163.33
		4/25/2011	42	7.53	9.91	5420	6400	10761.2	21920.36	565	430	944.23	398.33
		5/9/2011	56	8.09	5.36	2980	3500	1711.09	5483.18	265	200	375.68	135
		5/17/2011	64	7.86	4.65	2450	2600	657.81	3853.04	290	182.5	357.34	101.67
		6/3/2011	81	7.86	4.65	2450	2600	0	2420.5	271.67	195	224.43	161.5
		6/14/2011	92	7.74	3.58	1900	2150	147.37	1452.3	85	83.33	88.57	82.57
		6/28/2011	106	7.69	2.94	1539	1900	50.08	933.62	98.33	78.33	73.02	111
		7/6/2011	114	7.69	2.94	1540	1900	86.28	795.31	31	29	56.49	81.4
		7/13/2011	121	7.89	2.65	1379	1600	68.73	658.23	42	29	29.27	82.83
		7/25/2011	133	7.6	2.56	1320	1600	54.66	621.18	31	23	48.78	73.8
		8/4/2011	143	8.02	2.39	1236	1600	88.74	766.9	28.75	22.5	35.02	54.43
		8/10/2011	149	7.96	2.19	1130	1300	50.19	577.96	31	27	21.05	60.03
		8/22/2011	161	7.92	2.28	1178	1350	48.92	518.68	36	32	16.06	44.93
		9/9/2011	179	7.92	1.95	1015	1150	58.31	482.87	100	45	22.69	78.13
R19	1/31/2011	3/28/2011	56	7.3	2.14	1095	1155	0	1264.59	28	28	103.72	
		3/31/2011	59	7.08	2.21	1124	1166.5	313.85	1232.48	30	23	101.43	103.37
		4/4/2011	63	7.24	1.993	1011	1016.5	219.2	1008.95	21	19	100.5	92.83
		4/11/2011	70	7.46	1.956	989	1050	86	747.14	11	17	53.72	133.67
		4/28/2011	87	7.63	2.25	1145	1166.5	71.44	786.66	34	34	86.86	88.23
		5/23/2011	112	7.11	1.529	821	850	44.09	349.49	14	10	43.58	55.47
		6/6/2011	126	7.69	1.3	719	733.33	32.31	254.4	12.5	8.75	39.24	58.93
		6/30/2011	150	7.16	1.14	574	566.67	26.35	209.94	9	15	23.03	38.5
		7/18/2011	168	7.29	1.03	514	533.33	27.71	184.01	7.14	3.57	38.3	31.57

R19	1/31/2011	7/28/2011	178	6.94	1.06	535	533.33	22.22	167.95	3.26	3.26	18.77	41.37
		8/29/2011	210	7.23	0.95	477	500	25.8	140.78	10.5	7	10.52	22.67
		9/21/2011	233	7.43	1.28	650	666.67	32.76	234.64	21	20	29.49	43.07
		10/17/2011	259	7.46	1.15	606	600	16.44	163.01	10	5	35.34	57.73
		11/14/2011	287	7.47	1.06	556	550	13.32	145.72	11.25	6.25	18.95	67.7
		1/17/2012	351	7.25	1.11	600	600	23.56	170.42	26	24	20.09	46.37
R20	2/25/2011	3/31/2011	34	0	7.86	4230		0	9929	50	38	608.22	279
		4/7/2011	41	6.25	4.99	2630	2650	3211.93	6545.24	55	51	437.65	1389.33
		4/20/2011	54	5.6	2.56	1468	1450	2112.89	4495.22	64	55	271.6	-
		5/2/2011	66	5.58	2.56	1306	1200	2010.84	3692.5	25	35	195.85	111.5
		5/31/2011	95	6.51	1.017	525	550	735.66	1333.75	63	57	117.69	48.7
		6/16/2011	111	6.7	0.78	398	400	593.82	1017.6	62	54	95.5	33.13
		7/18/2011	143	6.25	0.65	320	375	700.43	1111.46	72	66	89.93	26.97
		7/28/2011	153	5.47	0.67	333	366.67	761.33	1360.91	42	36	44.83	48.1
		8/9/2011	165	5.91	0.58	289	333.33	603.83	1148.5	50	38	45.98	20.47
		8/23/2011	179	5.42	0.64	320	300	659.77	1323.87	38	36	32.6	18.2
		9/12/2011	199	5.79	0.69	344	366.67	785.15	1237.42	53	53	32.74	15.17
		9/26/2011	213	5.62	0.71	354	400	777.18	1341.16	57	50	51.35	18.83
		10/19/2011	236	7.38	0.46	230	233.33	466.44	855.82	55	50	23.85	6.36
		11/14/2011	262	6.52	0.47	242	200	186.44	510.03	42	34	21.88	15.67
		12/13/2011	291	6.63	0.49	254	233.33	83.95	434.7	38	36	15.56	9.31
		1/12/2012	321	6.82	0.47	250	233.33	70.22	285.27	35.56	34.44	2.35	<5.262
		2/21/2012	361	7.09	0.5	263	266.67	36.04	125.96	23	16	12.05	30.83
R21	1/6/2011	3/28/2011	81	6.69	1.258	628	931.13	650	1677.06	29	21	55.6	0
		4/4/2011	88	7.03	1.017	564	650	658.73	1575.8	20	13	55.34	4.31
		4/18/2011	102	6.87	1	501	433	666.62	1420.19	7	18	30.19	83.13
		5/5/2011	119	6.4	0.93	486	700	601.39	1397.96	23	16	28.65	20.1
		5/31/2011	145	6.79	0.807	414	500	689.42	1091.7	23	20	31.41	4.93
		6/30/2011	175	6.85	0.65	574	325	400	792.84	26	23.5	23.53	4.91
		7/18/2011	193	6.87	0.54	270	0	158.02	351.96	25	18	37.92	0.5
		7/28/2011	203	7.08	0.51	255	275	62.04	223.53	19	16.5	20.13	0.13
		8/22/2011	228	7.11	0.51	250	233.33	26.23	153.13	19	19	8.75	4
		9/9/2011	246	7.21	0.48	242	222.22	0	164.24	28	16	12.04	10.33
		10/3/2011	270	7.23	0.5	250	233.33	27.16	121.03	26	17	22.77	5.47
		10/24/2011	291	6.92	0.51	258	266.67	30.54	128.43	19	17	18.57	4.04
		11/14/2011	312	6.82	0.47	241	233.33	17.31	96.33	23	13	11.7	0.08
		12/14/2011	342	6.53	0.55	287	266.67	22.94	134.61	14	14	12.61	11.2

R22	5/20/2011	6/3/2011	14	6.88	6.31	339	4900	0	9163.33	146.67	110	55.81	4.28
		6/14/2011	25	7	2.76	1470	2000	2318.66	3704.85	54	36	115.48	3.16
		6/27/2011	38	7.25	1.57	797	983	535.51	965.73	27.14	19.29	39.07	17.87
		7/5/2011	46	7.25	1.35	670	766.67	225.39	426.06	17	13	31.63	11.53
		7/13/2011	54	7.49	1.15	580	700	82.14	275.39	23	18	26.59	4.47
		7/25/2011	66	7.24	1.11	560	666.67	68.42	223.53	16.25	13.12	66.06	1.97
		8/3/2011	75	7.4	1.11	560	700	39.16	187.71	7.14	12.14	43.81	5.14
		8/10/2011	82	7.26	1.07	540	600	26.72	144.49	8.13	8.75	11.24	8.2
		8/18/2011	90	7.09	1.28	642	750	48.31	227.23	45	42	26.48	5.85
		8/25/2011	97	7.14	1.12	563	640	18.56	104.97	11	10	10.25	26.27
		9/8/2011	111	7.41	1.07	543	600	10.49	104.97	45.71	25.71	11.6	9.09
		9/19/2011	122	7.42	1.13	562	666.67	12.19	114.85	52	32	6.74	0
		9/28/2011	131	7.06	1.11	553	633.33	12.94	88.92	16	12	23.4	4.23
		10/4/2011	137	7.14	1.1	556	600	7.94	74.1	15	7	15.8	5.96
		10/12/2011	145	7.1	0.96	498	533.33	8.46	74.1	10	9	15.42	10.17
		10/19/2011	152	7.13	1.26	665	566.67	6.5	70.39	8	2	83.98	10.9
		10/24/2011	157	7.37	1.11	569	566.67	8.89	66.69	10	5	39.96	3.69
		10/31/2011	164	7.39	1.24	649	700	17.5	109.91	27	13	30.72	10.22
		11/9/2011	173	6.88	1.06	555	600	6.98	61.75	12	7	24.17	9.05
		11/14/2011	178	6.94	1.07	554	600	10.1	76.57	15	8	20.83	<1.964
		11/22/2011	186	6.89	1.07	555	600	0	134.61	38	28	16.54	2.23
		11/28/2011	192	6.81	1.18	587	650	13.61	155.6	29	18	42.81	2.03
		12/5/2011	199	7.06	0.86	443	466.67	0	280.33	17	11	13.9	3.77
		12/13/2011	207	6.85	1.02	540	533.33	0	197.59	24	19	11.72	4.19
		12/21/2011	215	7.02	1	532	533.33	0	185.24	22	8	28.43	24.97
		12/30/2011	224	6.9	0.88	466	500	0	81.51	110.5	6.5	3.35	6.82
		1/10/2012	235	7.03	0.99	519	566.67	21.24	86.45	22	9	1.04	6.01
		1/26/2012	251	7.28	0.91	480	500	33.51	121.03	17	14	10.72	4.35
		2/2/2012	258	6.98	0.96	510	533.33	12.74	61.75	16	6	21.97	9.79
		2/14/2012	270	7.05	0.89	472	466.67	9.15	64.22	8	8	10.21	3.16
R23	5/18/2011	6/1/2011	14	5.61	17.47	10840	11700	16958.44	34331.61	150	143	1189.63	667.33
		6/15/2011	28	7.21	9.65	5430	5600	6792.26	14819.4	310	283	233.33	199
		7/1/2011	44	7.65	4.65	2500	2700	2330.69	4594.01	233.33	206.67	109.5	85.6
		7/12/2011	55	7.96	3.41	1880	1900	306.47	1512.81	162.5	146.25	83.42	73
		7/20/2011	63	7.72	2.98	1560	1700	106.21	1133.68	97.5	87.5	84.75	72.63
		7/27/2011	70	7.92	3.05	1600	1666	132.63	1190.49	162.5	130	62.07	76.73
		8/3/2011	77	7.58	2.76	1430	1650	37.55	933.62	81	81	75.06	76.87

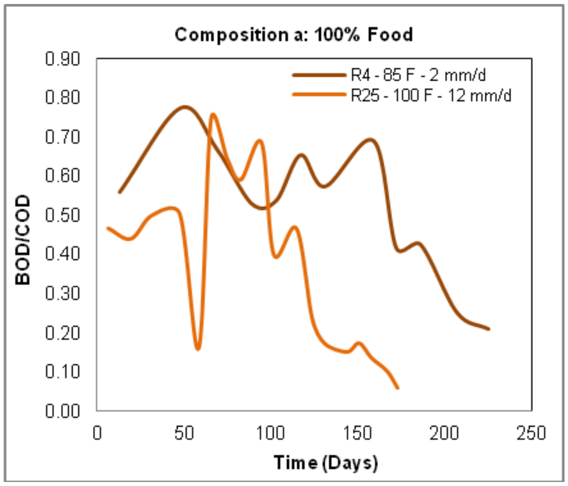
R23	5/18/2011	8/10/2011	84	7.76	2.49	1290	1500	35.17	800.25	46.25	56.25	28.77	73.67
		8/18/2011	92	7.5	2.38	1240	1300	43.18	682.93	88.33	76.67	32.74	64.53
		8/25/2011	99	7.46	2.18	1118	1200	46.77	582.9	56.67	50	14.2	63.6
		9/8/2011	113	7.28	1.77	880	950	18.36	401.36	13	14	27.36	41.3
		9/19/2011	124	7.62	1.5	756	850	11.3	326.03	23	18	8.64	32.7
		12/5/2011	201	6.79	1.04	543	566.67	16.64	196.36	4	4	40.85	47.63
R24	5/19/2011	5/27/2011	8	5.46	8.09	4650	5133.33	9081.77	16486.58	142.5	93.75	869.33	377.67
		6/13/2011	25	5.93	8.13	4560	6100	7530.25	14140.18	172	131	255.9	70.23
		6/27/2011	39	7.12	4.25	2240	2700	2903.775	4396.42	175	138.33	86.94	6.03
		7/7/2011	49	7.37	2.76	1430	1750	2034.31	3217.04	92.5	75	86.31	8.08
		7/14/2011	56	6.87	2.3	1180	1550	1523.52	2721.83	120	100	59.51	5.81
		7/25/2011	67	7.59	2.03	104	1250	588.55	1415.25	70	55	56.37	1.25
		8/3/2011	76	7.81	1.9	970	1250	68.2	743.44	50	55	57.85	2.42
		8/10/2011	83	7.86	1.62	830	1016.5	57.02	669.34	65	57	28.19	3.67
		8/18/2011	91	7.33	1.5	770	850	-	873.11	38.75	38.75	25.32	8
		8/23/2011	96	7.3	1.42	718	800	280.19	886.69	35	36.25	29.89	2.37
		9/7/2011	111	6.87	1.15	581	650	82.2	529.79	63.33	55	27.58	10.37
		9/15/2011	119	7.24	1.09	544	566.67	0	433.47	36.25	26.25	22.17	6.99
		9/21/2011	125	7.06	1.04	523	600	50.53	448.29	28.75	25	26.43	6.53
		9/29/2011	133	6.73	1.02	510	533.33	26.88	435.94	40	33	27.31	13.2
		10/5/2011	139	6.83	0.97	490	533.33	30.73	398.89	38	28	23.38	13.13
		1/19/2012	245	7.05	0.7	379	366.67	13.71	171.66	32.5	23.75	1.68	5.64
R25	4/15/2011	4/22/2011	7	6.34	24.4	14380	16000	29891.98	64032.16	1182	902	1770.3	579
		5/5/2011	20	6.14	17.63	10670	11000	17335.55	39394.91	420	358	1182.18	838
		5/17/2011	32	6.19	11.94	7120	7100	11947.3	23896.28	175	135	1426.98	505
		6/2/2011	48	5.96	5.96	3140	3100	5275.43	10472.38	96	84	340.28	277.33
		6/13/2011	59	6.49	2.73	1450	1700	853.8	5310.29	152	132	303.42	149.33
		6/20/2011	66	6.73	2	1020	1050	2675.25	3581.36	152	132	234.62	102
		6/29/2011	75	6.71	1.3	650	666.67	1494.66	2306.89	114	107	119.92	61.63
		7/7/2011	83	6.33	0.98	490	550	1115.62	1887	62	59	95.95	31.47
		7/19/2011	95	6.7	0.64	330	350	728.77	1062.06	64	54	132.53	19.37
		7/26/2011	102	6.86	0.4	197	200	415.32	1039.83	94	92	78.82	20.43
		8/8/2011	115	6.87	0.58	284	300	389.91	836.06	68	56	35.19	20.53
		8/17/2011	124	7.26	0.5	250	250	102.42	433.47	95	67.5	42.41	16.17
		8/24/2011	131	7.38	0.61	301	314.29	52.78	306.27	62.5	50	13.15	23.73
		9/6/2011	144	7.28	0.68	339	333.33	35.96	239.58	63.33	46.67	10.73	22.83

R25	4/15/2011	9/13/2011	151	7.6	0.68	340	333.33	35.58	206.24	47.5	45	14.54	27.6
		9/20/2011	158	8.02	0.86	426	400	28.81	213.65	48	37	15.96	42.53
		9/29/2011	167	8.15	0.72	360	311	11.47	113.62	33.75	25	19.94	31.53
		10/5/2011	173	8.2	1.07	542	500	11.47	198.83	65	38.33	27.08	76.57
		1/17/2012	277	7.42	0.65	346	300	26.95	75.33	25	16	18.25	28.87
R26	4/15/2011	4/26/2011	11	6.15	22.9	13380	13900	15755.41	39024.42	295	235	1788.7	789.67
		5/16/2011	31	5.65	8.77	5180	5300	8691.89	6866.32	237.5	152.5	111.95	408.5
		6/2/2011	48	7.12	5.1	2740	2900	3193.46	6866.32	139	119	159.03	115
		6/13/2011	59	7.17	2.36	1230	1700	1438.19	2790.99	104	96	98.4	34.9
		6/20/2011	66	7.24	1.52	770	816.5	617.13	1296.7	72	65	47.72	14.3
		6/29/2011	75	7.36	1.046	523	533.33	568.94	1133.68	77	63	43.42	4.58
		7/7/2011	83	6.93	0.83	412	450	556.1	1150.97	105	110	44.47	2.51
		7/19/2011	95	7.08	0.62	310	350	226.79	694.04	55	45	30.01	1.04
		7/26/2011	102	6.7	0.54	266	266.5	119.61	511.27	40	37	30.73	3.07
		8/8/2011	115	6.94	0.51	251	255.33	60.82	359.37	34	25	25.87	4.86
		8/17/2011	124	7.57	0.45	221	233.33	22.63	277.86	16	13	20.91	3.14
		8/24/2011	131	7.25	0.47	234	228.57	25.14	243.29	13	12	10.36	6.09
		9/2/2011	140	7.09	0.45	219	200	10.22	195.12	16	18	18.58	1.87
		9/12/2011	150	7.52	0.43	209	175	27.53	166.72	27.5	28.75	15.31	4
		9/20/2011	158	6.63	0.45	222	211	44.25	318.62	75	63.33	16.58	6.73
		9/29/2011	167	7.46	0.45	221	200	36.82	209.94	32	26	19.74	5.86
		10/5/2011	173	7.56	0.46	227	200	31.93	209.94	62.5	40	18.71	4.63
		10/12/2011	180	7.62	0.45	230	200	40.18	250.69	26	21	23.32	6.11
		10/19/2011	187	7.38	0.46	230	233.33	29.89	261.81	35	26.67	23.17	7.49
		10/25/2011	193	6.97	0.45	231	200	41.25	261.81	37	31	23.34	2.83
		11/4/2011	203	7.07	0.43	220	200	30.53	221.06	25	18	8.38	6.16
		11/10/2011	209	7.2	0.41	212	200	35.94	200.06	28.75	20	15.19	0
		11/15/2011	214	7.61	0.41	208	200	25.73	185.24	70	55	19.63	4.03
		11/23/2011	222	6.91	0.48	247	233.33	20.9	190.18	27	22	12.21	0.61
		11/30/2011	229	7.28	0.49	250	216.67	0	242.05	26.67	25	17.93	0.13
		12/8/2011	237	7.25	0.49	256	250	26.15	214.88	21	13	3.59	8.71
		12/13/2011	242	6.92	0.5	262	233.33	20.14	209.94	30	25	9.87	2.83
		12/21/2011	250	6.84	0.49	254	233.33	20.65	203.77	44	21	28.99	9.28
		1/3/2012	263	6.6	0.48	254	233.33	20.08	243.29	31	26	1.1	3.99
		1/17/2012	277	7.02	0.46	246	233.33	32.83	212.41	30	28	15.36	3.22
		2/16/2012	307	6.87	0.39	206	200	11.6	106.21	4	7	3.69	2.03

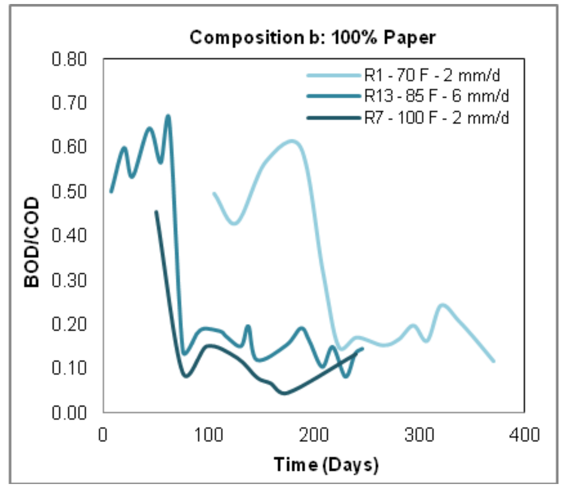
R27	3/10/2011	4/1/2011	22	7.1	4.65	2440	3650	0	10571.17	144	129	478.17	24
		4/8/2011	29	7.49	3.29	1696	2400	2670.15	5828.96	90	83	170.71	22.83
		4/19/2011	40	7.09	2.104	1066	1250	1631.33	3729.55	94	83	62.53	8.88
		5/3/2011	54	7.29	1.336	695	900	499.65	1290.52	42	34	49.32	10.2
		5/17/2011	68	7.57	0.992	530	622	68.93	498.92	36.67	26.67	59.4	7.77
		6/2/2011	84	7.37	0.867	435	611	44.6	348.26	30	25	39.6	7.1
		6/29/2011	111	7.31	0.689	342	366.5	29.46	240.82	26.5	21.5	23.97	0.77
		7/8/2011	120	7.23	0.64	326	375	26.18	216.12	14.5	13	28.86	2.17
		7/19/2011	131	7.35	0.65	322	300	18.56	187.71	21	19	24.11	0.95
		7/26/2011	138	7.39	0.7	347	333.25	16.7	192.65	23	18	21.96	1.93
		8/8/2011	151	7.42	0.65	321	344.33	7.11	185.24	18	10	25	3.92
		11/9/2011	244	7.2	0.67	329	333.33	7.29	142.02	18	16	12.1	<1.6

APPENDIX B

BOD/COD RATIOS FOR REACTORS

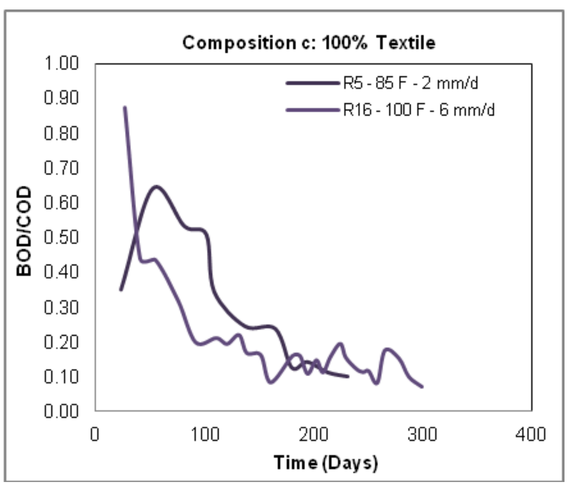


(a)

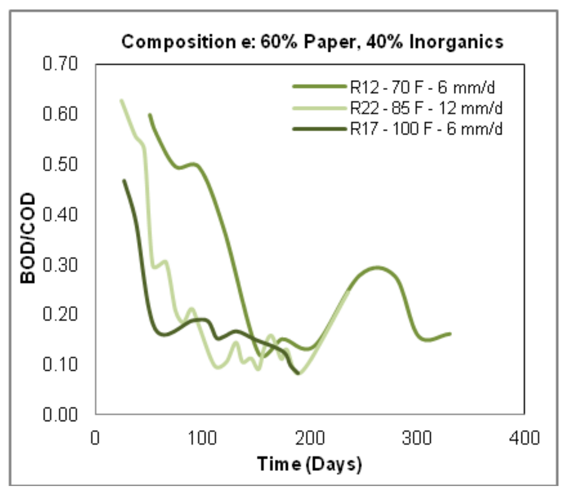


(b)

Figure B1: BOD/COD Ratio for Waste Composition a and b Reactors

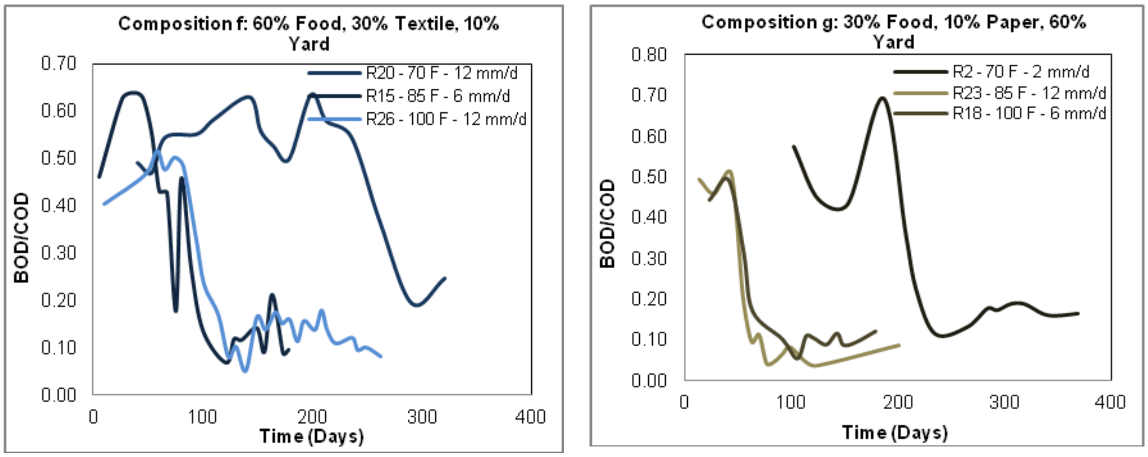


(a)



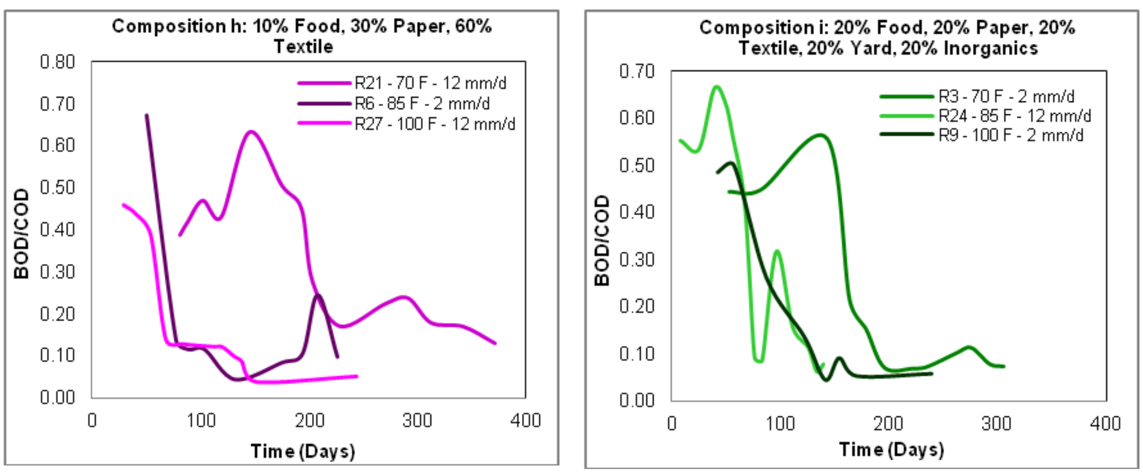
(b)

Figure B2: BOD/COD Ratio for Waste Composition c and e Reactors



(a) (b)

Figure B3: BOD/COD Ratio for Waste Composition f and g Reactors

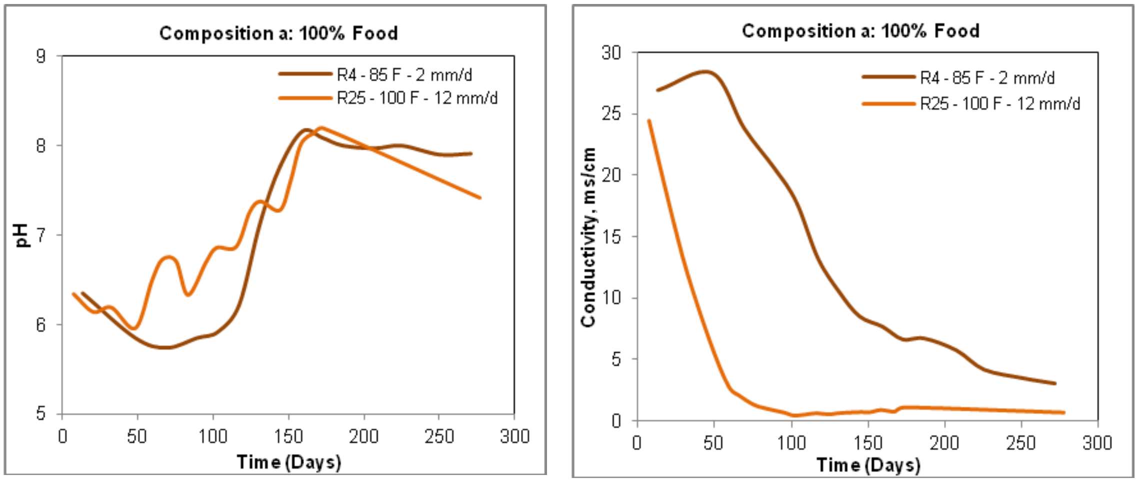


(a) (b)

Figure B4: BOD/COD Ratio for Waste Composition h and i Reactors

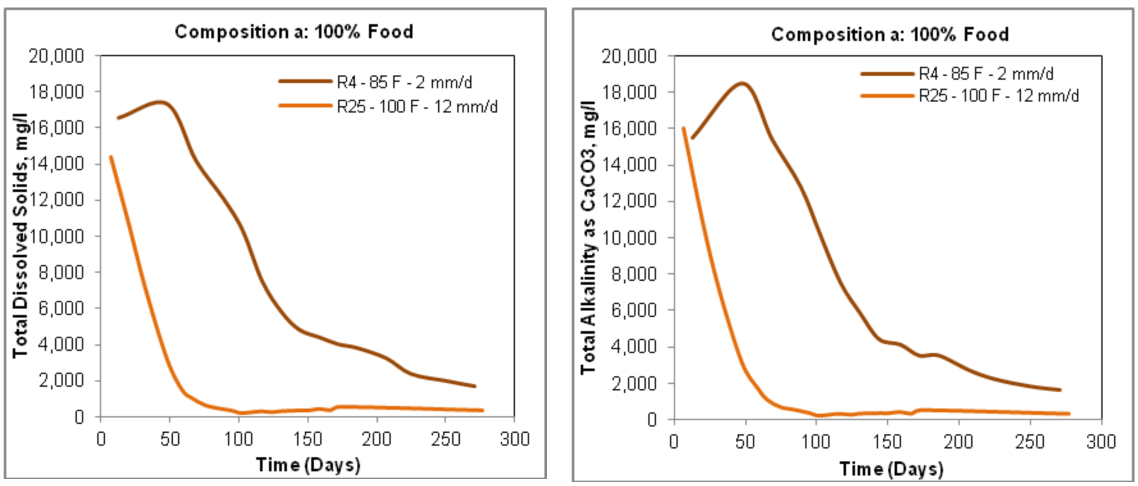
APPENDIX C

LEACHATE PARAMETERS TREND FOR REACTORS



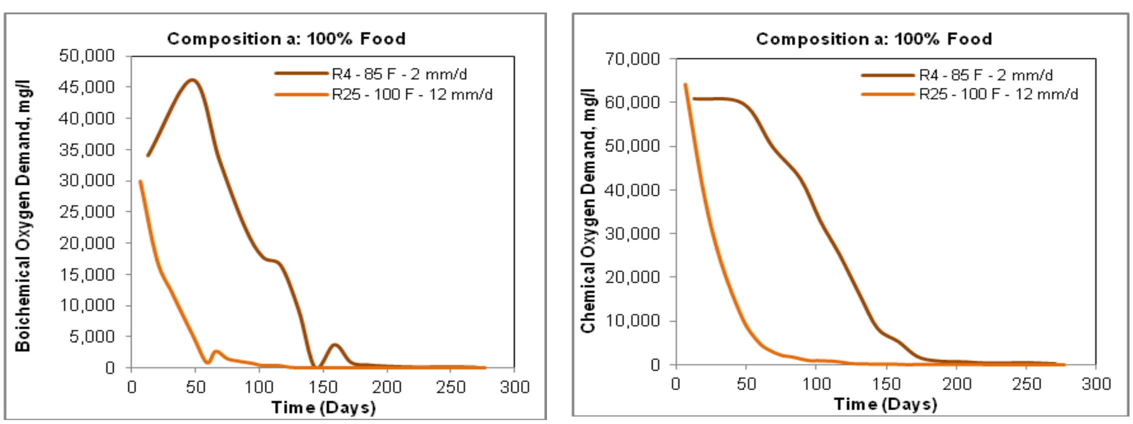
(a) (b)

Figure C1: pH and Conductivity for Waste Composition “a” Reactors



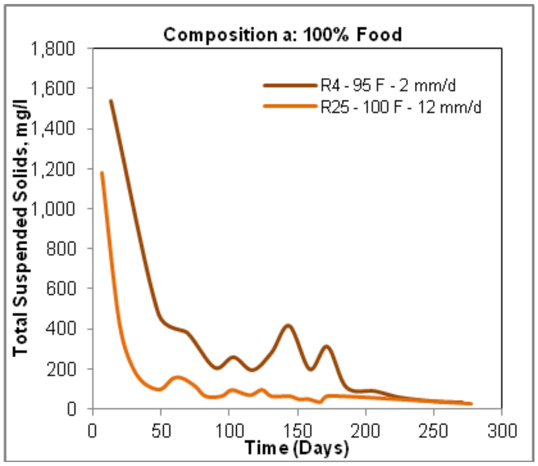
(c) (d)

Figure C1: TDS and Total Alkalinity for Waste Composition “a” Reactors

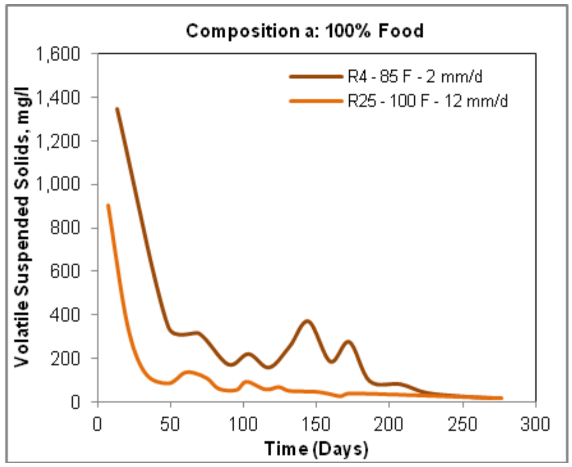


(e) (f)

Figure C1: BOD and COD for Waste Composition “a” Reactors

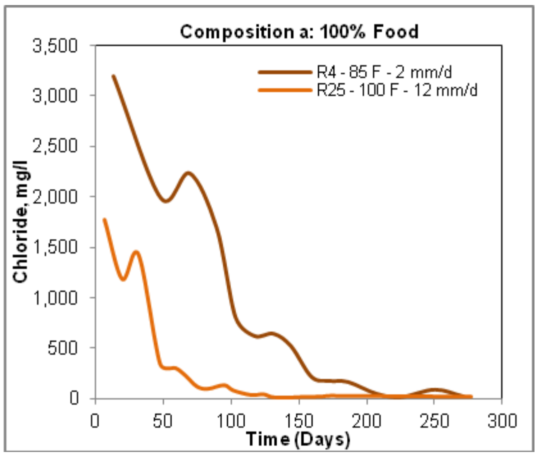


(g)

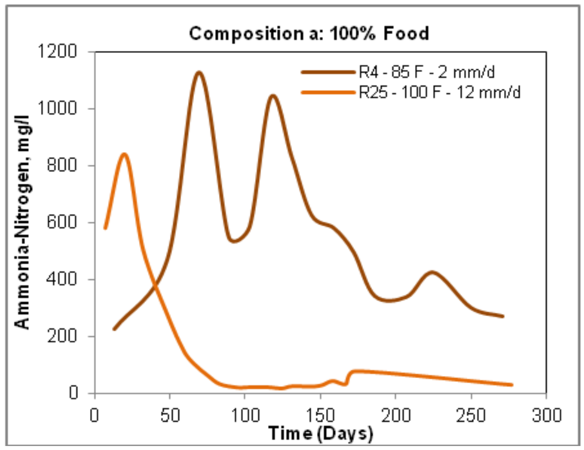


(h)

Figure C1: TSS and VSS for Waste Composition “a” Reactors

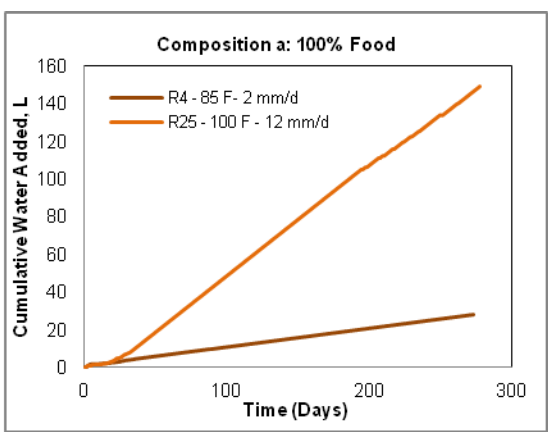


(i)

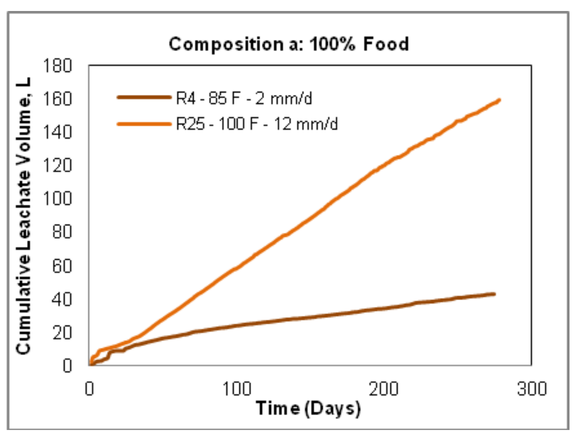


(j)

Figure C1: Chloride and Nh3-N for Waste Composition “a” Reactors

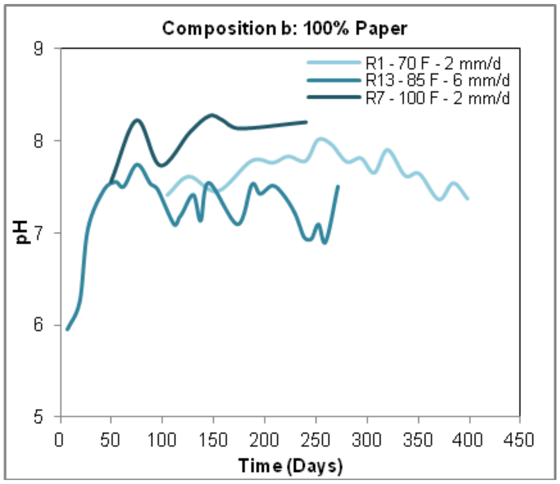


(k)

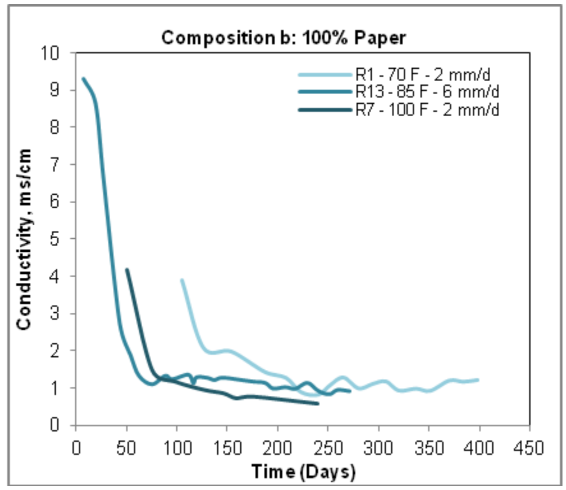


(l)

Figure C1: Cumulative Water Addition and Leachate Generation for Waste Composition “a” Reactors

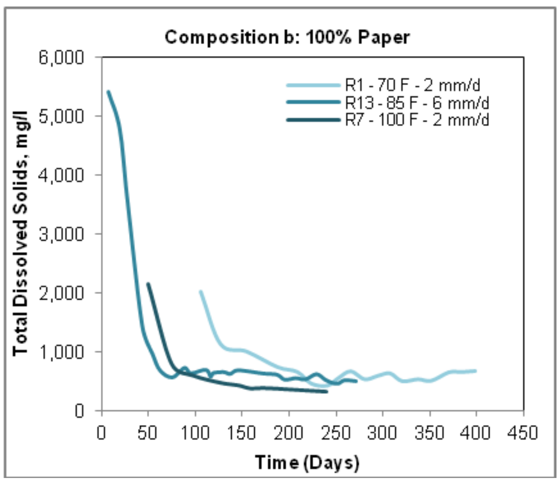


(a)

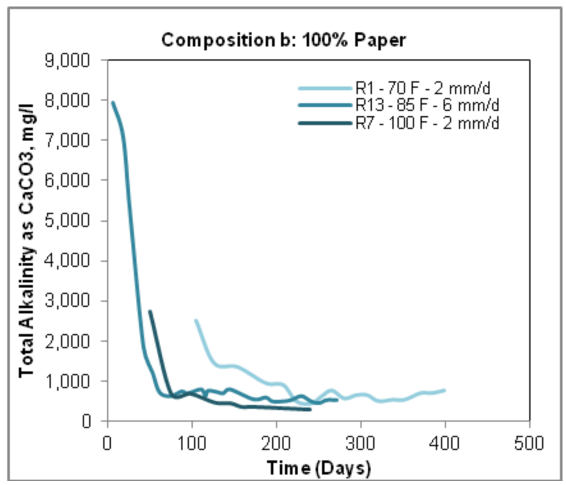


(b)

Figure C2: pH and Conductivity for Waste Composition “b” Reactors

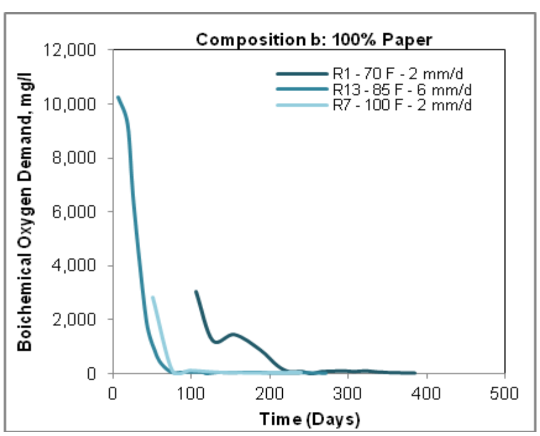


(c)



(d)

Figure C2: TDS and Total Alkalinity for Waste Composition “b” Reactors



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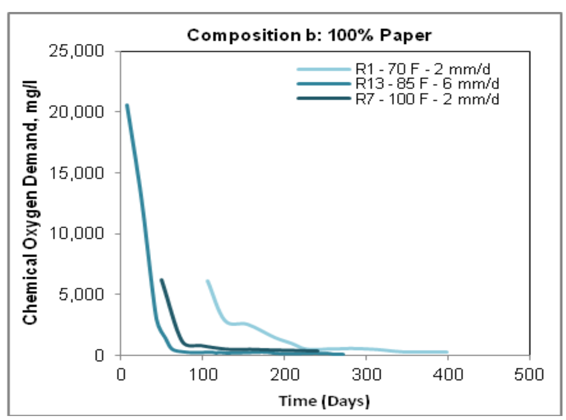

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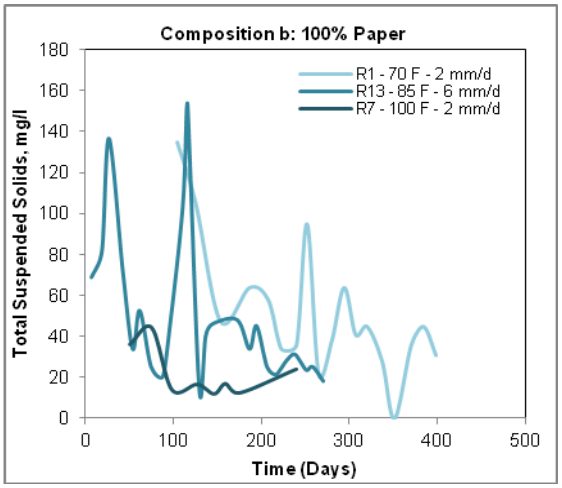
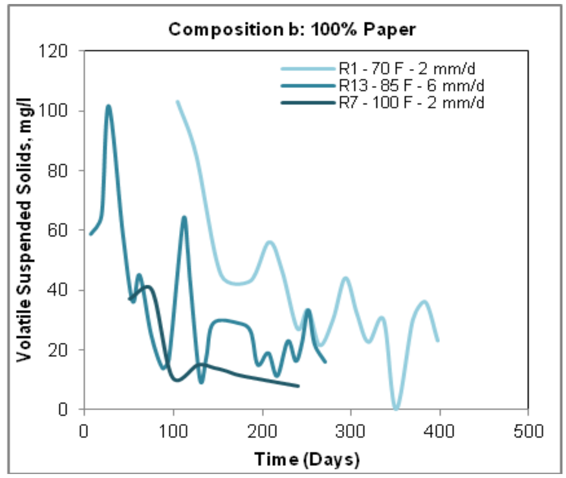
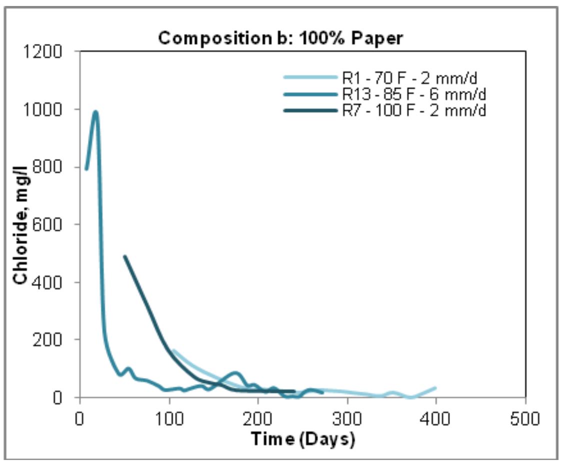
Figure C2: BOD and COD for Waste Composition “b” Reactors





(g) (h)

Figure C2: TSS and VSS for Waste Composition "b" Reactors



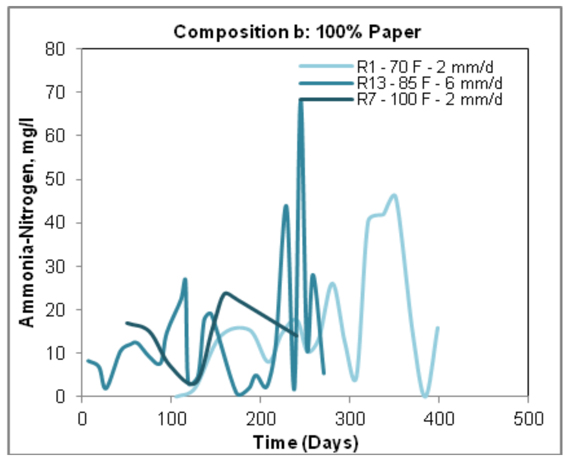


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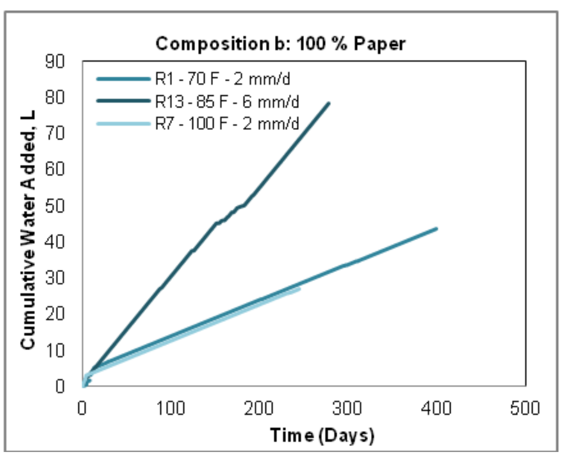
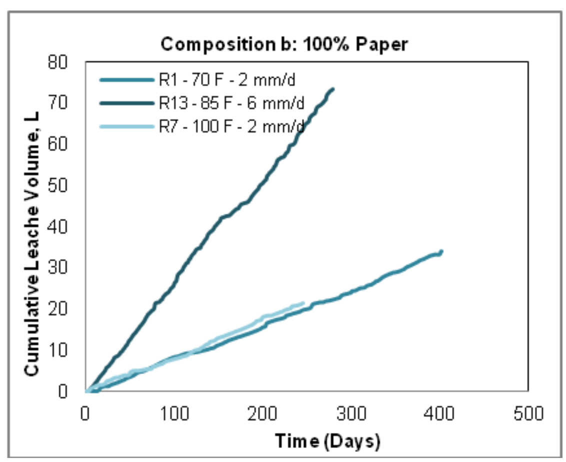
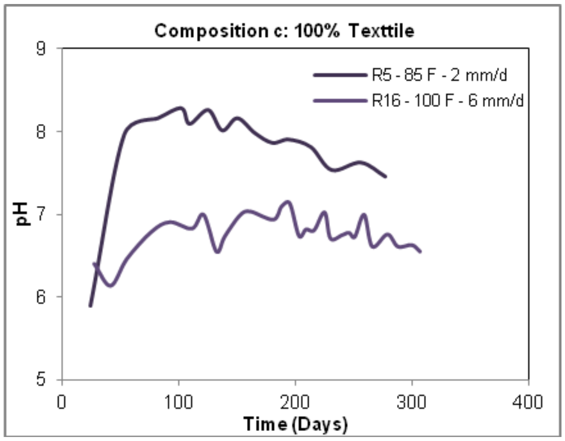
Figure C2: Chloride and NH_3-N for Waste Composition "b" Reactors

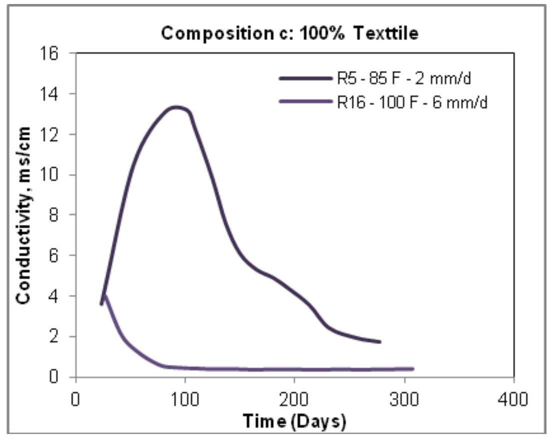




(k) (l)

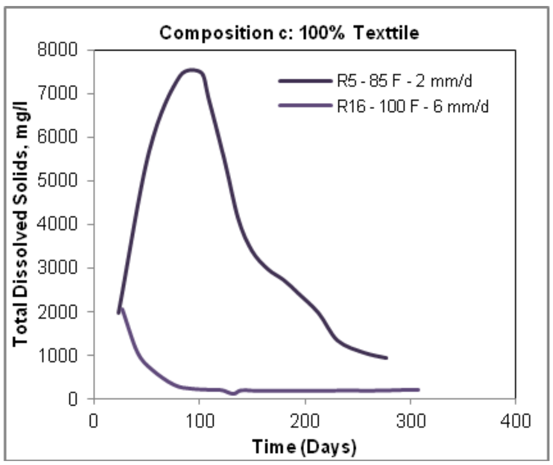
Figure C2: Cumulative Water Addition and Leachate Generation for Waste Composition "b" Reactors





(a) (b)

Figure C3: pH and Conductivity for Waste Composition "b" Reactors



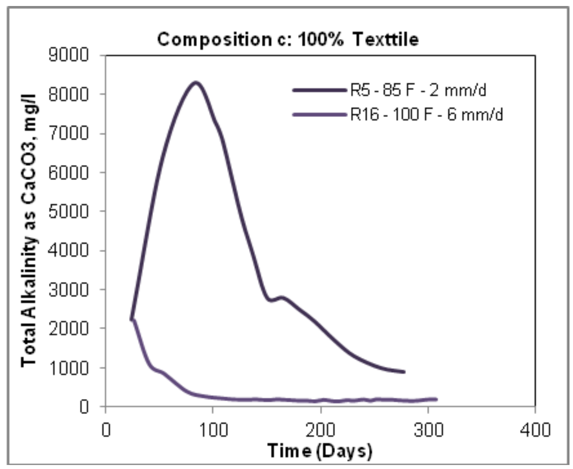


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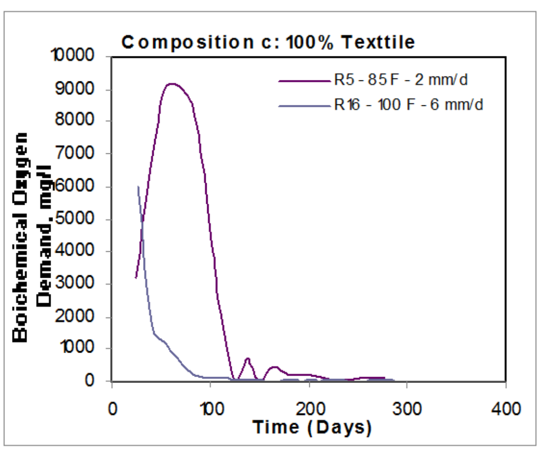
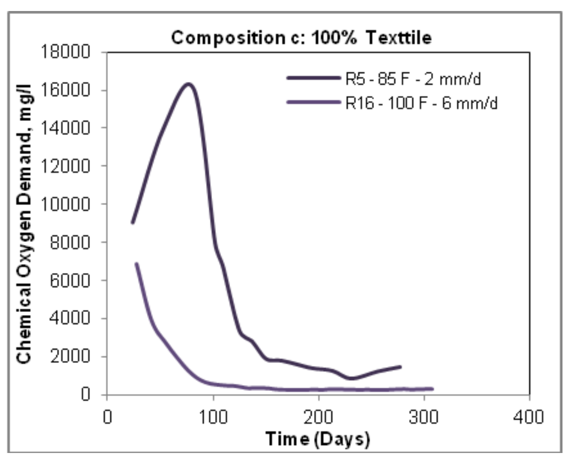
Figure C3: TDS and Total Alkalinity for Waste Composition "c" Reactors

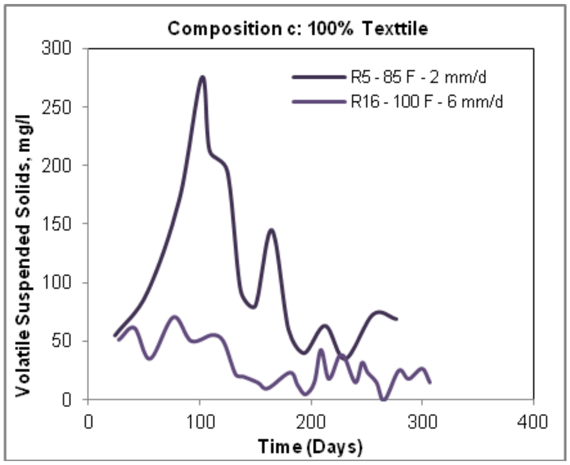




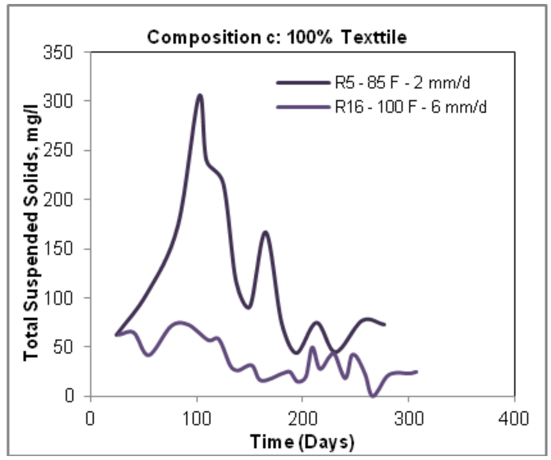
(e)

(f)

Figure C3: BOD and COD for Waste Composition "c" Reactors

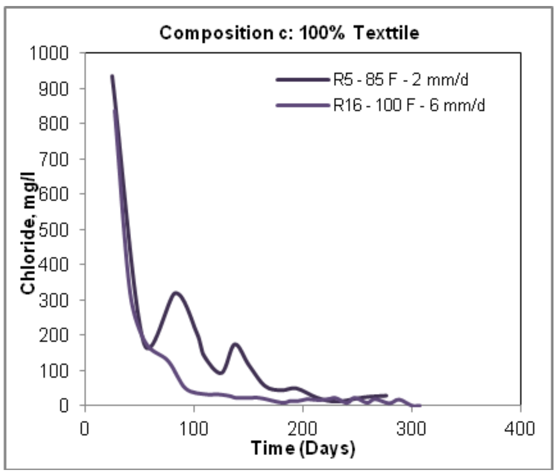


(g)

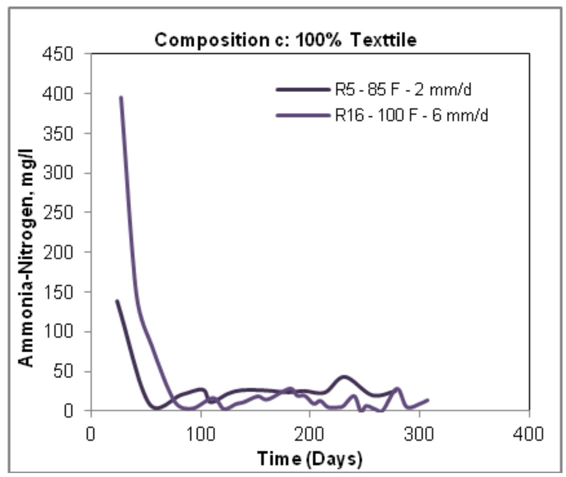


(h)

Figure C3: VSS and TSS for Waste Composition “c” Reactors

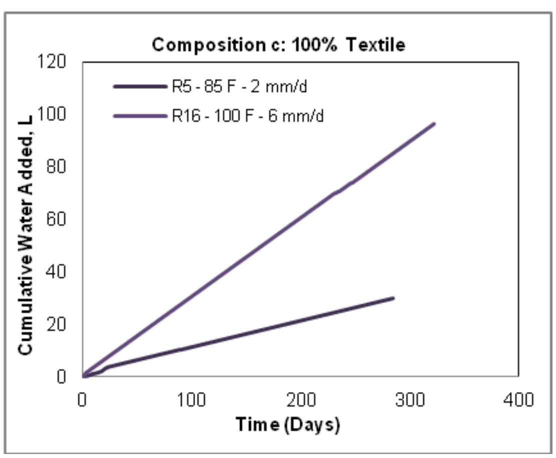


(i)



(j)

Figure C3: Chloride and NH_3-N for Waste Composition “c” Reactors



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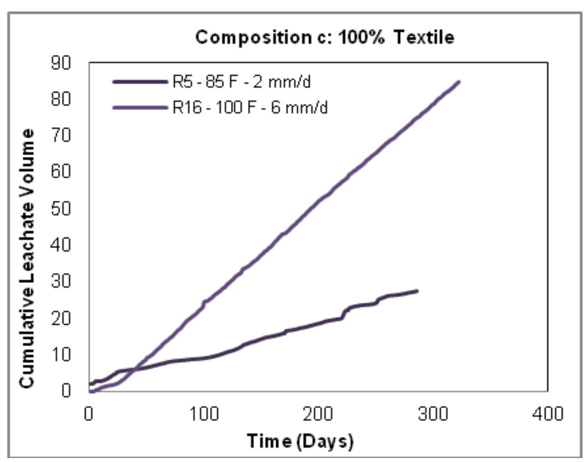
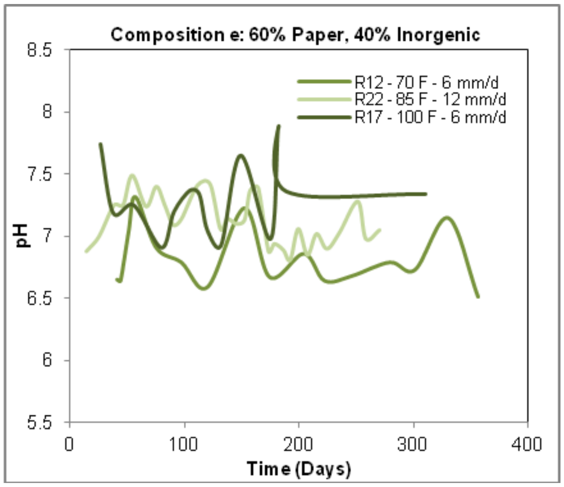


(l)

Figure C3: Cumulative Water Addition and Leachate Generation for Waste Composition “c” Reactors



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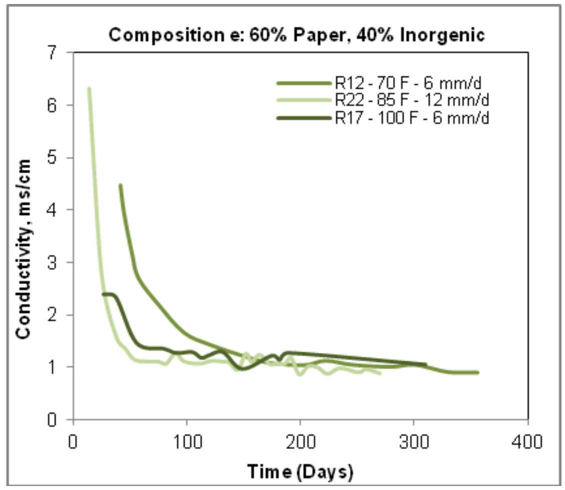
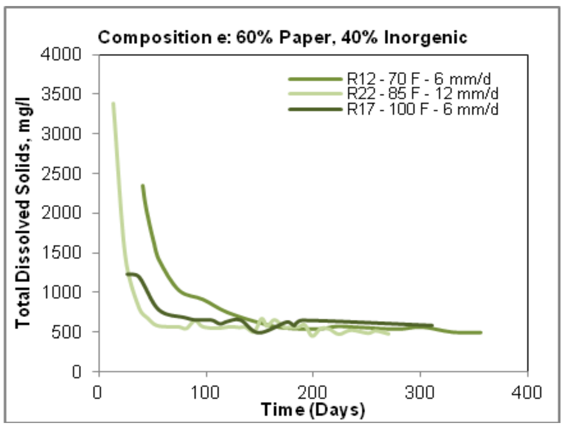


(b)

Figure C4: pH and Conductivity for Waste Composition "e" Reactors



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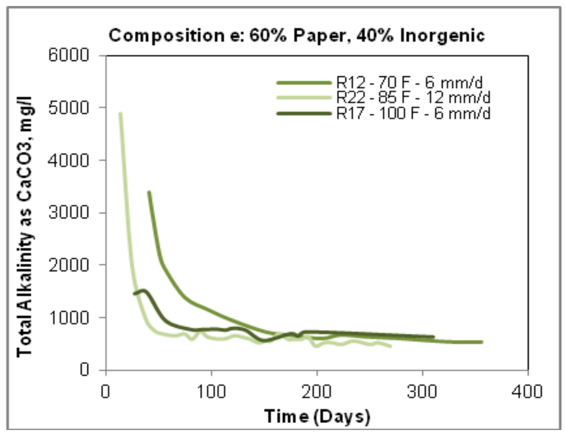
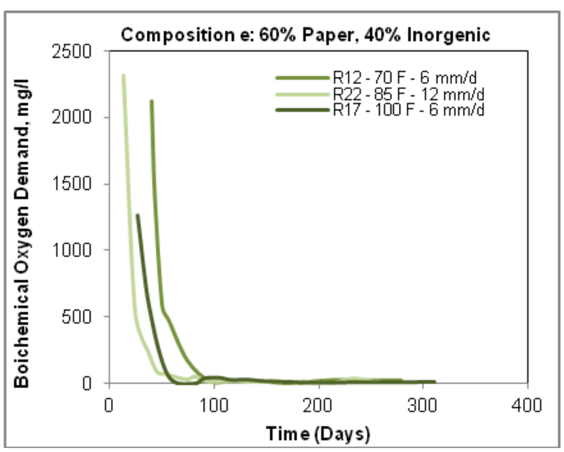


(d)

Figure C4: TDS and Total Alkalinity for Waste Composition "e" Reactors



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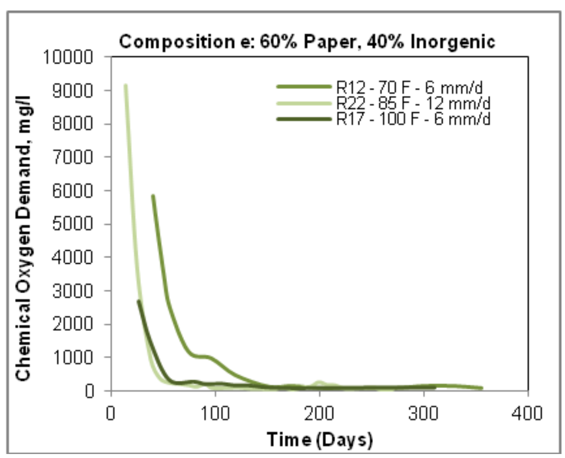
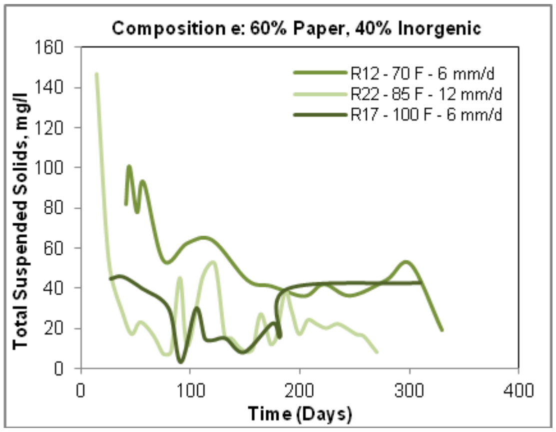


(f)

Figure C4: BOD and COD for Waste Composition "e" Reactors



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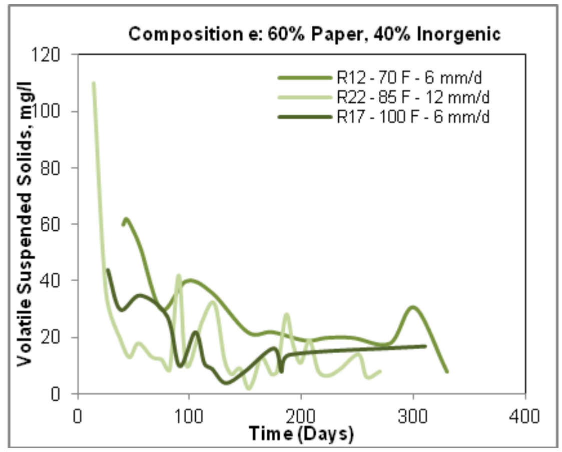
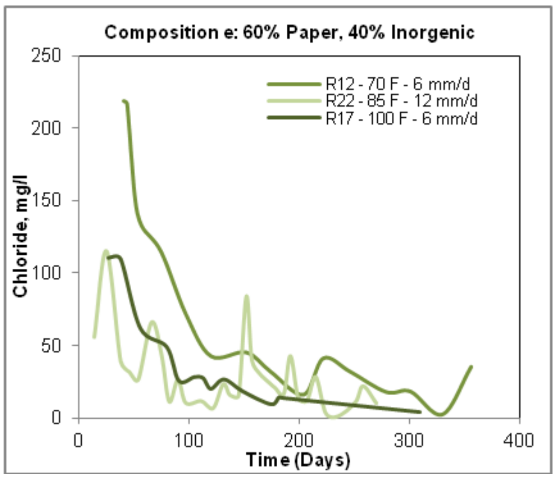


(h)

Figure C4: TSS and VSS for Waste Composition “e” Reactors



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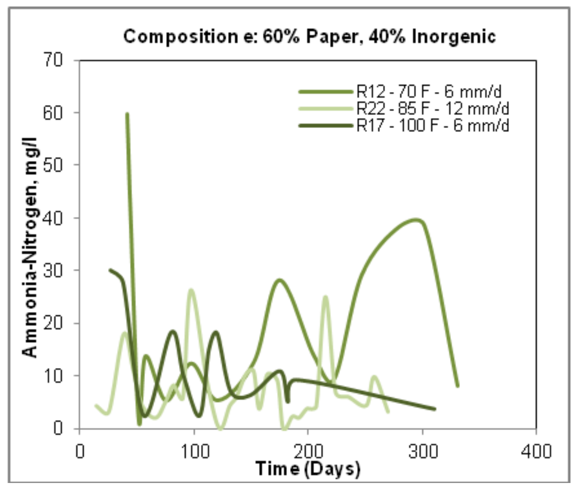
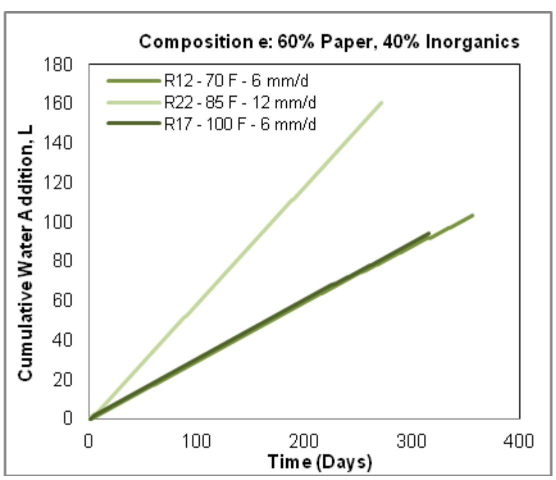


(j)

Figure C4: Chloride and NH_3-N for Waste Composition “e” Reactors



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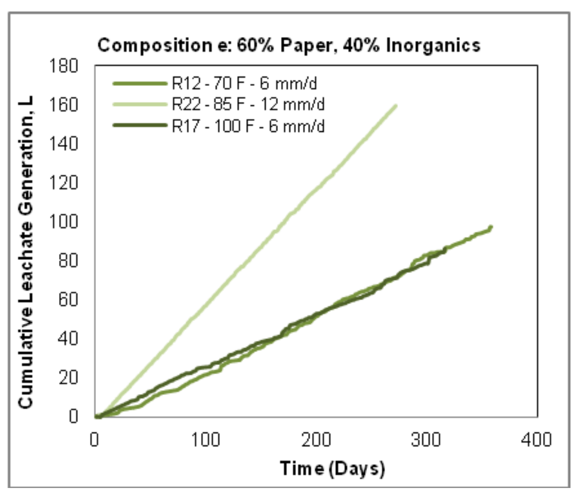
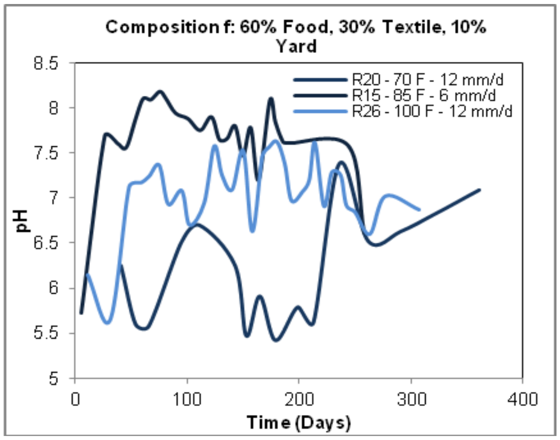


(l)

Figure C4: Cumulative Water Addition and Leachate Generation for Waste Composition “e” Reactors



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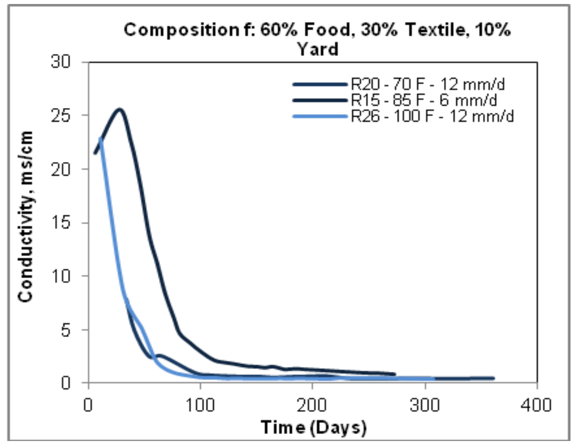
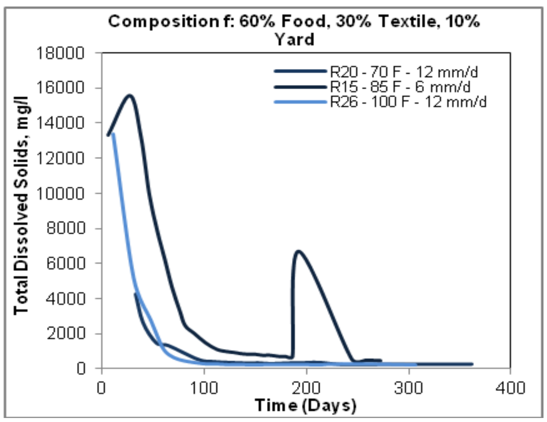


(b)

Figure C5: pH and Conductivity for Waste Composition "f" Reactors



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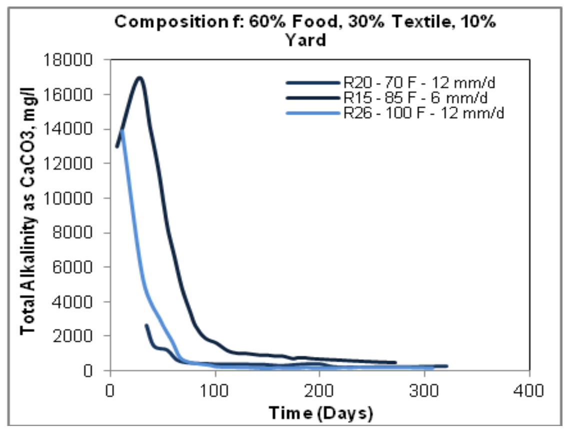
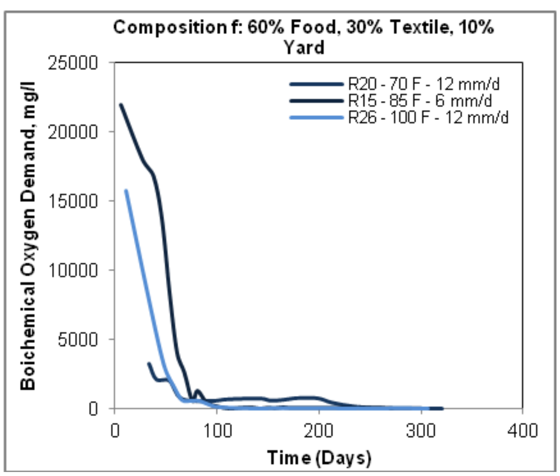


(d)

Figure C5: TDS and Total Alkalinity for Waste Composition "f" Reactors



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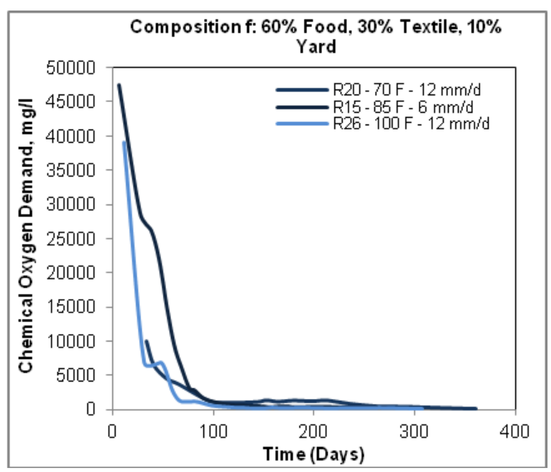
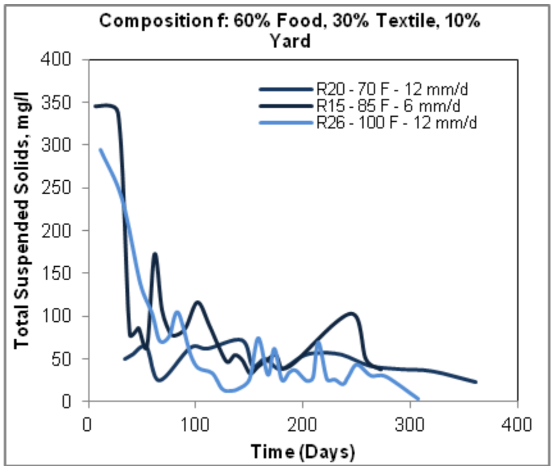


(f)

Figure C5: BOD and COD for Waste Composition "f" Reactors



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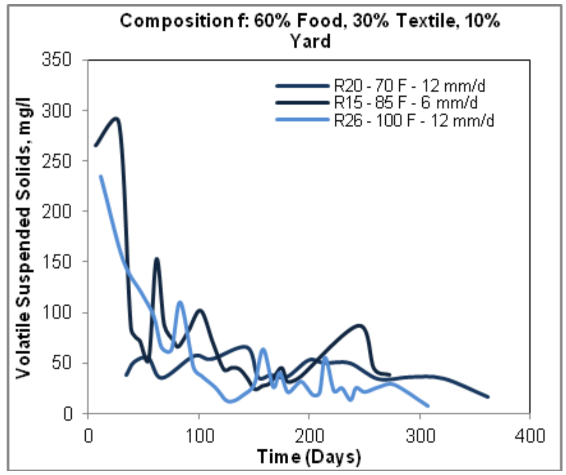
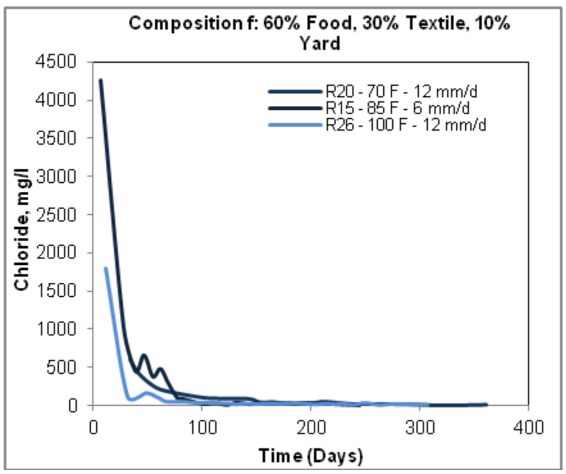


(h)

Figure C5: TSS and VSS for Waste Composition “f” Reactors



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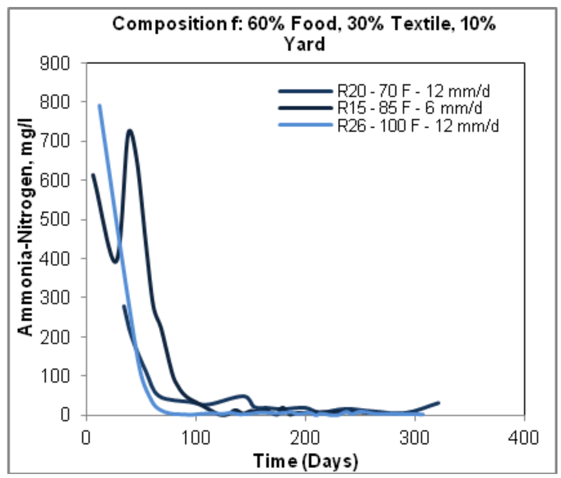
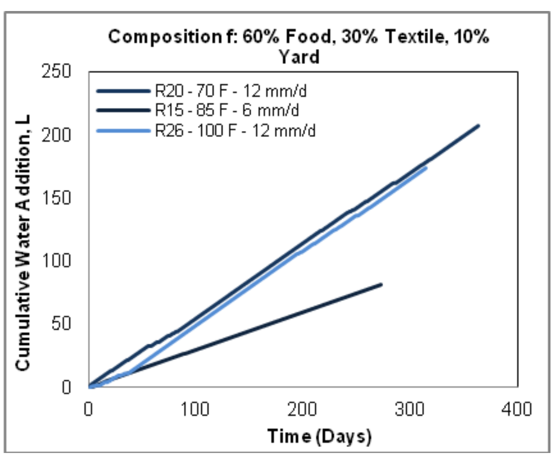


(j)

Figure C5: Chloride and NH_3-N for Waste Composition “f” Reactors



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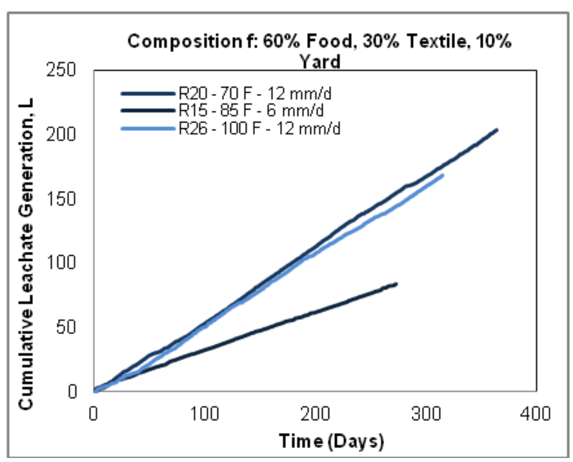
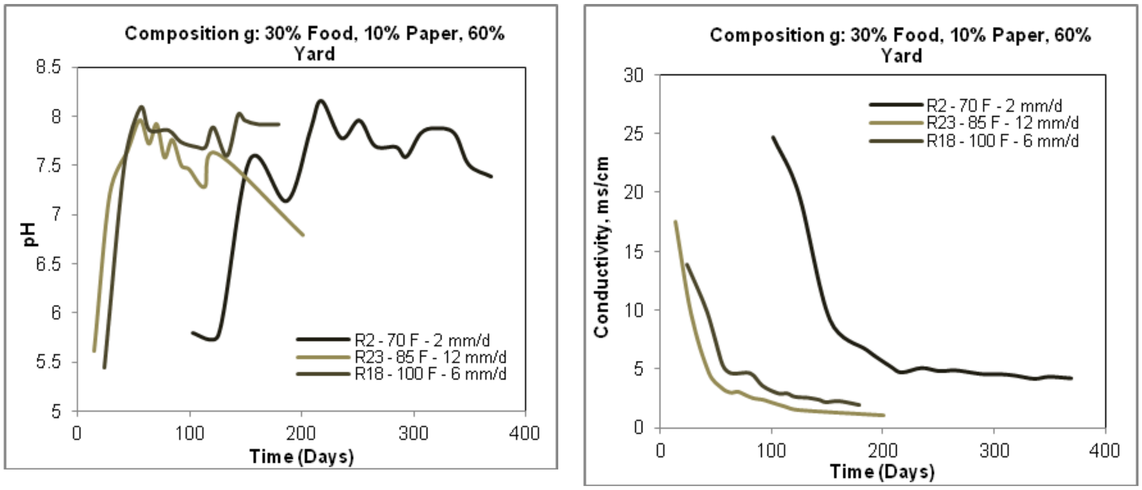


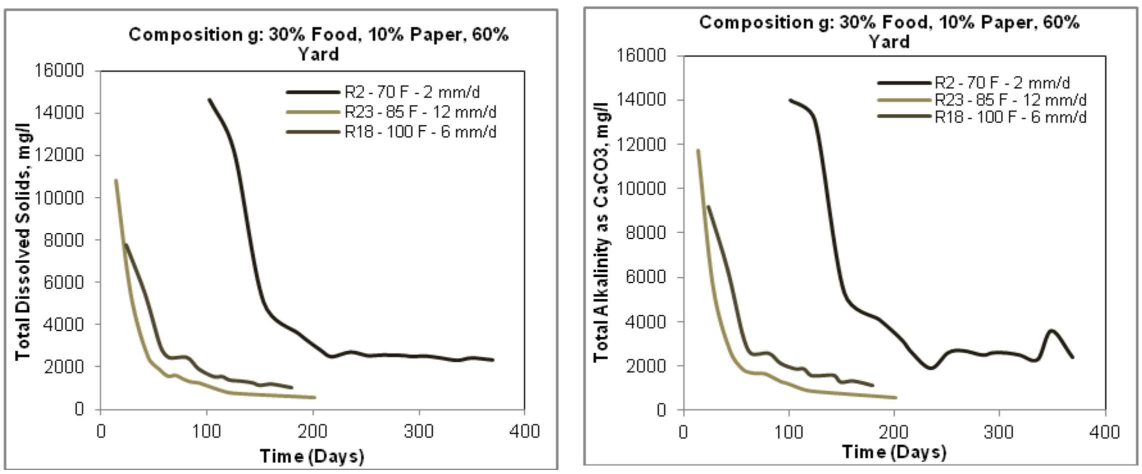
(l)

Figure C5: Cumulative Water Addition and Leachate Generation for Waste Composition “f” Reactors



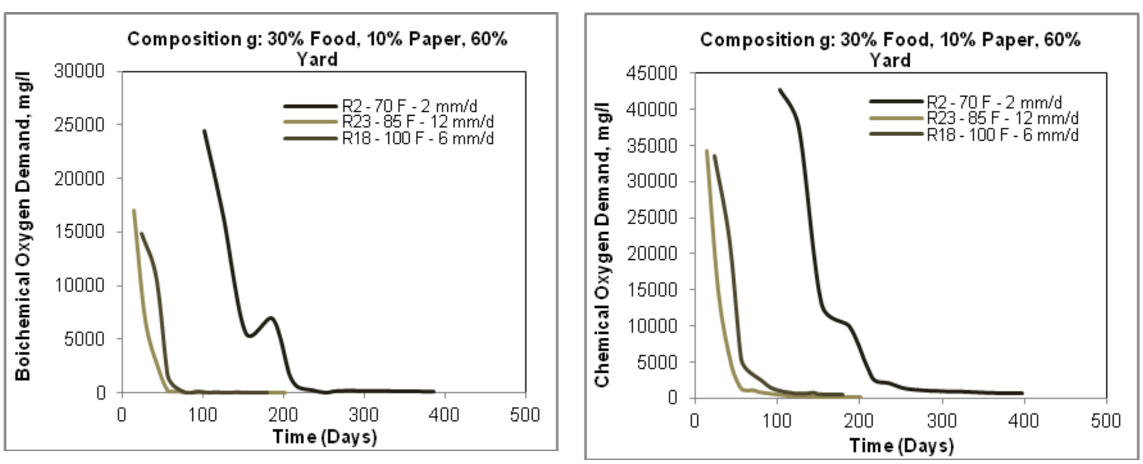
(a) (b)

Figure C6: pH and Conductivity for Waste Composition “g” Reactors



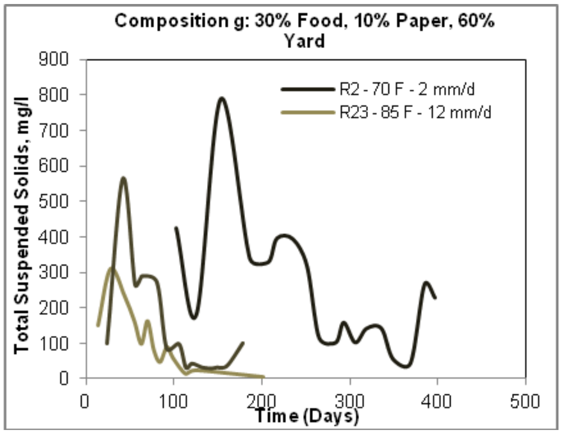
(c) (d)

Figure C6: TDS and Total Alkalinity for Waste Composition “g” Reactors



(e) (f)

Figure C6: BOD and COD for Waste Composition “g” Reactors



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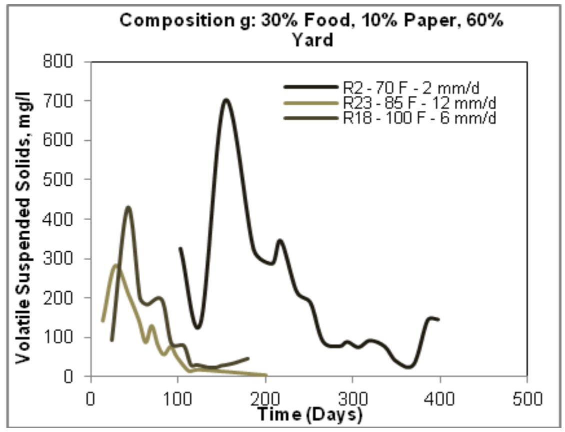
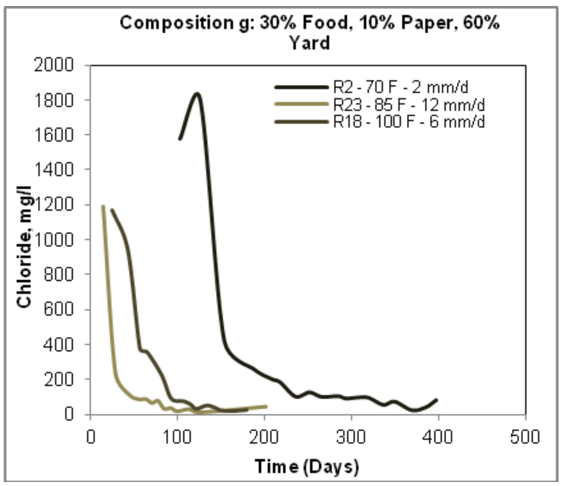


(h)

Figure C6: TSS and VSS for Waste Composition "g" Reactors



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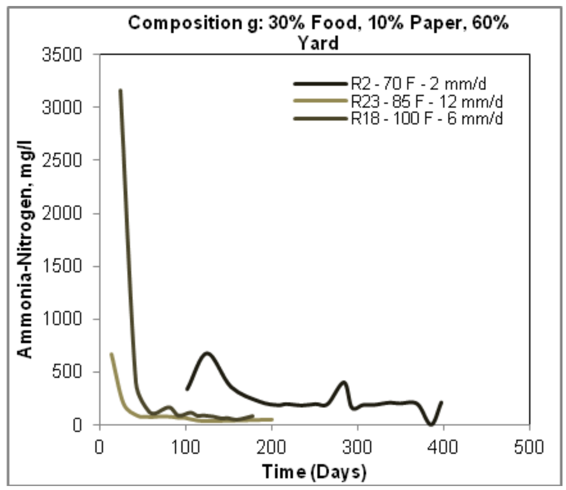

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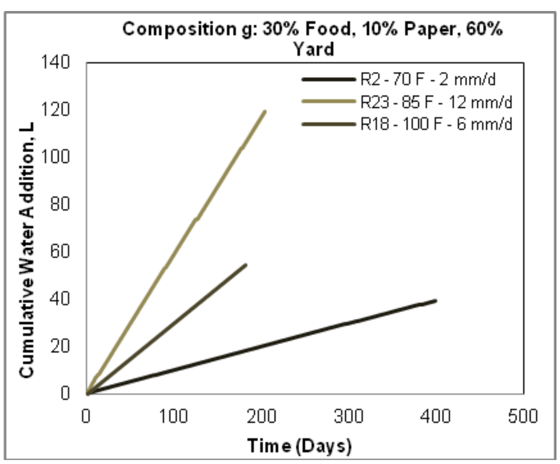
Figure C6: Chloride and NH_3-N for Waste Composition "g" Reactors



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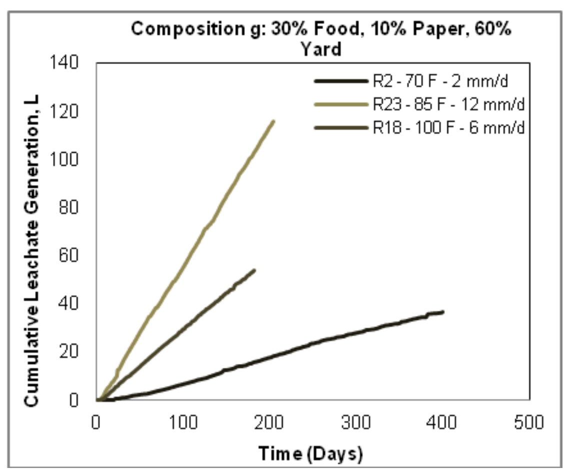
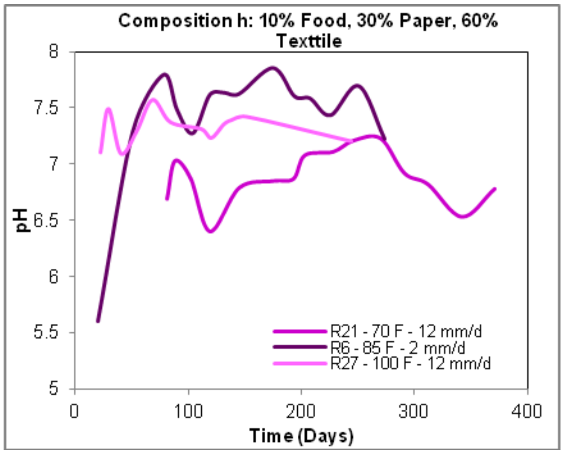


(l)

Figure C6: Cumulative Water Addition and Leachate Generation for Waste Composition "g" Reactors



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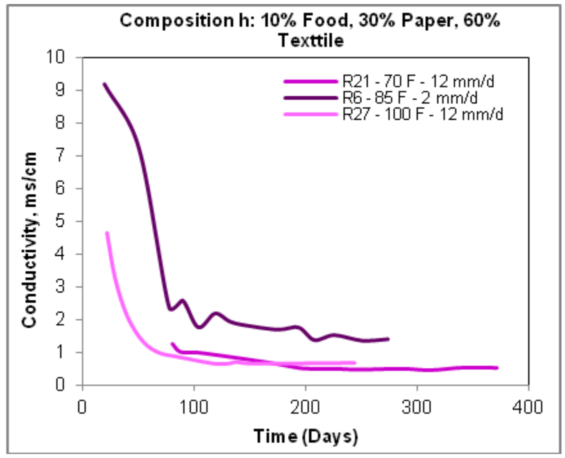
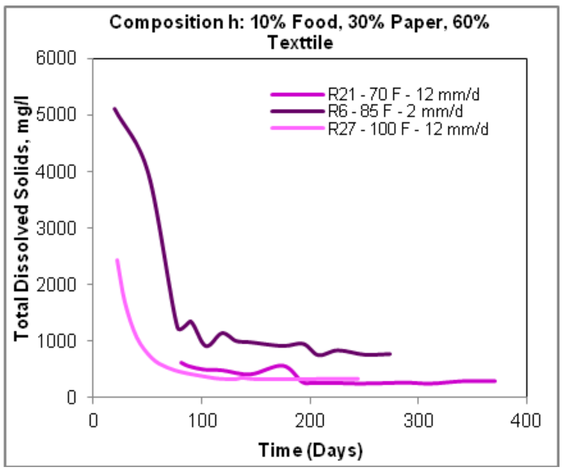


(b)

Figure C7: pH and Conductivity for Waste Composition “h” Reactors



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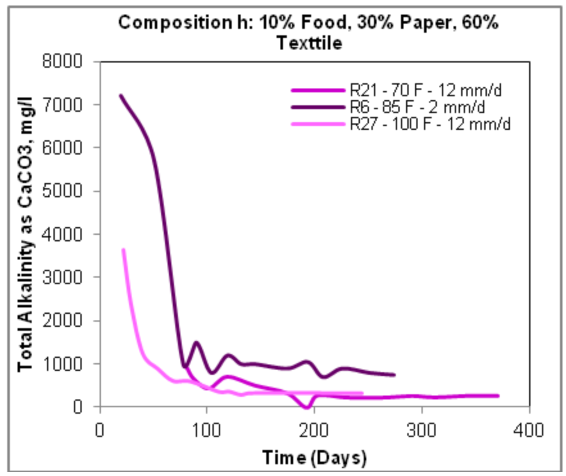
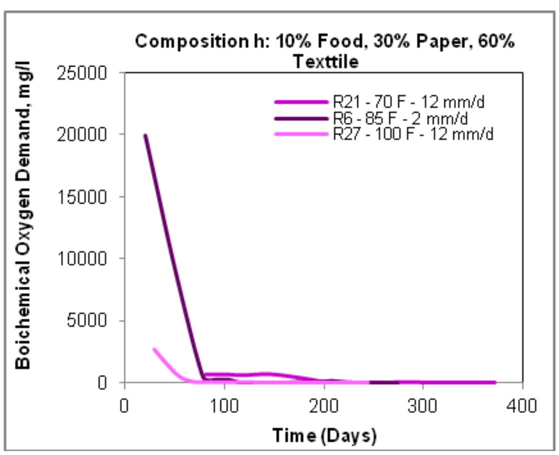


(d)

Figure C7: TDS and Total Alkalinity for Waste Composition “h” Reactors



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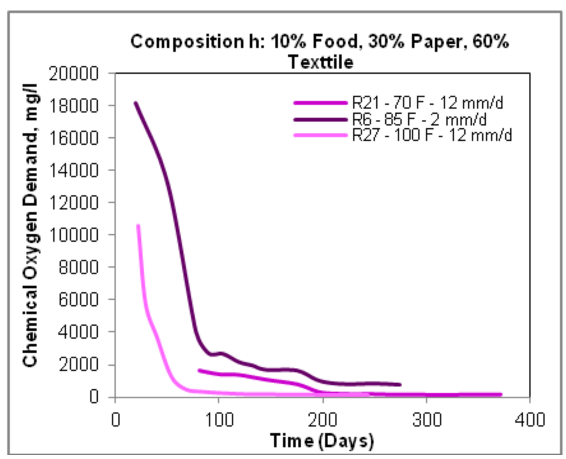

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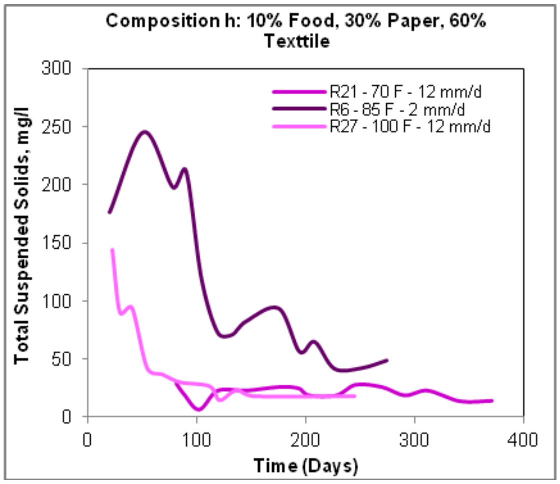
Figure C6: BOD and COD for Waste Composition “g” Reactors



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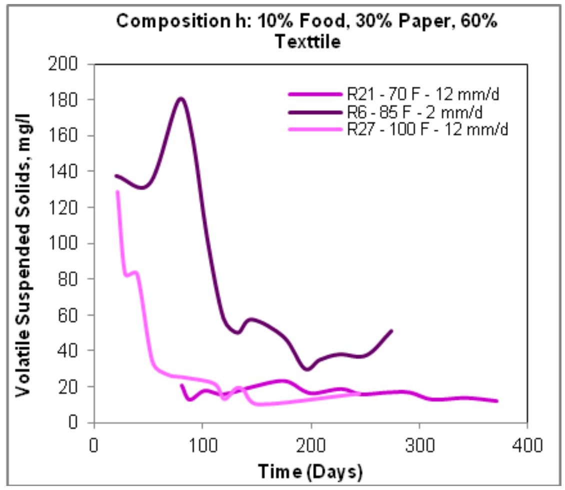
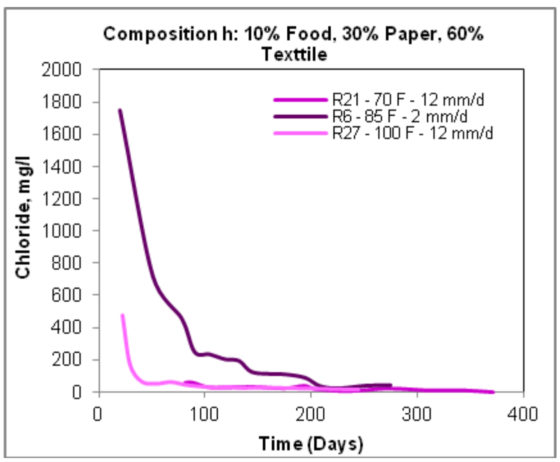


(h)

Figure C7: TSS and VSS for Waste Composition “h” Reactors



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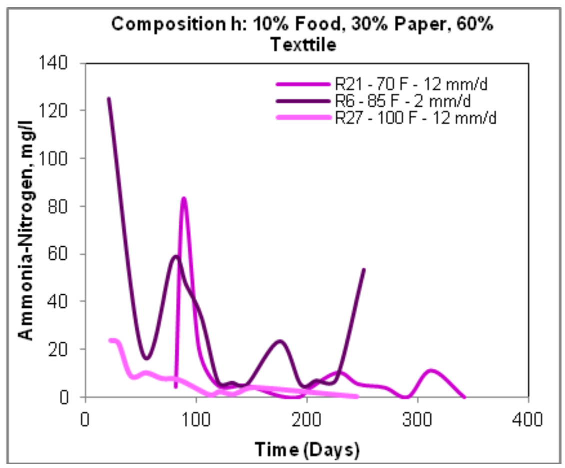

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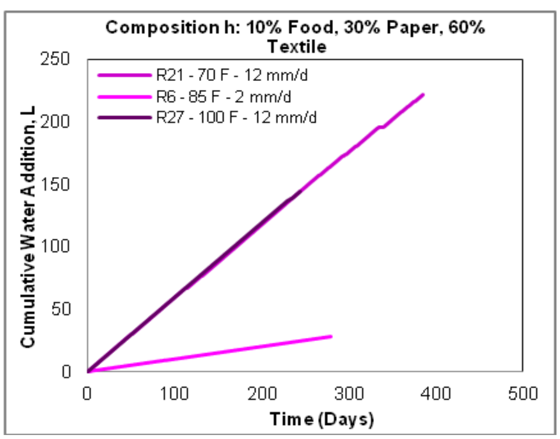
Figure C7: Chloride and NH_3-N for Waste Composition “h” Reactors



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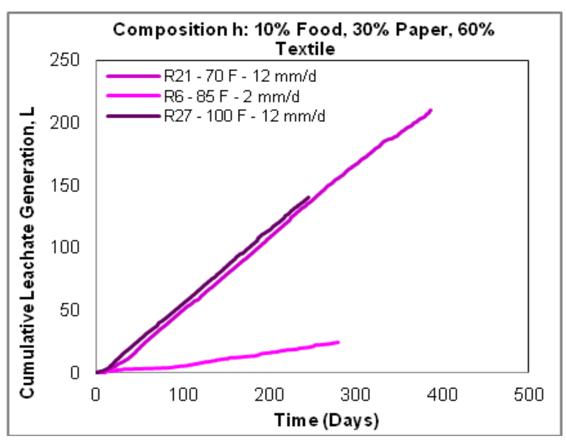
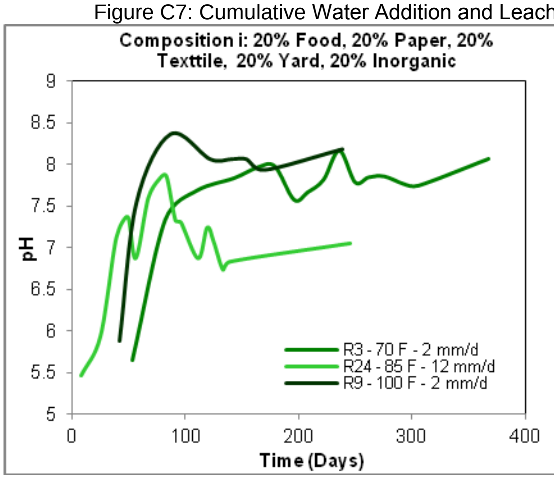


(l)

Figure C7: Cumulative Water Addition and Leachate Generation for Waste Composition “h” Reactors



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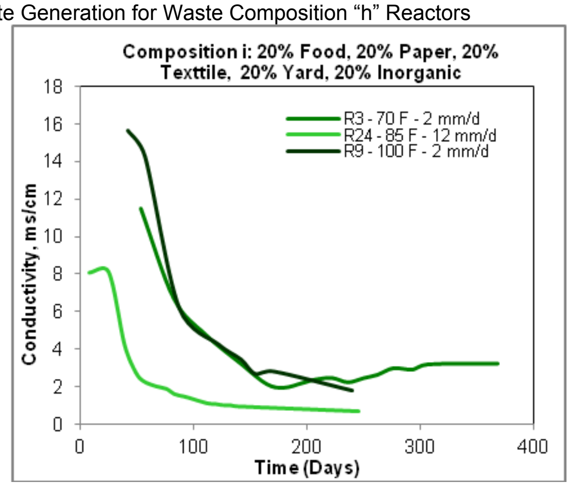
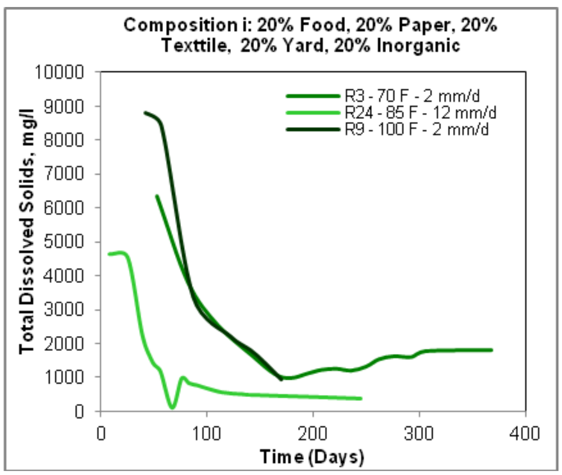
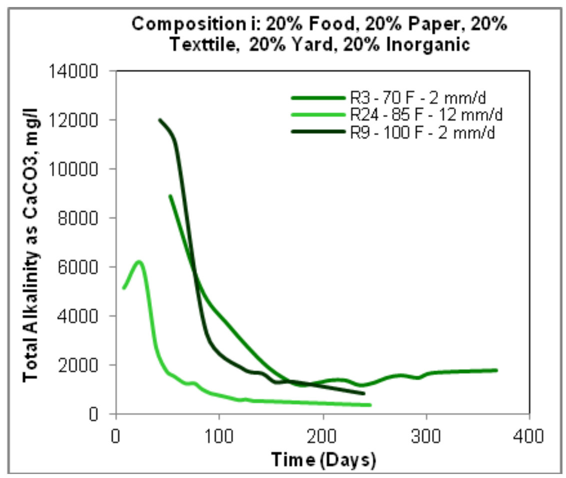


(b)

Figure C8: pH and Conductivity for Waste Composition “i” Reactors

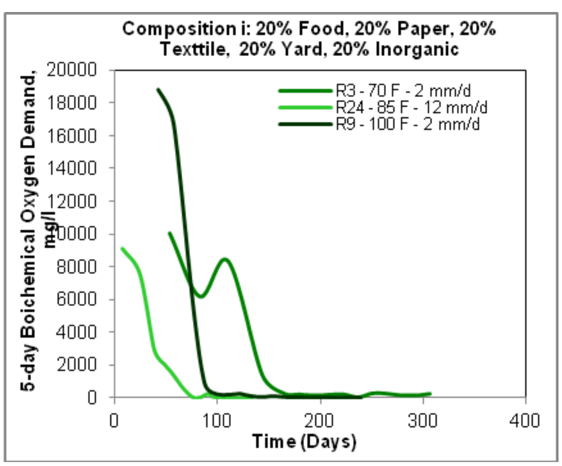




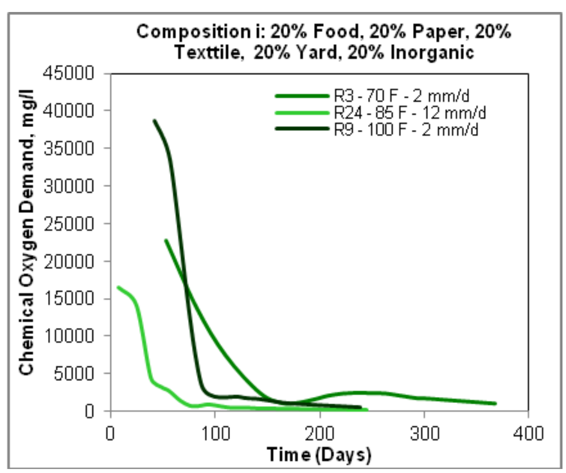
(c)

(d)

Figure C8: TDS and Total Alkalinity for Waste Composition “i” Reactors

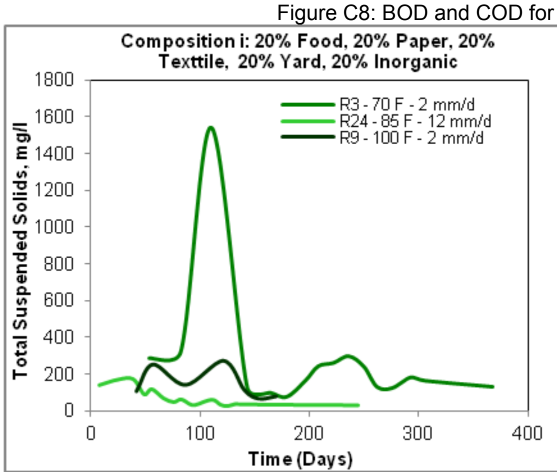


(e)

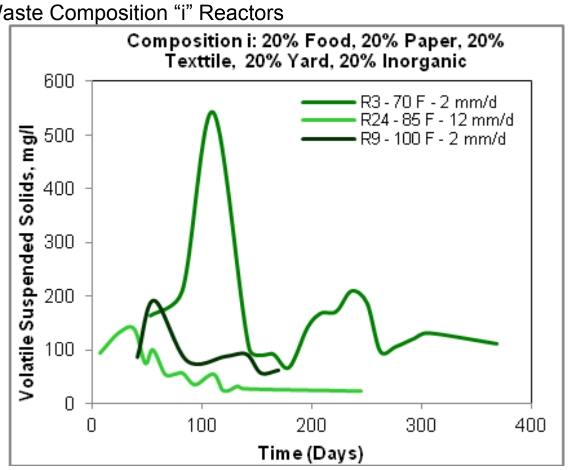


(f)

Figure C8: BOD and COD for Waste Composition “i” Reactors

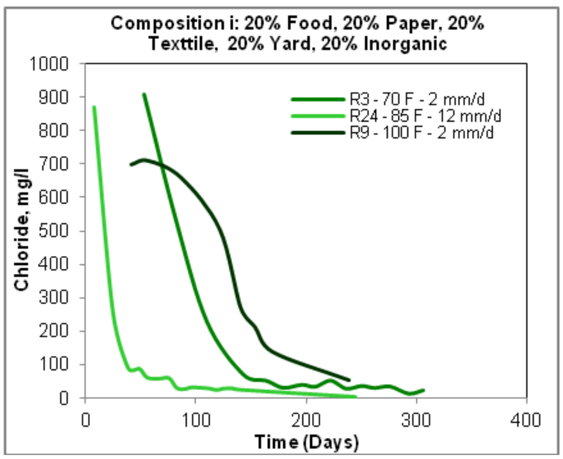


(g)

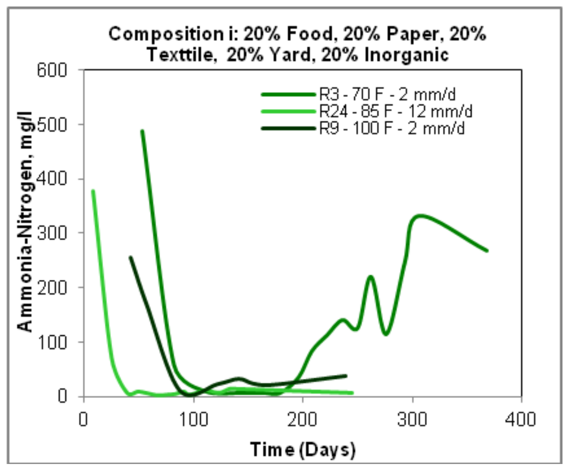


(h)

Figure C8: TSS and VSS for Waste Composition “i” Reactors

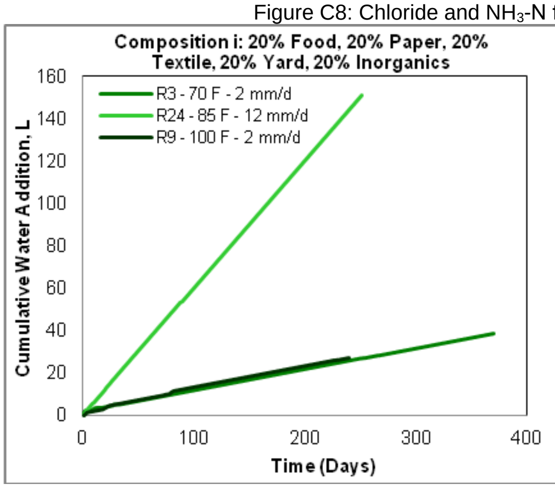


(i)

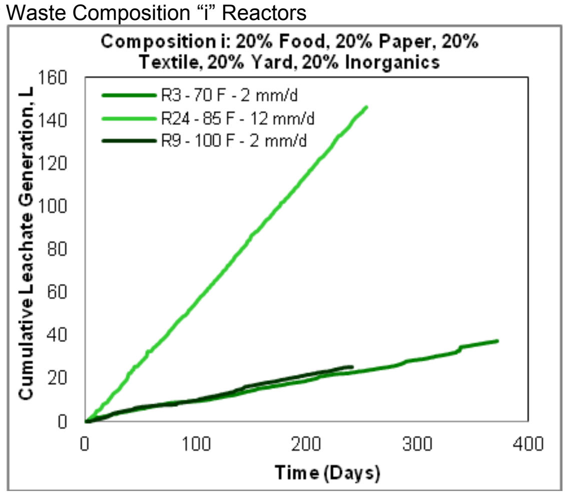


(j)

Figure C8: Chloride and NH_3-N for Waste Composition “i” Reactors



(k)



(l)

Figure C8: Cumulative Water Addition and Leachate Generation for Waste Composition “i” Reactors

APPENDIX D

RESIDUAL PLOTS FOR TOTAL ALKALINITY

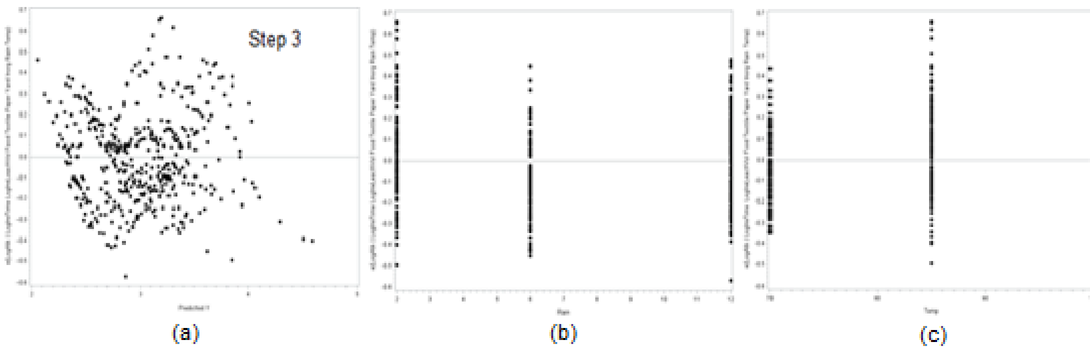


Figure D1: e vs. Yhat, e vs. Rain, and e vs. Temperature – Step 3

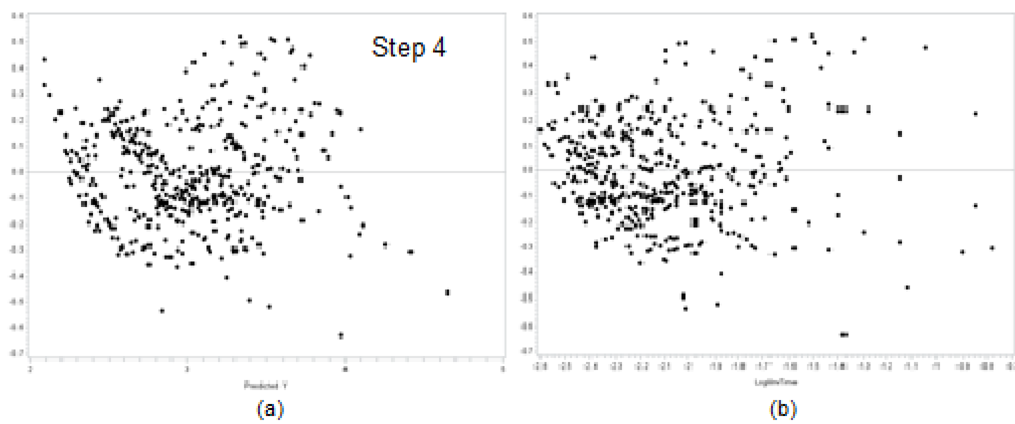


Figure D2: e vs. Yhat and e vs. Log(Time) – Step 4

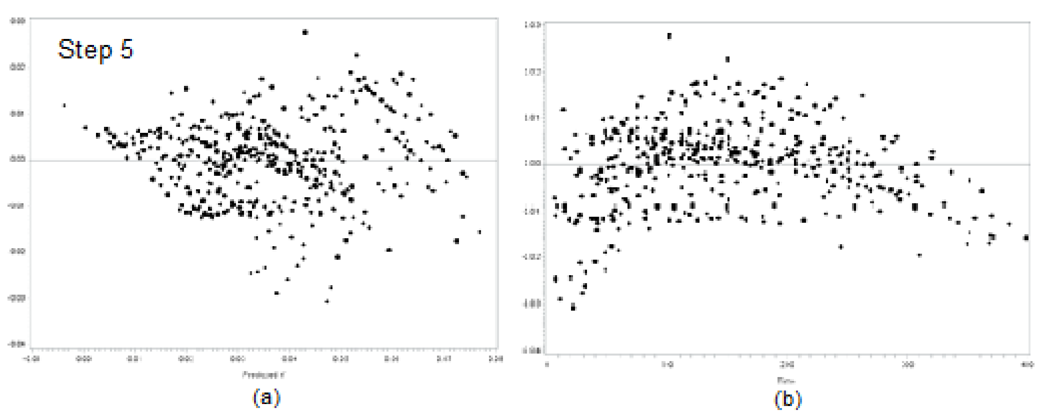


Figure D3: e vs. Yhat and e vs. Time – Step 5

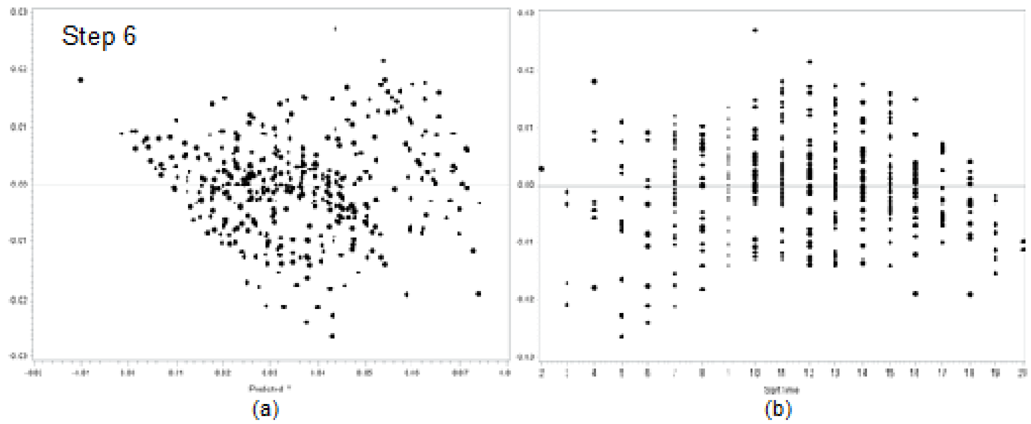


Figure D4: e vs. Yhat and e vs. $\sqrt{Time}$ – Step 6

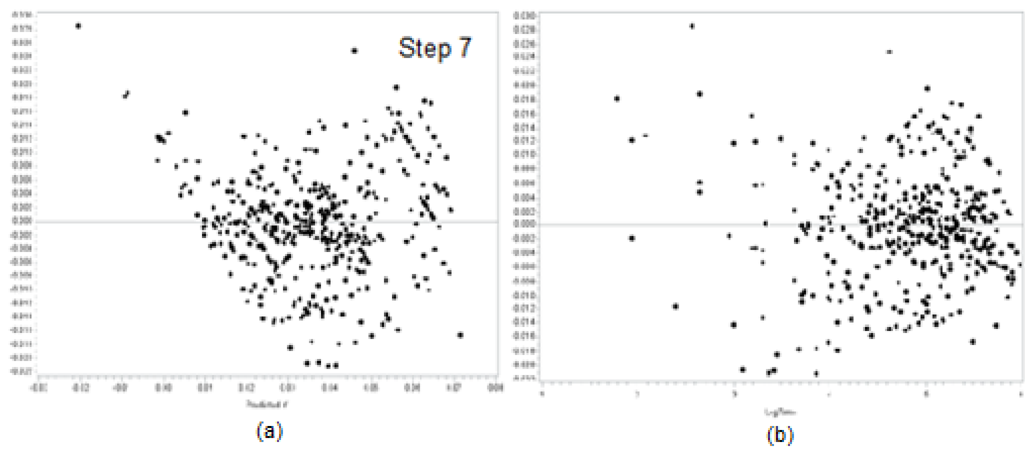


Figure D5: e vs. Yhat and e vs. Log(Time) – Step 7

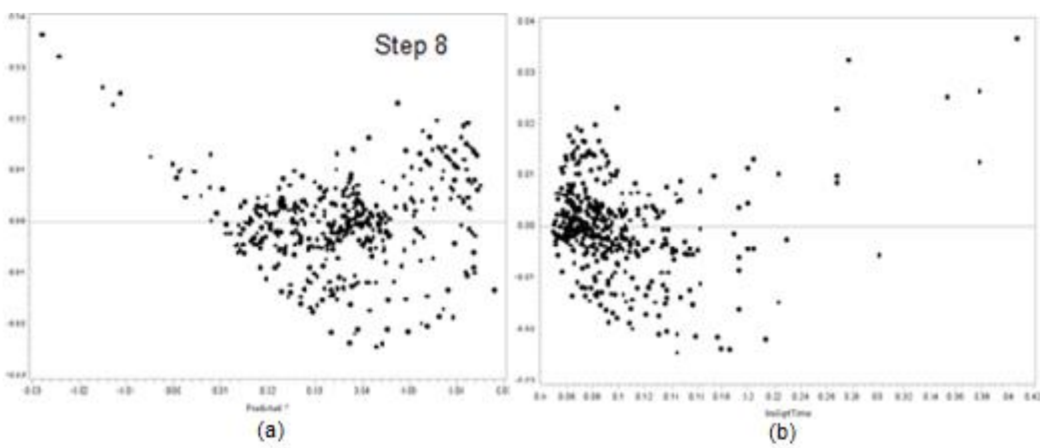


Figure D6: e vs. Yhat and e vs. (1/$\sqrt{Time}$) – Step 8

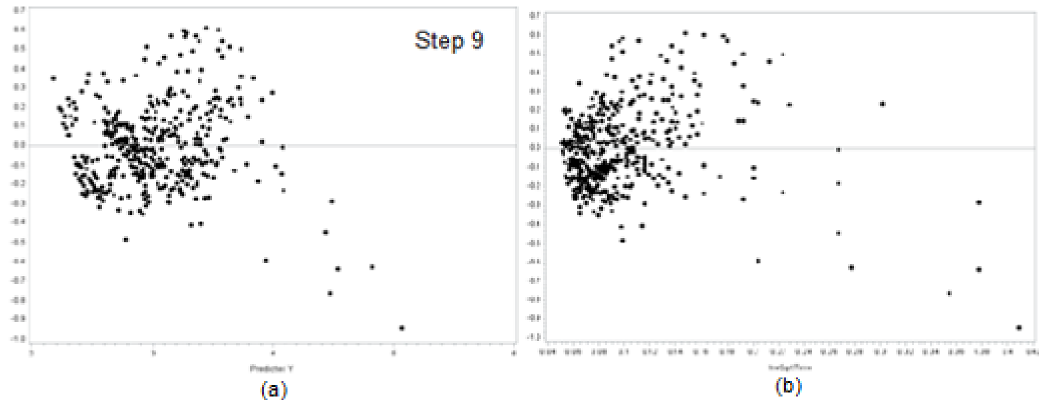


Figure D7: e vs. Yhat and e vs. (1/$\sqrt{Time}$) – Step 9

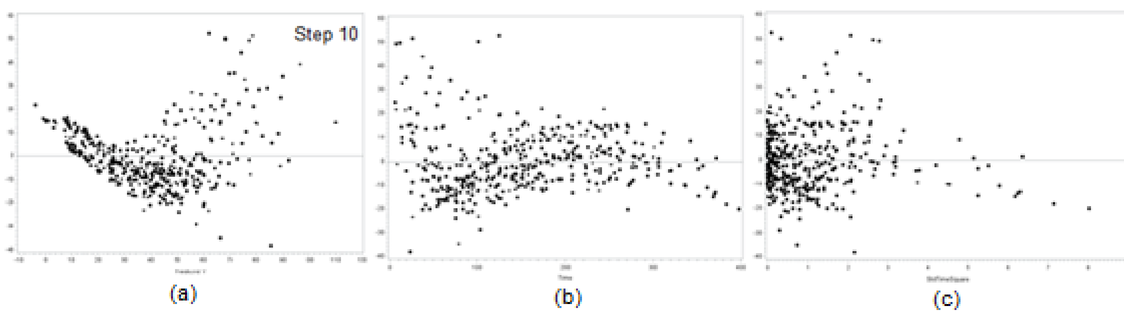


Figure D8: e vs. Yhat, e vs. Time and Std(Time)^2 – Step 10

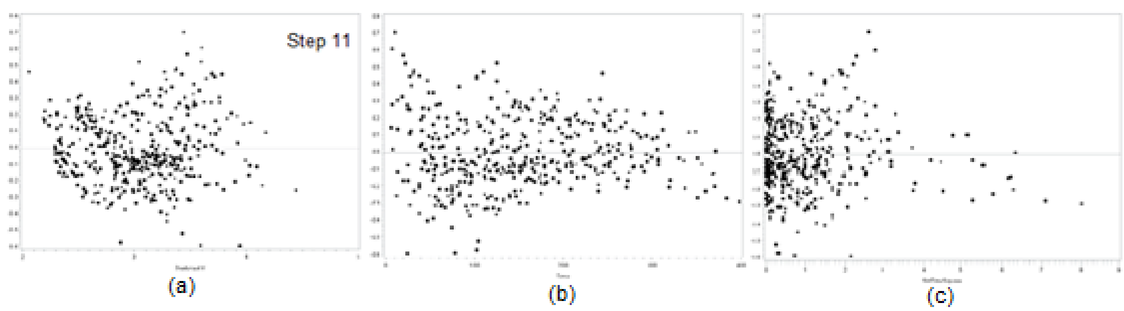


Figure D9: e vs. Yhat, e vs. Time and Std(Time)^2 – Step 11

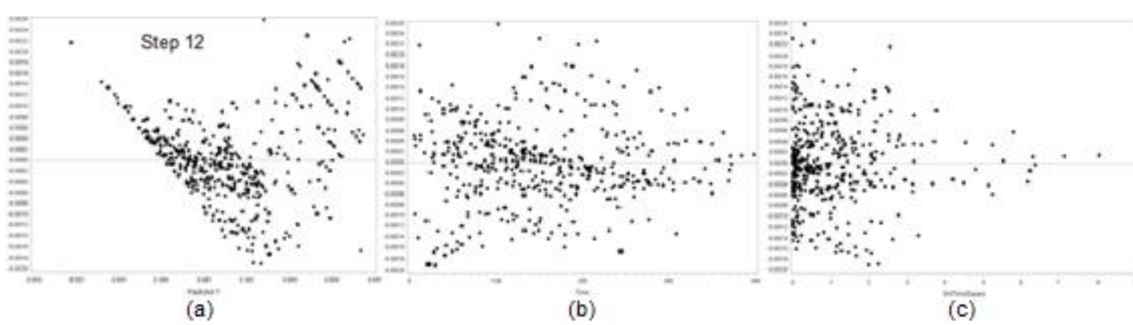


Figure D10: e vs. Yhat, e vs. Time and Std(Time)^2 – Step 12

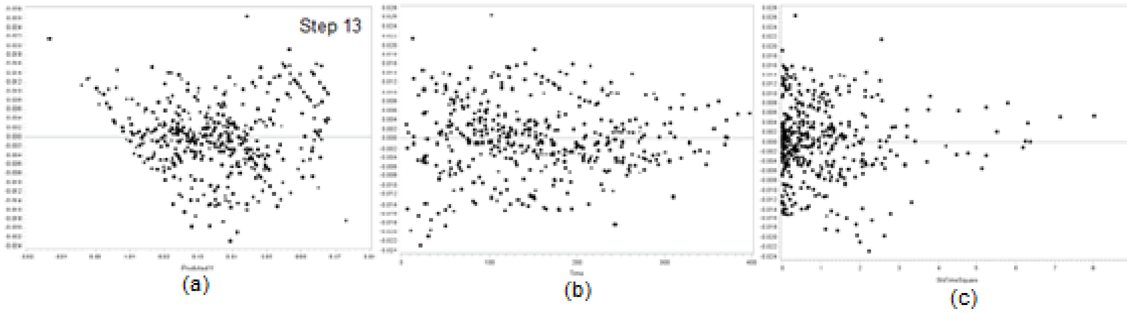


Figure D11: e vs. Yhat, e vs. Time and Std(Time)^2 – Step 13

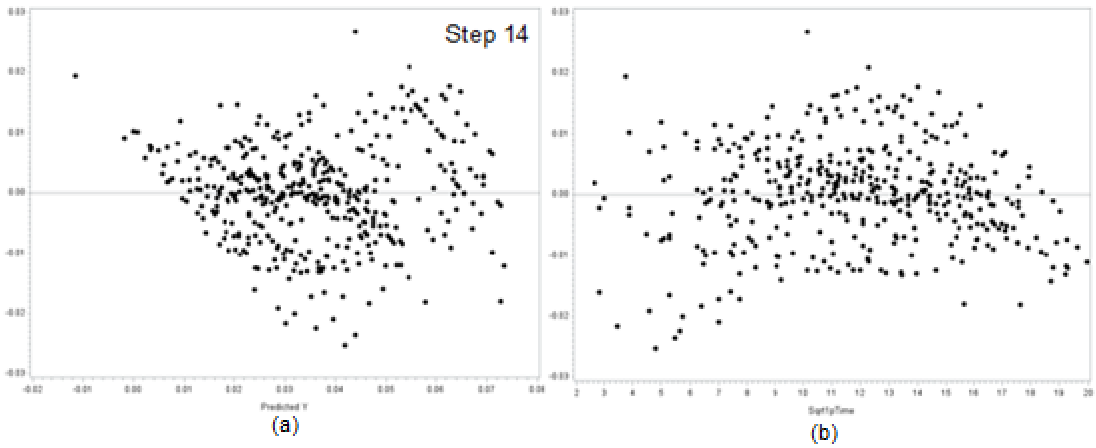


Figure D12: e vs. Yhat, e vs. $\sqrt{1+Time}$ – Step 14

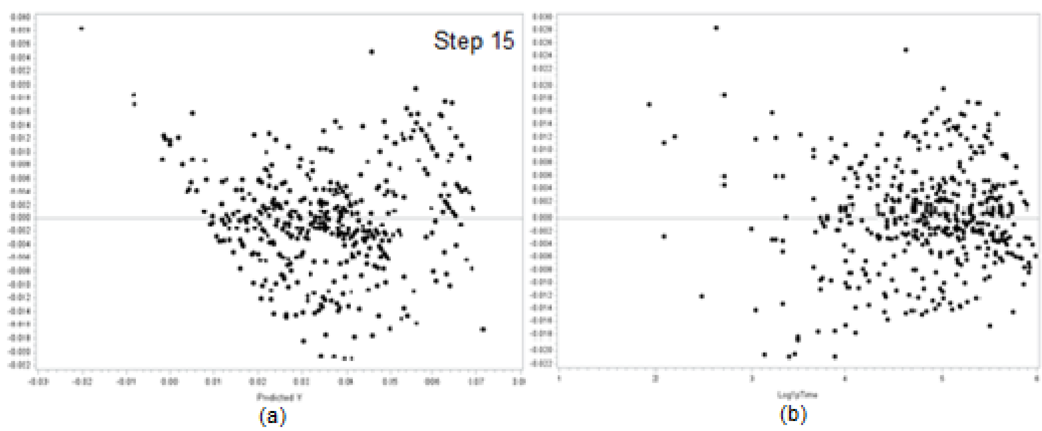


Figure D13: e vs. Yhat, e vs. Log(1+Time) – Step 15

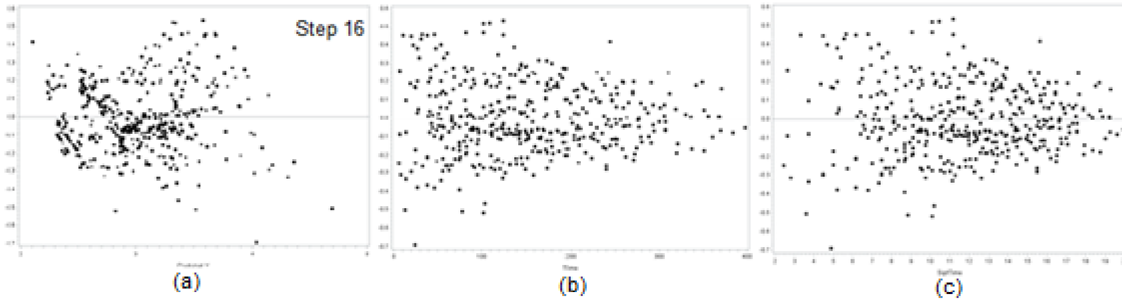


Figure D14: e vs. Yhat, e vs. Time and $\sqrt{Time}$ – Step 16

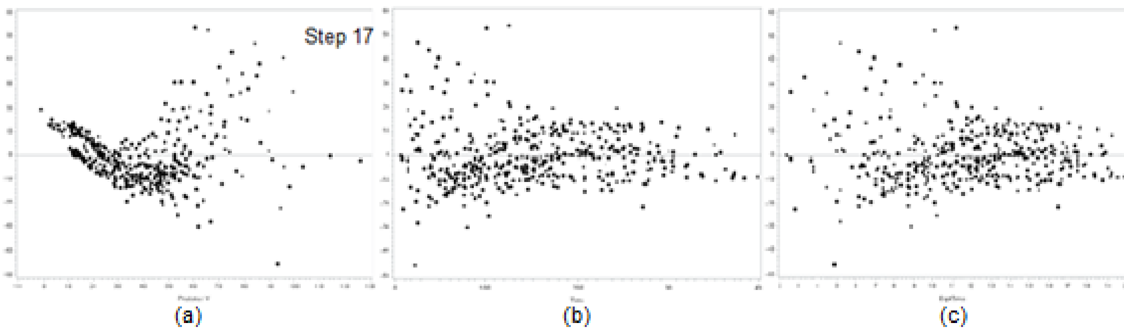


Figure D15: e vs. Yhat, e vs. Time and $\sqrt{Time}$ – Step 17

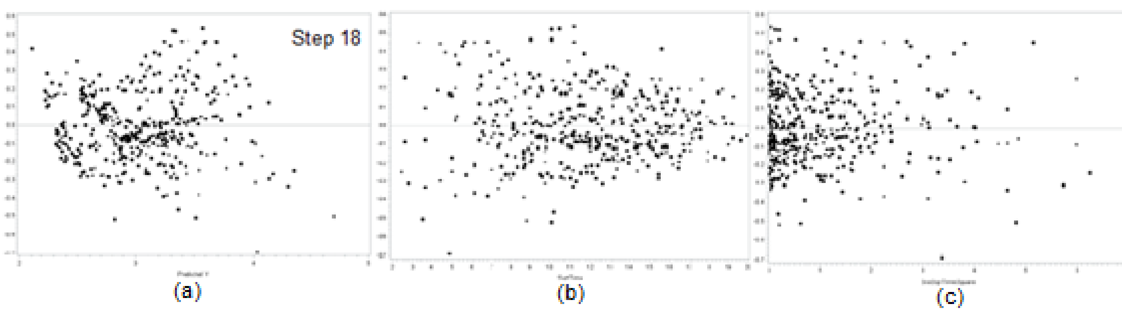


Figure D16: e vs. Yhat, e vs. $\sqrt{Time}$ and Std($\sqrt{Time}$)^2 – Step 18

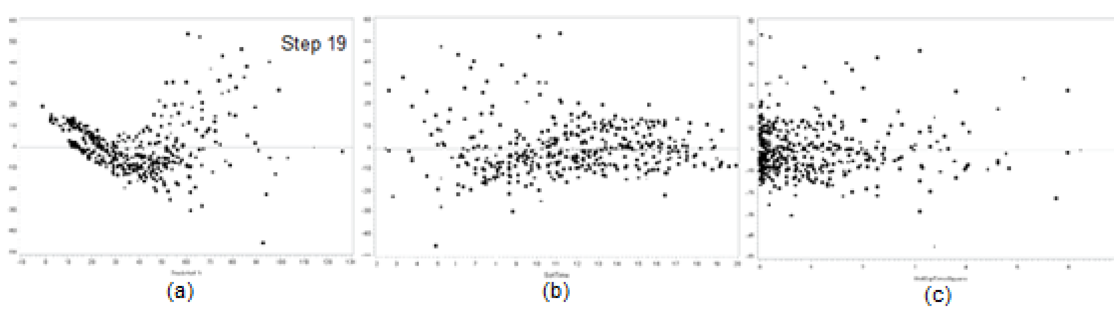


Figure D17: e vs. Yhat, e vs. $\sqrt{Time}$ and Std($\sqrt{Time}$)^2 – Step 19

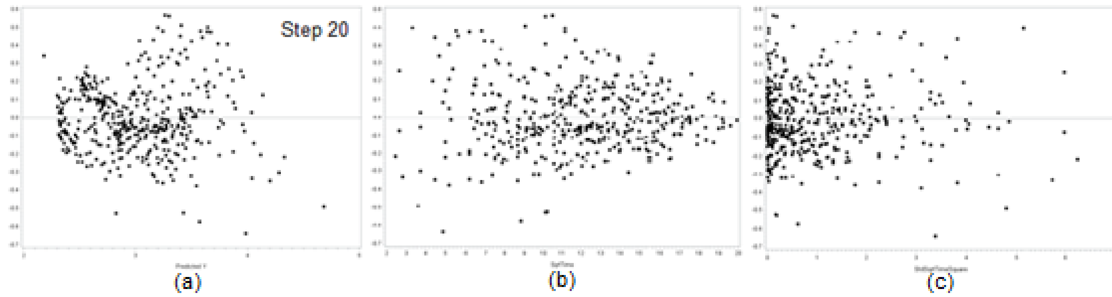


Figure D18: e vs. Yhat, e vs. $\sqrt{Time}$ and Std($\sqrt{Time}$)^2 – Step 20

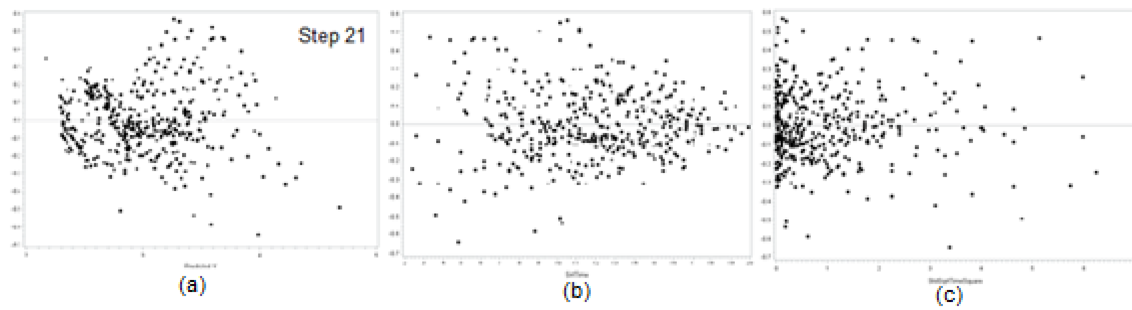


Figure D19: e vs. Yhat, e vs. $\sqrt{Time}$ and Std($\sqrt{Time}$)^2 – Step 21

APPENDIX E

MARS MODEL OUTPUT FOR LEACHATE PARAMETERS

This launch supports up to 32768 variables.

Random seeds: 13579 12345 131

VARIABLES IN RECT FILE ARE:

LOGALK	TIME	LEACHVOL	FOOD	TEXTILE
PAPER	YARD	RAIN	TEMP	

C:\Users\Hetal\Desktop\ALK.xlsx: 428 records.

Model reset.
Model reset: LOGALK

Salford Predictive Modeler: MARS(R) version 6.6.0.091

Records Read: 427
Records Kept in Learning sample: 427

CV Results
==========

10-fold cross validation used to find the optimal model.

Optimal Model Nr = 37, DF = 3.00000, Estimated PSE = 0.01981

Forward Stepwise Knot Placement
===============================

BasFn(s)	GCV	IndBsFns	EfPrms	Variable	Knot	Parent	BsF
0	0.23800	0.0	1.0				
2 1	0.15683	2.0	6.0	TIME	95.99999		
4 3	0.08563	4.0	11.0	RAIN	6.00000		
6 5	0.06436	6.0	16.0	YARD	60.00000		
8 7	0.05111	8.0	21.0	TEMP	85.00000	YARD	6
9	0.04085	9.0	25.0	FOOD	0.00000	TIME	2
11 10	0.03354	11.0	30.0	PAPER	30.00000	RAIN	4
13 12	0.03143	13.0	35.0	TIME	74.99999	RAIN	4
15 14	0.02929	14.0	39.0	TIME	236.00000	RAIN	4
17 16	0.02777	16.0	44.0	YARD	10.00000	RAIN	3
19 18	0.02327	18.0	49.0	TEXTILE	20.00000		
21 20	0.02106	20.0	54.0	TIME	105.99999	TEXTILE	19
23 22	0.02014	22.0	59.0	TEMP	85.00000	TEXTILE	18
25 24	0.01942	23.0	63.0	TIME	56.00000	TEXTILE	19
27 26	0.01883	25.0	68.0	PAPER	30.00000	YARD	6
29 28	0.01842	27.0	73.0	LEACHVOL	340.00000	TIME	2
31 30	0.01807	29.0	78.0	RAIN	6.00000	YARD	5
33 32	0.01811	31.0	83.0	PAPER	60.00000	TIME	2
35 34	0.01818	33.0	88.0	TIME	171.00000	YARD	5
37 36	0.01772	34.0	92.0	TIME	22.00000		
38	0.01713	35.0	96.0	FOOD	0.00000	TIME	37
40 39	0.01699	36.0	100.0	TIME	149.00000		
41	0.01683	37.0	104.0	TEMP	70.00000	TIME	39
43 42	0.01658	39.0	109.0	RAIN	6.00000	TIME	1
45 44	0.01655	41.0	114.0	TEMP	85.00000	TIME	2
47 46	0.01666	43.0	119.0	LEACHVOL	450.00000	TEXTILE	18
49 48	0.01648	45.0	124.0	TIME	37.99998	RAIN	3
50	0.01667	46.0	128.0	YARD	0.00000	TIME	40

Final Model (After Backward Stepwise Elimination)
==

Basis Fun	Coefficient	Variable	Parent	Knot
0	3.33036			
1	-0.00329	TIME		95.99999
2	0.01051	TIME		95.99999
3	-0.08700	RAIN		6.00000
6	-0.00178	YARD		60.00000
7	-0.00023	TEMP	YARD	85.00000
8	0.00009	TEMP	YARD	85.00000
9	0.00016	FOOD	TIME	0.00000
10	0.00043	PAPER	RAIN	30.00000
11	0.00602	PAPER	RAIN	30.00000
12	0.00194	TIME	RAIN	74.99999
13	-0.00187	TIME	RAIN	74.99999
14	0.00116	TIME	RAIN	236.00000
16	0.00068	YARD	RAIN	10.00000
17	0.00391	YARD	RAIN	10.00000
18	-0.00359	TEXTILE		20.00000
19	-0.01976	TEXTILE		20.00000
20	-0.00036	TIME	TEXTILE	105.99999
22	-0.00016	TEMP	TEXTILE	85.00000
23	-0.00045	TEMP	TEXTILE	85.00000
24	0.00037	TIME	TEXTILE	56.00000
26	-0.00006	PAPER	YARD	30.00000
27	-0.00008	PAPER	YARD	30.00000
29	0.00002	LEACHVOL	TIME	340.00000
30	-0.00114	RAIN	YARD	6.00000
31	-0.00152	RAIN	YARD	6.00000
32	0.00010	PAPER	TIME	60.00000
33	-0.00005	PAPER	TIME	60.00000
38	-0.00058	FOOD	TIME	0.00000
39	0.00156	TIME		149.00000
41	0.00005	TEMP	TIME	70.00000
43	-0.00247	RAIN	TIME	6.00000
44	0.00011	TEMP	TIME	85.00000
46	0.00001	LEACHVOL	TEXTILE	450.00000
47	0.00001	LEACHVOL	TEXTILE	450.00000
48	0.00015	TIME	RAIN	37.99998
49	0.00154	TIME	RAIN	37.99998
50	0.00002	YARD	TIME	0.00000

Piecewise Linear GCV = 0.01457, #efprms = 103.15215

ANOVA Decomposition on 37 Basis Functions
===

fun	std. dev.	-gcv	#bsfns	#efprms	variable
1	0.35065	0.02696	3	8.28261	TIME
2	0.25388	0.02730	1	2.76087	RAIN
3	0.04158	0.01465	1	2.76087	YARD
4	0.16143	0.01954	2	5.52174	TEXTILE
5	0.09910	0.01967	2	5.52174	YARD TEMP
6	0.13607	0.02073	2	5.52174	TIME FOOD
7	0.22270	0.02902	2	5.52174	PAPER RAIN
8	0.09555	0.02082	6	16.56522	TIME RAIN
9	0.10229	0.01732	4	11.04348	YARD

					RAIN
10	0.18199	0.01850	2	5.52174	TIME
					TEXTILE
11	0.06733	0.01584	2	5.52174	TEXTILE
					TEMP
12	0.08409	0.01566	2	5.52174	PAPER
					YARD
13	0.03117	0.01517	1	2.76087	TIME
					LEACHVOL
14	0.06426	0.01546	2	5.52174	TIME
					PAPER
15	0.04334	0.01518	2	5.52174	TIME
					TEMP
16	0.02494	0.01440	2	5.52174	LEACHVOL
					TEXTILE
17	0.04840	0.01487	1	2.76087	TIME
					YARD

Piecewise Cubic Fit on 37 Basis Functions, GCV = 0.01617

Relative Variable Importance
============================

Variable	Importance	-gcv
TIME	100.00000	0.13997
RAIN	76.32967	0.08763
PAPER	42.35207	0.03706
YARD	40.12404	0.03476
TEXTILE	31.74441	0.02720
TEMP	24.53185	0.02211
FOOD	22.16418	0.02073
LEACHVOL	6.68754	0.01513

MARS Regression: Training Data
==============================

N: 427.00 R-SQUARED: 0.96463

MEAN DEP VAR: 3.01295 ADJ R-SQUARED: 0.96126

UNCENTERED R-SQUARED = R-0 SQUARED: 0.99910

Parameter	Estimate	S.E.	T-Ratio	P-Value
Constant	3.33035	0.03103	107.33291	0.00000
Basis Function 1	-0.00329	0.00039	-8.43503	0.00000
Basis Function 2	0.01051	0.00080	13.13151	0.00000
Basis Function 3	-0.08700	0.00463	-18.77750	0.00000
Basis Function 6	-0.00178	0.00060	-2.97687	0.00309
Basis Function 7	-0.00023	0.00002	-9.98184	0.00000
Basis Function 8	0.00009	0.00003	3.54257	0.00044
Basis Function 9	0.00016	0.00001	13.11980	0.00000
Basis Function 10	0.00043	0.00015	2.82691	0.00494
Basis Function 11	0.00602	0.00031	19.44144	0.00000
Basis Function 12	0.00194	0.00042	4.65040	0.00000
Basis Function 13	-0.00187	0.00027	-6.80115	0.00000
Basis Function 14	0.00116	0.00013	8.81405	0.00000
Basis Function 16	0.00068	0.00013	5.21490	0.00000
Basis Function 17	0.00391	0.00047	8.28655	0.00000
Basis Function 18	-0.00359	0.00053	-6.72153	0.00000
Basis Function 19	-0.01976	0.00182	-10.85187	0.00000
Basis Function 20	-0.00036	0.00004	-9.13093	0.00000
Basis Function 22	-0.00016	0.00003	-4.91160	0.00000
Basis Function 23	-0.00045	0.00007	-6.13110	0.00000
Basis Function 24	0.00037	0.00004	10.25744	0.00000

```
 Basis Function 26       |     -0.00006      0.00001     -5.97483      0.00000
 Basis Function 27       |     -0.00008      0.00001     -5.68569      0.00000
 Basis Function 29       |      0.00002      0.00000      4.80909      0.00000
 Basis Function 30       |     -0.00114      0.00026     -4.43650      0.00001
 Basis Function 31       |     -0.00152      0.00025     -5.99807      0.00000
 Basis Function 32       |      0.00010      0.00002      4.36664      0.00002
 Basis Function 33       |     -0.00005      0.00002     -2.61840      0.00918
 Basis Function 38       |     -0.00058      0.00007     -8.20593      0.00000
 Basis Function 39       |      0.00156      0.00046      3.41923      0.00069
 Basis Function 41       |      0.00005      0.00001      4.93315      0.00000
 Basis Function 43       |     -0.00247      0.00046     -5.36139      0.00000
 Basis Function 44       |      0.00011      0.00003      3.25903      0.00122
 Basis Function 46       |      0.00001      0.00000      2.52842      0.01185
 Basis Function 47       |      0.00001      0.00000      2.44120      0.01508
 Basis Function 48       |      0.00015      0.00003      5.27348      0.00000
 Basis Function 49       |      0.00154      0.00036      4.29976      0.00002
 Basis Function 50       |      0.00002      0.00001      3.84176      0.00014
 -----------------------------------------------------------------------------
 F-STATISTIC =  286.71325                 S.E. OF REGRESSION =  0.09590
     P-VALUE =  0.00000               RESIDUAL SUM OF SQUARES =  3.57791
   [MDF,NDF] = [ 37, 389 ]          REGRESSION SUM OF SQUARES =  97.57284
 -----------------------------------------------------------------------------

<a name="6"></a>
 Basis Functions
 ===============

 BF1 = max( 0, TIME - 96);
 BF2 = max( 0, 96 - TIME);
 BF3 = max( 0, RAIN - 6);
 BF4 = max( 0, 6 - RAIN);
 BF5 = max( 0, YARD - 60);
 BF6 = max( 0, 60 - YARD);
 BF7 = max( 0, TEMP - 85) * BF6;
 BF8 = max( 0, 85 - TEMP) * BF6;
 BF9 = max( 0, FOOD - 1.32041e-006) * BF2;
 BF10 = max( 0, PAPER - 30) * BF4;
 BF11 = max( 0, 30 - PAPER) * BF4;
 BF12 = max( 0, TIME - 75) * BF4;
 BF13 = max( 0, 75 - TIME) * BF4;
 BF14 = max( 0, TIME - 236) * BF4;
 BF16 = max( 0, YARD - 10) * BF3;
 BF17 = max( 0, 10 - YARD) * BF3;
 BF18 = max( 0, TEXTILE - 20);
 BF19 = max( 0, 20 - TEXTILE);
 BF20 = max( 0, TIME - 106) * BF19;
 BF22 = max( 0, TEMP - 85) * BF18;
 BF23 = max( 0, 85 - TEMP) * BF18;
 BF24 = max( 0, TIME - 56) * BF19;
 BF26 = max( 0, PAPER - 30) * BF6;
 BF27 = max( 0, 30 - PAPER) * BF6;
 BF29 = max( 0, 340 - LEACHVOL) * BF2;
 BF30 = max( 0, RAIN - 6) * BF5;
 BF31 = max( 0, 6 - RAIN) * BF5;
 BF32 = max( 0, PAPER - 60) * BF2;
 BF33 = max( 0, 60 - PAPER) * BF2;
 BF37 = max( 0, 22 - TIME);
 BF38 = max( 0, FOOD - 1.32041e-006) * BF37;
 BF39 = max( 0, TIME - 149);
 BF40 = max( 0, 149 - TIME);
 BF41 = max( 0, TEMP - 70) * BF39;
 BF43 = max( 0, 6 - RAIN) * BF1;
 BF44 = max( 0, TEMP - 85) * BF2;
 BF46 = max( 0, LEACHVOL - 450) * BF18;
 BF47 = max( 0, 450 - LEACHVOL) * BF18;
 BF48 = max( 0, TIME - 38) * BF3;
 BF49 = max( 0, 38 - TIME) * BF3;
 BF50 = max( 0, YARD - 5.95825e-007) * BF40;
```

```
Y = 3.33036 - 0.00329156 * BF1 + 0.0105134 * BF2 - 0.0869964 * BF3
            - 0.00177851 * BF6 - 0.000226953 * BF7 + 9.47413e-005 * BF8
            + 0.000155796 * BF9 + 0.000429736 * BF10 + 0.00602451 * BF11
            + 0.00193694 * BF12 - 0.00186805 * BF13 + 0.00115805 * BF14
            + 0.000684049 * BF16 + 0.00390853 * BF17 - 0.00359028 * BF18
            - 0.0197582 * BF19 - 0.000364862 * BF20 - 0.000163728 * BF22
            - 0.000445339 * BF23 + 0.000373062 * BF24 - 6.25994e-005 * BF26
            - 8.09093e-005 * BF27 + 2.13875e-005 * BF29 - 0.00113587 * BF30
            - 0.00152031 * BF31 + 9.56936e-005 * BF32 - 5.05259e-005 * BF33
            - 0.00057755 * BF38 + 0.00155627 * BF39 + 4.54376e-005 * BF41
            - 0.00247204 * BF43 + 0.000105233 * BF44 + 6.09362e-006 * BF46
            + 5.49338e-006 * BF47 + 0.000145051 * BF48 + 0.00154349 * BF49
            + 2.27283e-005 * BF50;

MODEL LOGALK = BF1 BF2 BF3 BF6 BF7 BF8 BF9 BF10 BF11 BF12 BF13
               BF14 BF16 BF17 BF18 BF19 BF20 BF22 BF23 BF24 BF26
               BF27 BF29 BF30 BF31 BF32 BF33 BF38 BF39 BF41 BF43
               BF44 BF46 BF47 BF48 BF49 BF50;

Grove file created: C:\Users\Hetal\AppData\Local\Temp\s56o51: 80 kb

Grove file created containing:
     1 Mars model

                Examining and Preparing Data: 00:00:00
Forward Stepwise Knot Placement-- CV:      1: 00:00:00
                  Back Stepping-- CV:      1: 00:00:00
Forward Stepwise Knot Placement-- CV:      2: 00:00:00
                  Back Stepping-- CV:      2: 00:00:00
Forward Stepwise Knot Placement-- CV:      3: 00:00:00
                  Back Stepping-- CV:      3: 00:00:00
Forward Stepwise Knot Placement-- CV:      4: 00:00:00
                  Back Stepping-- CV:      4: 00:00:00
Forward Stepwise Knot Placement-- CV:      5: 00:00:00
                  Back Stepping-- CV:      5: 00:00:00
Forward Stepwise Knot Placement-- CV:      6: 00:00:00
                  Back Stepping-- CV:      6: 00:00:00
Forward Stepwise Knot Placement-- CV:      7: 00:00:00
                  Back Stepping-- CV:      7: 00:00:00
Forward Stepwise Knot Placement-- CV:      8: 00:00:00
                  Back Stepping-- CV:      8: 00:00:00
Forward Stepwise Knot Placement-- CV:      9: 00:00:00
                  Back Stepping-- CV:      9: 00:00:00
Forward Stepwise Knot Placement-- CV:     10: 00:00:00
                  Back Stepping-- CV:     10: 00:00:00
             Forward Stepwise Knot Placement: 00:00:00
                               Back Stepping: 00:00:00
                               Writing Grove: 00:00:00
```

This launch supports up to 32768 variables.

Random seeds: 13579 12345 131

VARIABLES IN RECT FILE ARE:

LOGCOND TIME LEACHVOL FOOD TEXTILE

PAPER YARD RAIN TEMP

C:\Users\Hetal\Desktop\LogCond.xlsx: 430 records.

Model reset.

Model reset: LOGCOND

Salford Predictive Modeler: MARS(R) version 6.6.0.091

Records Read: 429

Records Kept in Learning sample: 429

CV Results
==========

10-fold cross validation used to find the optimal model.

Optimal Model Nr = 31, DF = 3.00000, Estimated PSE = 0.01518

Forward Stepwise Knot Placement
===============================

BasFn(s)	GCV	IndBsFns	EfPrms	Variable	Knot	Parent	BsF
0	0.21029	0.0	1.0				
2 1	0.14381	2.0	6.0	TIME	92.00000		
4 3	0.07822	4.0	11.0	RAIN	6.00000		
6 5	0.05739	6.0	16.0	YARD	60.00000		
8 7	0.04447	8.0	21.0	PAPER	30.00000	RAIN	4
10 9	0.03534	10.0	26.0	FOOD	60.00000	TIME	2
12 11	0.02641	12.0	31.0	TEMP	85.00000	YARD	6
14 13	0.02273	14.0	36.0	TEXTILE	60.00000	YARD	6
16 15	0.02074	16.0	41.0	TIME	75.00000	RAIN	4
18 17	0.01889	17.0	45.0	TIME	222.00000	RAIN	4
20 19	0.01736	19.0	50.0	PAPER	30.00000	YARD	6
22 21	0.01626	21.0	55.0	TEXTILE	60.00000	RAIN	4
24 23	0.01558	23.0	60.0	LEACHVOL	340.00000	TIME	2
26 25	0.01521	25.0	65.0	TEXTILE	60.00000	TIME	2
28 27	0.01499	27.0	70.0	PAPER	30.00000	TIME	1
30 29	0.01482	29.0	75.0	FOOD	30.00000	TIME	1
32 31	0.01485	31.0	80.0	FOOD	10.00000		
34 33	0.01442	33.0	85.0	TIME	27.00000	FOOD	31
36 35	0.01393	35.0	90.0	TIME	38.00000	RAIN	3
38 37	0.01366	37.0	95.0	RAIN	6.00000	TIME	1
40 39	0.01362	39.0	100.0	PAPER	30.00000	RAIN	3
42 41	0.01349	41.0	105.0	TEMP	85.00000	TIME	1
44 43	0.01354	43.0	110.0	PAPER	60.00000	TIME	2
46 45	0.01318	45.0	115.0	TEMP	85.00000	TIME	2
48 47	0.01316	46.0	119.0	TIME	158.00000		
50 49	0.01241	48.0	124.0	YARD	20.00000	TIME	47

Final Model (After Backward Stepwise Elimination)
===

Basis Fun	Coefficient	Variable	Parent	Knot
0	3.34624			
1	-0.00142	TIME		92.00000
2	0.01622	TIME		92.00000
4	0.11751	RAIN		6.00000
5	-0.00905	YARD		60.00000
6	-0.00560	YARD		60.00000
7	-0.00308	PAPER	RAIN	30.00000
8	-0.00540	PAPER	RAIN	30.00000
10	-0.00012	FOOD	TIME	60.00000
11	-0.00038	TEMP	YARD	85.00000
12	-0.00015	TEMP	YARD	85.00000
13	-0.00023	TEXTILE	YARD	60.00000
16	-0.00279	TIME	RAIN	75.00000
17	0.00107	TIME	RAIN	222.00000
19	-0.00009	PAPER	YARD	30.00000
21	0.00692	TEXTILE	RAIN	60.00000
22	0.00319	TEXTILE	RAIN	60.00000
24	0.00002	LEACHVOL	TIME	340.00000
26	-0.00005	TEXTILE	TIME	60.00000
29	0.00006	FOOD	TIME	30.00000
31	0.00947	FOOD		10.00000
32	0.05494	FOOD		10.00000
33	-0.00005	TIME	FOOD	27.00000
34	-0.00034	TIME	FOOD	27.00000
35	0.00013	TIME	RAIN	38.00000
36	0.00147	TIME	RAIN	38.00000
38	-0.00052	RAIN	TIME	6.00000
39	-0.00218	PAPER	RAIN	30.00000
40	-0.00224	PAPER	RAIN	30.00000
41	0.00006	TEMP	TIME	85.00000
45	0.00011	TEMP	TIME	85.00000

Piecewise Linear GCV = 0.01221, #efprms = 77.87500

ANOVA Decomposition on 30 Basis Functions

fun	std. dev.	-gcv	#bsfns	#efprms	variable
1	0.40464	0.02427	2	5.12500	TIME
2	0.20990	0.01600	1	2.56250	RAIN
3	0.10244	0.01586	2	5.12500	YARD
4	0.23284	0.01904	2	5.12500	FOOD
5	0.26638	0.02604	4	10.25000	PAPER RAIN
6	0.14065	0.02190	4	10.25000	TIME FOOD
7	0.13666	0.01544	2	5.12500	YARD TEMP
8	0.16803	0.01668	1	2.56250	TEXTILE YARD
9	0.12483	0.01818	5	12.81250	TIME RAIN
10	0.13308	0.01319	1	2.56250	PAPER YARD
11	0.33552	0.01532	2	5.12500	TEXTILE RAIN
12	0.03264	0.01294	1	2.56250	TIME LEACHVOL
13	0.05622	0.01274	1	2.56250	TIME TEXTILE
14	0.04449	0.01266	2	5.12500	TIME TEMP

Piecewise Cubic Fit on 30 Basis Functions, GCV = 0.01344

Relative Variable Importance

Variable	Importance	-gcv
TIME	100.00000	0.11253
RAIN	89.75130	0.09302
YARD	58.12185	0.04610
PAPER	44.66276	0.03222
FOOD	41.87233	0.02980
TEXTILE	24.85653	0.01841
TEMP	18.18761	0.01553
LEACHVOL	8.55359	0.01294

MARS Regression: Training Data

N: 429.00 R-SQUARED: 0.96093
MEAN DEP VAR: 3.26681 ADJ R-SQUARED: 0.95799
UNCENTERED R-SQUARED = R-0 SQUARED: 0.99925

Parameter	Estimate	S.E.	T-Ratio	P-Value
Constant	3.34624	0.02206	151.67357	0.00000
Basis Function 1	-0.00142	0.00015	-9.25725	0.00000
Basis Function 2	0.01622	0.00086	18.75963	0.00000
Basis Function 4	0.11751	0.01025	11.46193	0.00000
Basis Function 5	-0.00905	0.00132	-6.86302	0.00000
Basis Function 6	-0.00560	0.00059	-9.51415	0.00000
Basis Function 7	-0.00308	0.00030	-10.29674	0.00000
Basis Function 8	-0.00540	0.00087	-6.21692	0.00000
Basis Function 10	-0.00012	0.00002	-7.32423	0.00000
Basis Function 11	-0.00038	0.00004	-10.31376	0.00000
Basis Function 12	-0.00015	0.00003	-4.65603	0.00000
Basis Function 13	-0.00023	0.00002	-12.40491	0.00000
Basis Function 16	-0.00279	0.00026	-10.63094	0.00000
Basis Function 17	0.00107	0.00011	9.72440	0.00000
Basis Function 19	-0.00009	0.00002	-6.19938	0.00000
Basis Function 21	0.00692	0.00071	9.78736	0.00000
Basis Function 22	0.00319	0.00045	7.10352	0.00000
Basis Function 24	0.00002	0.00000	5.48740	0.00000
Basis Function 26	-0.00005	0.00001	-4.84970	0.00000
Basis Function 29	0.00006	0.00001	4.23905	0.00003
Basis Function 31	0.00947	0.00074	12.71625	0.00000
Basis Function 32	0.05494	0.00498	11.03090	0.00000
Basis Function 33	-0.00005	0.00001	-5.35749	0.00000
Basis Function 34	-0.00034	0.00006	-6.03156	0.00000
Basis Function 35	0.00013	0.00003	5.24008	0.00000
Basis Function 36	0.00147	0.00033	4.44153	0.00001
Basis Function 38	-0.00052	0.00007	-7.86374	0.00000
Basis Function 39	-0.00218	0.00023	-9.35914	0.00000
Basis Function 40	-0.00224	0.00014	-16.31386	0.00000
Basis Function 41	0.00006	0.00001	5.00789	0.00000
Basis Function 45	0.00011	0.00004	3.24043	0.00129

F-STATISTIC = 326.30565 S.E. OF REGRESSION = 0.09389
P-VALUE = 0.00000 RESIDUAL SUM OF SQUARES = 3.50818
[MDF,NDF] = [30, 398] REGRESSION SUM OF SQUARES = 86.28686

```
<a name="6"></a>
 Basis Functions
 ===============

 BF1 = max( 0, TIME - 92);
 BF2 = max( 0, 92 - TIME);
 BF3 = max( 0, RAIN - 6);
 BF4 = max( 0, 6 - RAIN);
 BF5 = max( 0, YARD - 60);
 BF6 = max( 0, 60 - YARD);
 BF7 = max( 0, PAPER - 30) * BF4;
 BF8 = max( 0, 30 - PAPER) * BF4;
 BF10 = max( 0, 60 - FOOD) * BF2;
 BF11 = max( 0, TEMP - 85) * BF6;
 BF12 = max( 0, 85 - TEMP) * BF6;
 BF13 = max( 0, TEXTILE - 60) * BF6;
 BF16 = max( 0, 75 - TIME) * BF4;
 BF17 = max( 0, TIME - 222) * BF4;
 BF19 = max( 0, PAPER - 30) * BF6;
 BF21 = max( 0, TEXTILE - 60) * BF4;
 BF22 = max( 0, 60 - TEXTILE) * BF4;
 BF24 = max( 0, 340 - LEACHVOL) * BF2;
 BF26 = max( 0, 60 - TEXTILE) * BF2;
 BF29 = max( 0, FOOD - 30) * BF1;
 BF31 = max( 0, FOOD - 10);
 BF32 = max( 0, 10 - FOOD);
 BF33 = max( 0, TIME - 27) * BF31;
 BF34 = max( 0, 27 - TIME) * BF31;
 BF35 = max( 0, TIME - 38) * BF3;
 BF36 = max( 0, 38 - TIME) * BF3;
 BF38 = max( 0, 6 - RAIN) * BF1;
 BF39 = max( 0, PAPER - 30) * BF3;
 BF40 = max( 0, 30 - PAPER) * BF3;
 BF41 = max( 0, TEMP - 85) * BF1;
 BF45 = max( 0, TEMP - 85) * BF2;

 Y = 3.34624 - 0.00141955 * BF1 + 0.0162234 * BF2 + 0.117514 * BF4
             - 0.00905358 * BF5 - 0.00559512 * BF6 - 0.00307662 * BF7
             - 0.00540483 * BF8 - 0.000117887 * BF10 - 0.000376683 * BF11
             - 0.00014756 * BF12 - 0.00023313 * BF13 - 0.00278759 * BF16
             + 0.00107109 * BF17 - 9.44314e-005 * BF19 + 0.00691953 * BF21
             + 0.0031883 * BF22 + 2.40027e-005 * BF24 - 5.30411e-005 * BF26
             + 6.13005e-005 * BF29 + 0.00946945 * BF31 + 0.0549366 * BF32
             - 5.23409e-005 * BF33 - 0.000338979 * BF34 + 0.000134117 * BF35
             + 0.00146841 * BF36 - 0.000517012 * BF38 - 0.00217504 * BF39
             - 0.00224498 * BF40 + 6.05386e-005 * BF41 + 0.000114653 * BF45;

 MODEL LOGCOND = BF1 BF2 BF4 BF5 BF6 BF7 BF8 BF10 BF11 BF12 BF13
                 BF16 BF17 BF19 BF21 BF22 BF24 BF26 BF29 BF31 BF32
                 BF33 BF34 BF35 BF36 BF38 BF39 BF40 BF41 BF45;

 Grove file created: C:\Users\Hetal\AppData\Local\Temp\shk51: 71 kb

 Grove file created containing:
      1 Mars model

                 Examining and Preparing Data: 00:00:00
 Forward Stepwise Knot Placement-- CV:      1: 00:00:00
                   Back Stepping-- CV:      1: 00:00:00
 Forward Stepwise Knot Placement-- CV:      2: 00:00:00
                   Back Stepping-- CV:      2: 00:00:00
 Forward Stepwise Knot Placement-- CV:      3: 00:00:00
                   Back Stepping-- CV:      3: 00:00:00
 Forward Stepwise Knot Placement-- CV:      4: 00:00:00
                   Back Stepping-- CV:      4: 00:00:00
```

```
Forward Stepwise Knot Placement-- CV:      5: 00:00:00
                  Back Stepping-- CV:      5: 00:00:00
Forward Stepwise Knot Placement-- CV:      6: 00:00:00
                  Back Stepping-- CV:      6: 00:00:00
Forward Stepwise Knot Placement-- CV:      7: 00:00:00
                  Back Stepping-- CV:      7: 00:00:00
Forward Stepwise Knot Placement-- CV:      8: 00:00:00
                  Back Stepping-- CV:      8: 00:00:00
Forward Stepwise Knot Placement-- CV:      9: 00:00:00
                  Back Stepping-- CV:      9: 00:00:00
Forward Stepwise Knot Placement-- CV:     10: 00:00:00
                  Back Stepping-- CV:     10: 00:00:00
             Forward Stepwise Knot Placement: 00:00:00
                               Back Stepping: 00:00:00
                               Writing Grove: 00:00:00
```

This launch supports up to 32768 variables.

Random seeds: 13579 12345 131

VARIABLES IN RECT FILE ARE:

LOGTDS	TIME	LEACHVOL	FOOD	TEXTILE
PAPER	YARD	RAIN	TEMP	

C:\Users\Hetal\Desktop\LogTDS data.xlsx: 430 records.

Model reset.
Model reset: LOGTDS

Salford Predictive Modeler: MARS(R) version 6.6.0.091

Records Read: 428
Records Kept in Learning sample: 428

CV Results
==========

10-fold cross validation used to find the optimal model.

Optimal Model Nr = 33, DF = 3.00000, Estimated PSE = 0.02162

Forward Stepwise Knot Placement
===============================

BasFn(s)	GCV	IndBsFns	EfPrms	Variable	Knot	Parent	BsF
0	0.23061	0.0	1.0				
2 1	0.16196	2.0	6.0	TIME	75.99999		
4 3	0.09142	4.0	11.0	RAIN	6.00000		
6 5	0.06910	6.0	16.0	YARD	60.00000		
8 7	0.05520	8.0	21.0	PAPER	30.00000	RAIN	4
10 9	0.04679	10.0	26.0	FOOD	60.00000	TIME	2
12 11	0.03721	12.0	31.0	TEMP	85.00000	YARD	6
14 13	0.03273	14.0	36.0	TEXTILE	60.00000	YARD	6
16 15	0.03069	16.0	41.0	TIME	68.99999	RAIN	4
18 17	0.02805	17.0	45.0	TIME	222.00000	RAIN	4
20 19	0.02677	19.0	50.0	PAPER	30.00000		
22 21	0.02541	21.0	55.0	TIME	30.99999	PAPER	20
24 23	0.02414	23.0	60.0	TEXTILE	60.00000	RAIN	4
26 25	0.02341	25.0	65.0	TEXTILE	20.00000	RAIN	3
28 27	0.02286	27.0	70.0	LEACHVOL	372.00003	TIME	2
30 29	0.02246	28.0	74.0	TIME	142.99998		
32 31	0.02175	30.0	79.0	FOOD	60.00000	TIME	30
34 33	0.02168	32.0	84.0	TEXTILE	60.00000	TIME	2
36 35	0.02161	34.0	89.0	TEMP	85.00000	TIME	29
38 37	0.02153	36.0	94.0	RAIN	6.00000	YARD	5
40 39	0.02141	38.0	99.0	TIME	38.00000	RAIN	3
42 41	0.02140	40.0	104.0	PAPER	60.00000	TIME	2
44 43	0.02164	42.0	109.0	TEMP	85.00000	TIME	1
45	0.02179	43.0	113.0	TEMP	70.00000	PAPER	19
47 46	0.02204	44.0	117.0	TIME	68.00000		
48	0.02203	45.0	121.0	FOOD	0.00000	TIME	47
49	0.02216	46.0	125.0	TEMP	70.00000	TIME	46
50	0.02237	47.0	129.0	TEMP	70.00000	PAPER	20

Final Model (After Backward Stepwise Elimination)

```
=================================================

Basis Fun  Coefficient Variable     Parent         Knot
-----------------------------------------------------------------------
       0      3.42683
       1     -0.02737 TIME                           75.99999
       2      0.04723 TIME                           75.99999
       3     -0.09356 RAIN                            6.00000
       6     -0.00351 YARD                           60.00000
       8      0.00427 PAPER        RAIN              30.00000
       9      0.00061 FOOD         TIME              60.00000
      10     -0.00048 FOOD         TIME              60.00000
      13     -0.00019 TEXTILE      YARD              60.00000
      15     -0.00044 TIME         RAIN              68.99999
      16     -0.00346 TIME         RAIN              68.99999
      17      0.00073 TIME         RAIN             222.00000
      19     -0.00329 PAPER                          30.00000
      21     -0.00002 TIME         PAPER             30.99999
      22     -0.00056 TIME         PAPER             30.99999
      23      0.00377 TEXTILE      RAIN              60.00000
      24      0.00146 TEXTILE      RAIN              60.00000
      26      0.00173 TEXTILE      RAIN              20.00000
      28      0.00002 LEACHVOL     TIME             372.00003
      29      0.00240 TIME                          142.99998
      31     -0.00008 FOOD         TIME              60.00000
      32     -0.00005 FOOD         TIME              60.00000
      34     -0.00006 TEXTILE      TIME              60.00000
      35      0.00032 TEMP         TIME              85.00000
      36      0.00026 TEMP         TIME              85.00000
      39      0.00015 TIME         RAIN              38.00000
      40      0.00131 TIME         RAIN              38.00000
      41      0.00011 PAPER        TIME              60.00000
      44     -0.00040 TEMP         TIME              85.00000
      45     -0.00014 TEMP         PAPER             70.00000
      46      0.02634 TIME                           68.00000
      48     -0.00047 FOOD         TIME               0.00000
      49     -0.00018 TEMP         TIME              70.00000
      50     -0.00016 TEMP         PAPER             70.00000

Piecewise Linear GCV = 0.01956, #efprms = 90.87234
```



```
ANOVA Decomposition on 33 Basis Functions
=========================================

 fun    std. dev.         -gcv #bsfns  #efprms variable
-----------------------------------------------------
   1      0.65750      0.02207   4    10.89362 TIME
   2      0.27352      0.03984   1     2.72340 RAIN
   3      0.08208      0.02395   1     2.72340 YARD
   4      0.07736      0.02088   1     2.72340 PAPER
   5      0.15867      0.02517   1     2.72340 PAPER
                                               RAIN
   6      0.48280      0.02974   5    13.61702 TIME
                                               FOOD
   7      0.13557      0.02751   1     2.72340 TEXTILE
                                               YARD
   8      0.13688      0.02537   5    13.61702 TIME
                                               RAIN
   9      0.07112      0.02122   3     8.17021 TIME
                                               PAPER
  10      0.16360      0.02601   3     8.17021 TEXTILE
                                               RAIN
  11      0.03079      0.02001   1     2.72340 TIME
                                               LEACHVOL
  12      0.04575      0.01974   1     2.72340 TIME
                                               TEXTILE
```

13	0.24502	0.02280	4	10.89362	TIME TEMP
14	0.06573	0.02078	2	5.44681	PAPER TEMP

Piecewise Cubic Fit on 33 Basis Functions, GCV = 0.01990

Relative Variable Importance
============================

Variable	Importance	-gcv
RAIN	100.00000	0.13454
TIME	94.22755	0.12165
PAPER	43.34694	0.04118
YARD	42.55708	0.04040
FOOD	29.72369	0.02974
TEXTILE	29.60074	0.02965
TEMP	20.97094	0.02463
LEACHVOL	6.13271	0.02001

MARS Regression: Training Data
==============================

N: 428.00 R-SQUARED: 0.94712

MEAN DEP VAR: 2.98778 ADJ R-SQUARED: 0.94269

UNCENTERED R-SQUARED = R-0 SQUARED: 0.99867

Parameter	Estimate	S.E.	T-Ratio	P-Value
Constant	3.42654	0.06401	53.53452	0.00000
Basis Function 1	-0.02741	0.00572	-4.79194	0.00000
Basis Function 2	0.04726	0.00710	6.65674	0.00000
Basis Function 3	-0.09356	0.00456	-20.51310	0.00000
Basis Function 6	-0.00351	0.00036	-9.78955	0.00000
Basis Function 8	0.00427	0.00039	10.99555	0.00000
Basis Function 9	0.00061	0.00014	4.45051	0.00001
Basis Function 10	-0.00048	0.00012	-4.07716	0.00006
Basis Function 13	-0.00019	0.00001	-12.99443	0.00000
Basis Function 15	-0.00044	0.00007	-6.73237	0.00000
Basis Function 16	-0.00346	0.00038	-9.01943	0.00000
Basis Function 17	0.00073	0.00014	5.16741	0.00000
Basis Function 19	-0.00329	0.00057	-5.74012	0.00000
Basis Function 21	-0.00002	0.00000	-5.43025	0.00000
Basis Function 22	-0.00056	0.00013	-4.18830	0.00003
Basis Function 23	0.00377	0.00042	9.03941	0.00000
Basis Function 24	0.00146	0.00019	7.91299	0.00000
Basis Function 26	0.00173	0.00019	9.30233	0.00000
Basis Function 28	0.00002	0.00001	3.91154	0.00011
Basis Function 29	0.00240	0.00082	2.94368	0.00344
Basis Function 31	-0.00008	0.00002	-3.42123	0.00069
Basis Function 32	-0.00005	0.00001	-4.03949	0.00006
Basis Function 34	-0.00006	0.00002	-3.11586	0.00197
Basis Function 35	0.00032	0.00005	6.66584	0.00000
Basis Function 36	0.00026	0.00005	4.71040	0.00000
Basis Function 39	0.00015	0.00003	4.68997	0.00000
Basis Function 40	0.00131	0.00046	2.86222	0.00443
Basis Function 41	0.00011	0.00003	3.11645	0.00196
Basis Function 44	-0.00040	0.00005	-7.90921	0.00000
Basis Function 45	-0.00014	0.00003	-5.49201	0.00000
Basis Function 46	0.02638	0.00565	4.66958	0.00000
Basis Function 48	-0.00047	0.00013	-3.65107	0.00030
Basis Function 49	-0.00018	0.00003	-6.79201	0.00000
Basis Function 50	-0.00016	0.00003	-4.81410	0.00000

```
---------------------------------------------------------------------------
F-STATISTIC =  213.84827                      S.E. OF REGRESSION =  0.11483
    P-VALUE =  0.00000                RESIDUAL SUM OF SQUARES =  5.19485
  [MDF,NDF] = [ 33, 394 ]           REGRESSION SUM OF SQUARES =  93.04569
---------------------------------------------------------------------------

<a name="6"></a>
Basis Functions
===============

BF1 = max( 0, TIME - 76);
BF2 = max( 0, 76 - TIME);
BF3 = max( 0, RAIN - 6);
BF4 = max( 0, 6 - RAIN);
BF6 = max( 0, 60 - YARD);
BF8 = max( 0, 30 - PAPER) * BF4;
BF9 = max( 0, FOOD - 60) * BF2;
BF10 = max( 0, 60 - FOOD) * BF2;
BF13 = max( 0, TEXTILE - 60) * BF6;
BF15 = max( 0, TIME - 69) * BF4;
BF16 = max( 0, 69 - TIME) * BF4;
BF17 = max( 0, TIME - 222) * BF4;
BF19 = max( 0, PAPER - 30);
BF20 = max( 0, 30 - PAPER);
BF21 = max( 0, TIME - 31) * BF20;
BF22 = max( 0, 31 - TIME) * BF20;
BF23 = max( 0, TEXTILE - 60) * BF4;
BF24 = max( 0, 60 - TEXTILE) * BF4;
BF26 = max( 0, 20 - TEXTILE) * BF3;
BF28 = max( 0, 372 - LEACHVOL) * BF2;
BF29 = max( 0, TIME - 143);
BF30 = max( 0, 143 - TIME);
BF31 = max( 0, FOOD - 60) * BF30;
BF32 = max( 0, 60 - FOOD) * BF30;
BF34 = max( 0, 60 - TEXTILE) * BF2;
BF35 = max( 0, TEMP - 85) * BF29;
BF36 = max( 0, 85 - TEMP) * BF29;
BF39 = max( 0, TIME - 38) * BF3;
BF40 = max( 0, 38 - TIME) * BF3;
BF41 = max( 0, PAPER - 60) * BF2;
BF44 = max( 0, 85 - TEMP) * BF1;
BF45 = max( 0, TEMP - 70) * BF19;
BF46 = max( 0, TIME - 68);
BF47 = max( 0, 68 - TIME);
BF48 = max( 0, FOOD - 1.56851e-007) * BF47;
BF49 = max( 0, TEMP - 70) * BF46;
BF50 = max( 0, TEMP - 70) * BF20;

Y = 3.42683 - 0.0273697 * BF1 + 0.0472299 * BF2 - 0.0935581 * BF3
            - 0.00351267 * BF6 + 0.00427277 * BF8 + 0.000607742 * BF9
            - 0.00048274 * BF10 - 0.000187905 * BF13 - 0.000441929 * BF15
            - 0.00346014 * BF16 + 0.000725344 * BF17 - 0.00329059 * BF19
            - 2.39692e-005 * BF21 - 0.000556778 * BF22 + 0.00377428 * BF23
            + 0.00146398 * BF24 + 0.00173104 * BF26 + 2.36265e-005 * BF28
            + 0.00239956 * BF29 - 8.17293e-005 * BF31 - 4.92631e-005 * BF32
            - 5.93324e-005 * BF34 + 0.00031582 * BF35 + 0.000255484 * BF36
            + 0.000148006 * BF39 + 0.00130656 * BF40 + 0.000108989 * BF41
            - 0.000399388 * BF44 - 0.00014308 * BF45 + 0.0263391 * BF46
            - 0.000465002 * BF48 - 0.000180366 * BF49 - 0.000160708 * BF50;

MODEL LOGTDS = BF1 BF2 BF3 BF6 BF8 BF9 BF10 BF13 BF15 BF16 BF17
               BF19 BF21 BF22 BF23 BF24 BF26 BF28 BF29 BF31 BF32
               BF34 BF35 BF36 BF39 BF40 BF41 BF44 BF45 BF46 BF48
               BF49 BF50;

Grove file created: C:\Users\Hetal\AppData\Local\Temp\s8ps51: 73 kb

Grove file created containing:
```

```
     1 Mars model

                Examining and Preparing Data: 00:00:00
Forward Stepwise Knot Placement-- CV:      1: 00:00:00
                  Back Stepping-- CV:      1: 00:00:00
Forward Stepwise Knot Placement-- CV:      2: 00:00:00
                  Back Stepping-- CV:      2: 00:00:00
Forward Stepwise Knot Placement-- CV:      3: 00:00:00
                  Back Stepping-- CV:      3: 00:00:00
Forward Stepwise Knot Placement-- CV:      4: 00:00:01
                  Back Stepping-- CV:      4: 00:00:00
Forward Stepwise Knot Placement-- CV:      5: 00:00:00
                  Back Stepping-- CV:      5: 00:00:00
Forward Stepwise Knot Placement-- CV:      6: 00:00:01
                  Back Stepping-- CV:      6: 00:00:00
Forward Stepwise Knot Placement-- CV:      7: 00:00:00
                  Back Stepping-- CV:      7: 00:00:00
Forward Stepwise Knot Placement-- CV:      8: 00:00:00
                  Back Stepping-- CV:      8: 00:00:00
Forward Stepwise Knot Placement-- CV:      9: 00:00:00
                  Back Stepping-- CV:      9: 00:00:00
Forward Stepwise Knot Placement-- CV:     10: 00:00:00
                  Back Stepping-- CV:     10: 00:00:00
             Forward Stepwise Knot Placement: 00:00:00
                               Back Stepping: 00:00:00
                               Writing Grove: 00:00:00
```

```
This launch supports up to  32768 variables.


 Random seeds:            13579           12345             131
 VARIABLES IN RECT FILE ARE:
    LOGTSS           TIME       LEACHVOL           FOOD        TEXTILE
     PAPER           YARD           RAIN           TEMP

 C:\Users\Hetal\Desktop\LogTSS data.xlsx: 428 records.

 Model reset.
 Model reset: LOGTSS

 Salford Predictive Modeler: MARS(R) version 6.6.0.091

 Records Read: 427
 Records Kept in Learning sample: 427
<a name="0"></a>


 CV Results
 ==========

 10-fold cross validation used to find the optimal model.

 Optimal Model Nr = 20, DF = 3.00000, Estimated PSE = 0.06926
<a name="1"></a>


 Forward Stepwise Knot Placement
 ===============================

 BasFn(s)      GCV  IndBsFns EfPrms Variable            Knot       Parent  BsF
 ----------------------------------------------------------------------------
     0        0.19490    0.0    1.0
   2   1      0.16347    2.0    6.0 RAIN             6.00000
   4   3      0.11974    4.0   11.0 TIME           131.00000
   6   5      0.08701    6.0   16.0 FOOD            20.00000
     7        0.08209    7.0   20.0 TEMP            70.00000 RAIN            2
     8        0.07786    8.0   24.0 PAPER            0.00000 RAIN            2
     9        0.07649    9.0   28.0 YARD             0.00000 TIME            4
  11  10      0.07488   11.0   33.0 TIME            55.99999 RAIN            1
    12        0.07368   12.0   37.0 FOOD            -0.00000 TIME            3
  14  13      0.07304   14.0   42.0 RAIN             6.00000 FOOD            5
  16  15      0.07272   16.0   47.0 LEACHVOL       435.00000
  18  17      0.07300   18.0   52.0 TIME            83.99999 LEACHVOL       15
  20  19      0.07262   19.0   56.0 TIME           193.00000 LEACHVOL       15
  22  21      0.07244   21.0   61.0 FOOD            20.00000 LEACHVOL       15
    23        0.07231   22.0   65.0 PAPER            0.00000 RAIN            1
    24        0.07262   23.0   69.0 TEMP            70.00000 FOOD            6
  26  25      0.07340   25.0   74.0 RAIN             6.00000 FOOD            6
  28  27      0.07416   27.0   79.0 YARD            60.00000 LEACHVOL       16
<a name="2"></a>


 Final Model (After Backward Stepwise Elimination)
 =================================================

 Basis Fun  Coefficient Variable     Parent         Knot
 ----------------------------------------------------------------------
        0      1.67744
        1     -0.05242 RAIN                            6.00000
        2      0.17635 RAIN                            6.00000
        3     -0.00059 TIME                          131.00000
        4      0.00338 TIME                          131.00000
        7     -0.00301 TEMP         RAIN              70.00000
```

8	-0.00113	PAPER	RAIN	0.00000
9	0.00004	YARD	TIME	0.00000
11	0.00088	TIME	RAIN	55.99999
12	-0.00003	FOOD	TIME	-0.00000
13	0.00094	RAIN	FOOD	6.00000
15	-0.00037	LEACHVOL		435.00000
16	0.00071	LEACHVOL		435.00000
17	0.00001	TIME	LEACHVOL	83.99999
18	0.00002	TIME	LEACHVOL	83.99999
19	-0.00001	TIME	LEACHVOL	193.00000
22	-0.00003	FOOD	LEACHVOL	20.00000
23	0.00103	PAPER	RAIN	0.00000
24	-0.00043	TEMP	FOOD	70.00000
25	-0.00260	RAIN	FOOD	6.00000
26	-0.00248	RAIN	FOOD	6.00000

Piecewise Linear GCV = 0.06860, #efprms = 58.77779

ANOVA Decomposition on 20 Basis Functions

===

fun	std. dev.	-gcv	#bsfns	#efprms	variable
1	0.41315	0.11314	2	5.77778	RAIN
2	0.14447	0.07687	2	5.77778	TIME
3	0.11795	0.07130	2	5.77778	LEACHVOL
4	0.09679	0.07159	1	2.88889	RAIN TEMP
5	0.15826	0.07661	2	5.77778	PAPER RAIN
6	0.07544	0.07269	1	2.88889	TIME YARD
7	0.03480	0.06853	1	2.88889	TIME RAIN
8	0.05694	0.06962	1	2.88889	TIME FOOD
9	0.17477	0.07862	3	8.66667	FOOD RAIN
10	0.16311	0.07082	3	8.66667	TIME LEACHVOL
11	0.09131	0.06981	1	2.88889	LEACHVOL FOOD
12	0.09307	0.07288	1	2.88889	FOOD TEMP

Piecewise Cubic Fit on 20 Basis Functions, GCV = 0.06995

Relative Variable Importance

============================

Variable	Importance	-gcv
RAIN	100.00000	0.12862
TIME	91.16444	0.11848
FOOD	60.93209	0.09089
TEMP	46.20616	0.08142
PAPER	36.53146	0.07661
YARD	26.09216	0.07269
LEACHVOL	24.03236	0.07207

MARS Regression: Training Data

==============================

N: 427.00 R-SQUARED: 0.73701
MEAN DEP VAR: 1.73745 ADJ R-SQUARED: 0.72406
UNCENTERED R-SQUARED = R-0 SQUARED: 0.98412

Parameter	Estimate	S.E.	T-Ratio	P-Value
Constant	1.67743	0.03525	47.58406	0.00000
Basis Function 1	-0.05242	0.00958	-5.47045	0.00000
Basis Function 2	0.17635	0.01341	13.14747	0.00000
Basis Function 3	-0.00059	0.00030	-1.92555	0.05486
Basis Function 4	0.00338	0.00050	6.71614	0.00000
Basis Function 7	-0.00301	0.00061	-4.93543	0.00000
Basis Function 8	-0.00113	0.00018	-6.35106	0.00000
Basis Function 9	0.00004	0.00001	5.56370	0.00000
Basis Function 11	0.00088	0.00036	2.44359	0.01497
Basis Function 12	-0.00003	0.00001	-3.53428	0.00046
Basis Function 13	0.00094	0.00016	5.80621	0.00000
Basis Function 15	-0.00037	0.00014	-2.69851	0.00726
Basis Function 16	0.00071	0.00016	4.40254	0.00001
Basis Function 17	0.00001	0.00000	5.43440	0.00000
Basis Function 18	0.00002	0.00000	4.45855	0.00001
Basis Function 19	-0.00001	0.00000	-4.72232	0.00000
Basis Function 22	-0.00003	0.00001	-3.69730	0.00025
Basis Function 23	0.00103	0.00022	4.77885	0.00000
Basis Function 24	-0.00043	0.00008	-5.66423	0.00000
Basis Function 25	-0.00260	0.00059	-4.43739	0.00001
Basis Function 26	-0.00248	0.00078	-3.15865	0.00170

F-STATISTIC = 56.89059 S.E. OF REGRESSION = 0.23164
P-VALUE = 0.00000 RESIDUAL SUM OF SQUARES = 21.78435
[MDF,NDF] = [20, 406] REGRESSION SUM OF SQUARES = 61.05046

Basis Functions
===============

```
BF1 = max( 0, RAIN - 6);
BF2 = max( 0, 6 - RAIN);
BF3 = max( 0, TIME - 131);
BF4 = max( 0, 131 - TIME);
BF5 = max( 0, FOOD - 20);
BF6 = max( 0, 20 - FOOD);
BF7 = max( 0, TEMP - 70) * BF2;
BF8 = max( 0, PAPER - 1.65544e-006) * BF2;
BF9 = max( 0, YARD - 1.69385e-006) * BF4;
BF11 = max( 0, 56 - TIME) * BF1;
BF12 = max( 0, FOOD + 6.51378e-008) * BF3;
BF13 = max( 0, RAIN - 6) * BF5;
BF15 = max( 0, LEACHVOL - 435);
BF16 = max( 0, 435 - LEACHVOL);
BF17 = max( 0, TIME - 84) * BF15;
BF18 = max( 0, 84 - TIME) * BF15;
BF19 = max( 0, TIME - 193) * BF15;
BF22 = max( 0, 20 - FOOD) * BF15;
BF23 = max( 0, PAPER - 1.65544e-006) * BF1;
BF24 = max( 0, TEMP - 70) * BF6;
BF25 = max( 0, RAIN - 6) * BF6;
BF26 = max( 0, 6 - RAIN) * BF6;

Y = 1.67744 - 0.0524239 * BF1 + 0.176351 * BF2 - 0.000586172 * BF3
            + 0.00338464 * BF4 - 0.00300885 * BF7 - 0.00112504 * BF8
            + 4.39924e-005 * BF9 + 0.00088089 * BF11 - 2.52599e-005 * BF12
            + 0.000944592 * BF13 - 0.000371611 * BF15 + 0.000711795 * BF16
            + 1.01596e-005 * BF17 + 1.72435e-005 * BF18 - 1.26328e-005 * BF19
            - 2.7213e-005 * BF22 + 0.00103349 * BF23 - 0.000431549 * BF24
            - 0.0026032 * BF25 - 0.00247617 * BF26;
```

```
MODEL LOGTSS = BF1 BF2 BF3 BF4 BF7 BF8 BF9 BF11 BF12 BF13 BF15
               BF16 BF17 BF18 BF19 BF22 BF23 BF24 BF25 BF26;

Grove file created: C:\Users\Hetal\AppData\Local\Temp\s8n051: 59 kb

Grove file created containing:
     1 Mars model

                Examining and Preparing Data: 00:00:00
Forward Stepwise Knot Placement-- CV:      1: 00:00:00
                  Back Stepping-- CV:      1: 00:00:00
Forward Stepwise Knot Placement-- CV:      2: 00:00:00
                  Back Stepping-- CV:      2: 00:00:00
Forward Stepwise Knot Placement-- CV:      3: 00:00:00
                  Back Stepping-- CV:      3: 00:00:00
Forward Stepwise Knot Placement-- CV:      4: 00:00:00
                  Back Stepping-- CV:      4: 00:00:00
Forward Stepwise Knot Placement-- CV:      5: 00:00:00
                  Back Stepping-- CV:      5: 00:00:00
Forward Stepwise Knot Placement-- CV:      6: 00:00:00
                  Back Stepping-- CV:      6: 00:00:00
Forward Stepwise Knot Placement-- CV:      7: 00:00:00
                  Back Stepping-- CV:      7: 00:00:00
Forward Stepwise Knot Placement-- CV:      8: 00:00:00
                  Back Stepping-- CV:      8: 00:00:00
Forward Stepwise Knot Placement-- CV:      9: 00:00:00
                  Back Stepping-- CV:      9: 00:00:00
Forward Stepwise Knot Placement-- CV:     10: 00:00:00
                  Back Stepping-- CV:     10: 00:00:00
             Forward Stepwise Knot Placement: 00:00:00
                              Back Stepping: 00:00:00
                              Writing Grove: 00:00:00
```

This launch supports up to 32768 variables.

Random seeds: 13579 12345 131

VARIABLES IN RECT FILE ARE:

LOGVSS	TIME	LEACHVOL	FOOD	TEXTILE
PAPER	YARD	RAIN	TEMP	

C:\Arpita_PhD\PhD Landfill Project\leachate Parameters Analysis\VSS Data\LogVSS_MARS Model Selection Process\LogVSS Data.xlsx: 428 records.

Model reset.
Model reset: LOGVSS

Salford Predictive Modeler: MARS(R) version 6.6.0.091

Records Read: 427
Records Kept in Learning sample: 427

CV Results
==========

10-fold cross validation used to find the optimal model.

Optimal Model Nr = 19, DF = 3.00000, Estimated PSE = 0.05788

Forward Stepwise Knot Placement
===============================

BasFn(s)	GCV	IndBsFns	EfPrms	Variable	Knot	Parent	BsF
0	0.19926	0.0	1.0				
2 1	0.16280	2.0	6.0	TIME	133.00000		
4 3	0.11618	4.0	11.0	RAIN	6.00000		
6 5	0.07538	6.0	16.0	FOOD	20.00000		
8 7	0.06957	8.0	21.0	TEMP	85.00000	RAIN	4
10 9	0.06542	10.0	26.0	PAPER	30.00000	FOOD	6
12 11	0.06395	12.0	31.0	TEMP	85.00000	FOOD	6
14 13	0.06227	14.0	36.0	RAIN	6.00000	FOOD	6
16 15	0.06138	16.0	41.0	FOOD	60.00000	TIME	1
18 17	0.06046	18.0	46.0	YARD	60.00000	TIME	2
20 19	0.05977	20.0	51.0	TIME	41.99998	FOOD	5
22 21	0.05843	22.0	56.0	TIME	103.99999	RAIN	4
24 23	0.05754	24.0	61.0	YARD	10.00000	RAIN	3
26 25	0.05778	26.0	66.0	LEACHVOL	550.00000	RAIN	4
27	0.05803	27.0	70.0	PAPER	0.00000	RAIN	4
28	0.05901	28.0	74.0	TEMP	70.00000	TIME	1

Final Model (After Backward Stepwise Elimination)
===

Basis Fun	Coefficient	Variable	Parent	Knot
0	1.52672			
1	-0.00178	TIME		133.00000
2	0.00849	TIME		133.00000
3	-0.02900	RAIN		6.00000
4	0.14664	RAIN		6.00000
6	-0.01340	FOOD		20.00000
7	-0.00375	TEMP	RAIN	85.00000

8	0.00474	TEMP	RAIN	85.00000
10	0.00027	PAPER	FOOD	30.00000
11	-0.00055	TEMP	FOOD	85.00000
13	-0.00289	RAIN	FOOD	6.00000
15	-0.00015	FOOD	TIME	60.00000
16	0.00003	FOOD	TIME	60.00000
18	-0.00005	YARD	TIME	60.00000
19	0.00003	TIME	FOOD	41.99998
20	0.00025	TIME	FOOD	41.99998
21	-0.00037	TIME	RAIN	103.99999
22	-0.00120	TIME	RAIN	103.99999
24	0.00330	YARD	RAIN	10.00000
27	-0.00081	PAPER	RAIN	0.00000

Piecewise Linear GCV = 0.05480, #efprms = 50.53572

ANOVA Decomposition on 19 Basis Functions
===

fun	std. dev.	-gcv	#bsfns	#efprms	variable
1	0.38150	0.08061	2	5.21429	TIME
2	0.31294	0.07830	2	5.21429	RAIN
3	0.12742	0.05888	1	2.60714	FOOD
4	0.10964	0.06102	2	5.21429	RAIN
					TEMP
5	0.06460	0.05624	1	2.60714	FOOD
					PAPER
6	0.05723	0.05631	1	2.60714	FOOD
					TEMP
7	0.11106	0.05907	1	2.60714	FOOD
					RAIN
8	0.12223	0.05770	4	10.42857	TIME
					FOOD
9	0.09951	0.05713	1	2.60714	TIME
					YARD
10	0.09799	0.05618	2	5.21429	TIME
					RAIN
11	0.07530	0.05688	1	2.60714	YARD
					RAIN
12	0.07648	0.05668	1	2.60714	PAPER
					RAIN

Piecewise Cubic Fit on 19 Basis Functions, GCV = 0.05767

Relative Variable Importance
============================

Variable	Importance	-gcv
RAIN	100.00000	0.12486
TIME	93.35110	0.11586
FOOD	71.06572	0.09019
TEMP	41.14675	0.06667
PAPER	31.69315	0.06184
YARD	22.42266	0.05833

MARS Regression: Training Data
==============================

N: 427.00 R-SQUARED: 0.78521
MEAN DEP VAR: 1.61722 ADJ R-SQUARED: 0.77518

UNCENTERED R-SQUARED = R-0 SQUARED: 0.98486

Parameter	Estimate	S.E.	T-Ratio	P-Value
Constant	1.52672	0.03846	39.69131	0.00000
Basis Function 1	-0.00178	0.00059	-2.99094	0.00295
Basis Function 2	0.00849	0.00060	14.08964	0.00000
Basis Function 3	-0.02900	0.00643	-4.51149	0.00001
Basis Function 4	0.14664	0.01294	11.32946	0.00000
Basis Function 6	-0.01340	0.00222	-6.03065	0.00000
Basis Function 7	-0.00375	0.00109	-3.44760	0.00062
Basis Function 8	0.00474	0.00102	4.65113	0.00000
Basis Function 10	0.00027	0.00007	4.05623	0.00006
Basis Function 11	-0.00055	0.00013	-4.11950	0.00005
Basis Function 13	-0.00289	0.00047	-6.14559	0.00000
Basis Function 15	-0.00015	0.00003	-4.64379	0.00000
Basis Function 16	0.00003	0.00001	2.93128	0.00357
Basis Function 18	-0.00005	0.00001	-4.81033	0.00000
Basis Function 19	0.00003	0.00001	3.69240	0.00025
Basis Function 20	0.00025	0.00005	4.78858	0.00000
Basis Function 21	-0.00037	0.00010	-3.79944	0.00017
Basis Function 22	-0.00120	0.00030	-3.96599	0.00009
Basis Function 24	0.00330	0.00071	4.61493	0.00001
Basis Function 27	-0.00081	0.00018	-4.44609	0.00001

```
F-STATISTIC =  78.30779                 S.E. OF REGRESSION =  0.21141
    P-VALUE =  0.00000              RESIDUAL SUM OF SQUARES =  18.19021
  [MDF,NDF] = [ 19, 407 ]         REGRESSION SUM OF SQUARES =  66.49697
```

```
<a name="6"></a>
 Basis Functions
 ===============

 BF1 = max( 0, TIME - 133);
 BF2 = max( 0, 133 - TIME);
 BF3 = max( 0, RAIN - 6);
 BF4 = max( 0, 6 - RAIN);
 BF5 = max( 0, FOOD - 20);
 BF6 = max( 0, 20 - FOOD);
 BF7 = max( 0, TEMP - 85) * BF4;
 BF8 = max( 0, 85 - TEMP) * BF4;
 BF10 = max( 0, 30 - PAPER) * BF6;
 BF11 = max( 0, TEMP - 85) * BF6;
 BF13 = max( 0, RAIN - 6) * BF6;
 BF15 = max( 0, FOOD - 60) * BF1;
 BF16 = max( 0, 60 - FOOD) * BF1;
 BF18 = max( 0, 60 - YARD) * BF2;
 BF19 = max( 0, TIME - 42) * BF5;
 BF20 = max( 0, 42 - TIME) * BF5;
 BF21 = max( 0, TIME - 104) * BF4;
 BF22 = max( 0, 104 - TIME) * BF4;
 BF24 = max( 0, 10 - YARD) * BF3;
 BF27 = max( 0, PAPER - 1.65544e-006) * BF4;

 Y = 1.52672 - 0.00177582 * BF1 + 0.00849023 * BF2 - 0.0290017 * BF3
            + 0.146644 * BF4 - 0.0134041 * BF6 - 0.00375475 * BF7
            + 0.0047351 * BF8 + 0.000266185 * BF10 - 0.00054614 * BF11
            - 0.00289181 * BF13 - 0.000146351 * BF15 + 3.31824e-005 * BF16
            - 5.21826e-005 * BF18 + 3.27984e-005 * BF19 + 0.000245943 * BF20
            - 0.000366141 * BF21 - 0.00120008 * BF22 + 0.0032982 * BF24
            - 0.000814065 * BF27;

 MODEL LOGVSS = BF1 BF2 BF3 BF4 BF6 BF7 BF8 BF10 BF11 BF13 BF15
               BF16 BF18 BF19 BF20 BF21 BF22 BF24 BF27;

 Grove file created: C:\Users\Hetal\AppData\Local\Temp\s76s51: 59 kb
```

```
Grove file created containing:
     1 Mars model

                Examining and Preparing Data: 00:00:00
Forward Stepwise Knot Placement-- CV:      1: 00:00:00
                  Back Stepping-- CV:      1: 00:00:00
Forward Stepwise Knot Placement-- CV:      2: 00:00:01
                  Back Stepping-- CV:      2: 00:00:00
Forward Stepwise Knot Placement-- CV:      3: 00:00:00
                  Back Stepping-- CV:      3: 00:00:00
Forward Stepwise Knot Placement-- CV:      4: 00:00:01
                  Back Stepping-- CV:      4: 00:00:00
Forward Stepwise Knot Placement-- CV:      5: 00:00:00
                  Back Stepping-- CV:      5: 00:00:00
Forward Stepwise Knot Placement-- CV:      6: 00:00:00
                  Back Stepping-- CV:      6: 00:00:01
Forward Stepwise Knot Placement-- CV:      7: 00:00:00
                  Back Stepping-- CV:      7: 00:00:00
Forward Stepwise Knot Placement-- CV:      8: 00:00:00
                  Back Stepping-- CV:      8: 00:00:00
Forward Stepwise Knot Placement-- CV:      9: 00:00:00
                  Back Stepping-- CV:      9: 00:00:00
Forward Stepwise Knot Placement-- CV:     10: 00:00:00
                  Back Stepping-- CV:     10: 00:00:00
             Forward Stepwise Knot Placement: 00:00:00
                               Back Stepping: 00:00:00
                               Writing Grove: 00:00:00
```

This launch supports up to 32768 variables.

Random seeds: 13579 12345 131

VARIABLES IN RECT FILE ARE:

LOGBOD	TIME	LEACHVOL	FOOD	TEXTILE
PAPER	YARD	RAIN	TEMP	

C:\Arpita_PhD\PhD Landfill Project\leachate Parameters Analysis\BOD Data\MARS BOD\Log BOD Data.xlsx: 403 records.

Model reset.
Model reset: LOGBOD

Salford Predictive Modeler: MARS(R) version 6.6.0.091

Records Read: 402
Records Kept in Learning sample: 402

CV Results
==========

10-fold cross validation used to find the optimal model.

Optimal Model Nr = 33, DF = 3.00000, Estimated PSE = 0.09626

Forward Stepwise Knot Placement
===============================

BasFn(s)	GCV	IndBsFns	EfPrms	Variable	Knot	Parent	BsF
0	0.84923	0.0	1.0				
2 1	0.41719	2.0	6.0	TIME	119.00000		
4 3	0.29347	4.0	11.0	RAIN	6.00000		
6 5	0.23512	6.0	16.0	FOOD	10.00000		
8 7	0.18258	8.0	21.0	TEMP	85.00000		
10 9	0.16253	10.0	26.0	TEXTILE	60.00000		
12 11	0.15454	12.0	31.0	TIME	110.00001	TEMP	8
14 13	0.14736	14.0	36.0	RAIN	6.00000	TEXTILE	10
16 15	0.13759	16.0	41.0	FOOD	60.00000	TIME	1
17	0.13409	17.0	45.0	RAIN	2.00000	TIME	1
19 18	0.12900	19.0	50.0	TIME	90.00001	RAIN	4
21 20	0.12449	21.0	55.0	TIME	75.00001	TEXTILE	10
23 22	0.12103	23.0	60.0	TEXTILE	60.00000	TEMP	7
25 24	0.11958	25.0	65.0	FOOD	10.00000	RAIN	3
27 26	0.11817	26.0	69.0	TIME	226.00002		
29 28	0.11641	28.0	74.0	PAPER	20.00000	TIME	27
31 30	0.11678	30.0	79.0	FOOD	60.00000	TIME	26
33 32	0.11661	32.0	84.0	YARD	20.00000	TIME	26
35 34	0.11530	34.0	89.0	PAPER	20.00000		
37 36	0.11471	36.0	94.0	TIME	32.00001	FOOD	5
39 38	0.11329	37.0	98.0	TIME	76.00001		
41 40	0.11017	39.0	103.0	FOOD	60.00000	TIME	38
43 42	0.11071	41.0	108.0	PAPER	20.00000	TEMP	8
45 44	0.11108	42.0	112.0	TIME	49.00001		
47 46	0.11115	44.0	117.0	FOOD	20.00000	TIME	44
49 48	0.11209	46.0	122.0	FOOD	10.00000	TIME	39
51 50	0.11330	48.0	127.0	LEACHVOL	600.00000	TIME	2
52	0.11449	49.0	131.0	RAIN	2.00000	FOOD	5
54 53	0.11539	50.0	135.0	TIME	124.00001	FOOD	5
56 55	0.11770	52.0	140.0	TEMP	85.00000	TIME	38

Final Model (After Backward Stepwise Elimination)

Basis Fun	Coefficient	Variable	Parent	Knot
0	4.14639			
1	-0.02731	TIME		119.00000
2	0.03206	TIME		119.00000
3	-0.39557	RAIN		6.00000
4	-0.58945	RAIN		6.00000
5	0.01916	FOOD		10.00000
6	-0.16414	FOOD		10.00000
7	-0.08553	TEMP		85.00000
9	0.04920	TEXTILE		60.00000
10	-0.02530	TEXTILE		60.00000
12	-0.00070	TIME	TEMP	110.00001
14	0.01309	RAIN	TEXTILE	6.00000
15	-0.00099	FOOD	TIME	60.00000
17	0.00051	RAIN	TIME	2.00000
19	-0.00318	TIME	RAIN	90.00001
20	0.00004	TIME	TEXTILE	75.00001
22	-0.00347	TEXTILE	TEMP	60.00000
23	0.00082	TEXTILE	TEMP	60.00000
24	0.01848	FOOD	RAIN	10.00000
25	0.02778	FOOD	RAIN	10.00000
30	0.00108	FOOD	TIME	60.00000
31	0.00039	FOOD	TIME	60.00000
32	-0.00023	YARD	TIME	20.00000
33	-0.00092	YARD	TIME	20.00000
34	-0.00379	PAPER		20.00000
36	-0.00067	TIME	FOOD	32.00001
38	0.01982	TIME		76.00001
40	0.00035	FOOD	TIME	60.00000
42	0.00077	PAPER	TEMP	20.00000
43	0.00179	PAPER	TEMP	20.00000
46	0.00047	FOOD	TIME	20.00000
48	-0.00047	FOOD	TIME	10.00000
52	-0.00894	RAIN	FOOD	2.00000
53	0.00039	TIME	FOOD	124.00001
56	-0.00023	TEMP	TIME	85.00000

Piecewise Linear GCV = 0.10017, #efprms = 91.88455

ANOVA Decomposition on 34 Basis Functions

fun	std. dev.	-gcv	#bsfns	#efprms	variable
1	1.00428	0.38942	3	8.01923	TIME
2	1.11988	0.17534	2	5.34615	RAIN
3	1.22768	0.16696	2	5.34615	FOOD
4	0.61120	0.13728	1	2.67308	TEMP
5	1.05933	0.16459	2	5.34615	TEXTILE
6	0.10322	0.10464	1	2.67308	PAPER
7	0.27466	0.10974	2	5.34615	TIME TEMP
8	1.19765	0.15771	1	2.67308	TEXTILE RAIN
9	1.04307	0.14204	8	21.38461	TIME FOOD
10	0.26284	0.12166	2	5.34615	TIME RAIN
11	0.15852	0.10337	1	2.67308	TIME

					TEXTILE
12	0.63447	0.14004	2	5.34615	TEXTILE
					TEMP
13	0.84660	0.16006	3	8.01923	FOOD
					RAIN
14	0.48566	0.11250	2	5.34615	TIME
					YARD
15	0.23369	0.11675	2	5.34615	PAPER
					TEMP

Piecewise Cubic Fit on 34 Basis Functions, GCV = 0.10371

Relative Variable Importance
============================

Variable	Importance	-gcv
TIME	100.00000	0.82535
RAIN	54.68585	0.31704
FOOD	43.11766	0.23499
TEMP	41.32536	0.22402
TEXTILE	29.55535	0.16352
PAPER	16.47618	0.11986
YARD	13.03944	0.11250

MARS Regression: Training Data
==============================

N: 402.00 R-SQUARED: 0.92946

MEAN DEP VAR: 2.21128 ADJ R-SQUARED: 0.92292

UNCENTERED R-SQUARED = R-0 SQUARED: 0.98961

Parameter	Estimate	S.E.	T-Ratio	P-Value
Constant	4.14649	0.22447	18.47199	0.00000
Basis Function 1	-0.02731	0.00301	-9.06261	0.00000
Basis Function 2	0.03207	0.00152	21.05291	0.00000
Basis Function 3	-0.39559	0.02423	-16.32482	0.00000
Basis Function 4	-0.58948	0.05253	-11.22242	0.00000
Basis Function 5	0.01917	0.00286	6.70911	0.00000
Basis Function 6	-0.16415	0.01200	-13.67750	0.00000
Basis Function 7	-0.08553	0.00711	-12.02749	0.00000
Basis Function 9	0.04920	0.00398	12.35029	0.00000
Basis Function 10	-0.02530	0.00228	-11.10782	0.00000
Basis Function 12	-0.00070	0.00013	-5.21806	0.00000
Basis Function 14	0.01310	0.00088	14.86077	0.00000
Basis Function 15	-0.00099	0.00015	-6.68272	0.00000
Basis Function 17	0.00051	0.00006	8.30037	0.00000
Basis Function 19	-0.00318	0.00046	-6.97093	0.00000
Basis Function 20	0.00004	0.00001	4.27313	0.00002
Basis Function 22	-0.00347	0.00033	-10.44744	0.00000
Basis Function 23	0.00082	0.00014	6.00064	0.00000
Basis Function 24	0.01848	0.00122	15.20030	0.00000
Basis Function 25	0.02778	0.00256	10.86146	0.00000
Basis Function 30	0.00108	0.00018	6.17023	0.00000
Basis Function 31	0.00039	0.00005	8.56149	0.00000
Basis Function 32	-0.00023	0.00003	-6.84380	0.00000
Basis Function 33	-0.00092	0.00012	-7.61178	0.00000
Basis Function 34	-0.00379	0.00079	-4.79606	0.00000
Basis Function 36	-0.00067	0.00008	-8.29226	0.00000
Basis Function 38	0.01982	0.00276	7.18731	0.00000
Basis Function 40	0.00035	0.00010	3.46979	0.00058
Basis Function 42	0.00077	0.00010	7.55520	0.00000
Basis Function 43	0.00179	0.00026	6.81023	0.00000

```
 Basis Function 46      |      0.00047      0.00008      5.65835      0.00000
 Basis Function 48      |     -0.00047      0.00006     -8.05265      0.00000
 Basis Function 52      |     -0.00894      0.00065    -13.70947      0.00000
 Basis Function 53      |      0.00039      0.00005      7.19138      0.00000
 Basis Function 56      |     -0.00023      0.00003     -6.60511      0.00000
 -----------------------------------------------------------------------------
 F-STATISTIC =  142.21948                    S.E. OF REGRESSION =  0.25553
     P-VALUE =  0.00000               RESIDUAL SUM OF SQUARES =  23.96324
   [MDF,NDF] = [ 34, 367 ]          REGRESSION SUM OF SQUARES =  315.73115
 -----------------------------------------------------------------------------
```


Basis Functions
===============

```
 BF1 = max( 0, TIME - 119);
 BF2 = max( 0, 119 - TIME);
 BF3 = max( 0, RAIN - 6);
 BF4 = max( 0, 6 - RAIN);
 BF5 = max( 0, FOOD - 10);
 BF6 = max( 0, 10 - FOOD);
 BF7 = max( 0, TEMP - 85);
 BF8 = max( 0, 85 - TEMP);
 BF9 = max( 0, TEXTILE - 60);
 BF10 = max( 0, 60 - TEXTILE);
 BF12 = max( 0, 110 - TIME) * BF8;
 BF14 = max( 0, 6 - RAIN) * BF10;
 BF15 = max( 0, FOOD - 60) * BF1;
 BF17 = max( 0, RAIN - 2) * BF1;
 BF19 = max( 0, 90 - TIME) * BF4;
 BF20 = max( 0, TIME - 75) * BF10;
 BF22 = max( 0, TEXTILE - 60) * BF7;
 BF23 = max( 0, 60 - TEXTILE) * BF7;
 BF24 = max( 0, FOOD - 10) * BF3;
 BF25 = max( 0, 10 - FOOD) * BF3;
 BF26 = max( 0, TIME - 226);
 BF30 = max( 0, FOOD - 60) * BF26;
 BF31 = max( 0, 60 - FOOD) * BF26;
 BF32 = max( 0, YARD - 20) * BF26;
 BF33 = max( 0, 20 - YARD) * BF26;
 BF34 = max( 0, PAPER - 20);
 BF36 = max( 0, TIME - 32) * BF5;
 BF38 = max( 0, TIME - 76);
 BF39 = max( 0, 76 - TIME);
 BF40 = max( 0, FOOD - 60) * BF38;
 BF42 = max( 0, PAPER - 20) * BF8;
 BF43 = max( 0, 20 - PAPER) * BF8;
 BF44 = max( 0, TIME - 49);
 BF46 = max( 0, FOOD - 20) * BF44;
 BF48 = max( 0, FOOD - 10) * BF39;
 BF52 = max( 0, RAIN - 2) * BF5;
 BF53 = max( 0, TIME - 124) * BF5;
 BF56 = max( 0, 85 - TEMP) * BF38;

 Y = 4.14639 - 0.0273126 * BF1 + 0.0320644 * BF2 - 0.395571 * BF3
             - 0.589446 * BF4 + 0.0191643 * BF5 - 0.164141 * BF6
             - 0.0855275 * BF7 + 0.0492011 * BF9 - 0.0252999 * BF10
             - 0.000703961 * BF12 + 0.0130944 * BF14 - 0.000986625 * BF15
             + 0.000506437 * BF17 - 0.00317975 * BF19 + 3.66086e-005 * BF20
             - 0.00346841 * BF22 + 0.000822644 * BF23 + 0.018479 * BF24
             + 0.0277776 * BF25 + 0.00108455 * BF30 + 0.00038589 * BF31
             - 0.000231243 * BF32 - 0.000920115 * BF33 - 0.00378562 * BF34
             - 0.000673196 * BF36 + 0.0198213 * BF38 + 0.000352621 * BF40
             + 0.000771462 * BF42 + 0.0017938 * BF43 + 0.000469123 * BF46
             - 0.000466733 * BF48 - 0.00893983 * BF52 + 0.000386207 * BF53
             - 0.000230089 * BF56;

 MODEL LOGBOD = BF1 BF2 BF3 BF4 BF5 BF6 BF7 BF9 BF10 BF12 BF14 BF15
```

```
               BF17 BF19 BF20 BF22 BF23 BF24 BF25 BF30 BF31 BF32
               BF33 BF34 BF36 BF38 BF40 BF42 BF43 BF46 BF48 BF52
               BF53 BF56;

Grove file created: C:\Users\Hetal\AppData\Local\Temp\s6l451: 73 kb

Grove file created containing:
     1 Mars model

                Examining and Preparing Data: 00:00:00
Forward Stepwise Knot Placement-- CV:      1: 00:00:00
                  Back Stepping-- CV:      1: 00:00:00
Forward Stepwise Knot Placement-- CV:      2: 00:00:00
                  Back Stepping-- CV:      2: 00:00:00
Forward Stepwise Knot Placement-- CV:      3: 00:00:00
                  Back Stepping-- CV:      3: 00:00:00
Forward Stepwise Knot Placement-- CV:      4: 00:00:00
                  Back Stepping-- CV:      4: 00:00:00
Forward Stepwise Knot Placement-- CV:      5: 00:00:00
                  Back Stepping-- CV:      5: 00:00:00
Forward Stepwise Knot Placement-- CV:      6: 00:00:00
                  Back Stepping-- CV:      6: 00:00:00
Forward Stepwise Knot Placement-- CV:      7: 00:00:00
                  Back Stepping-- CV:      7: 00:00:00
Forward Stepwise Knot Placement-- CV:      8: 00:00:00
                  Back Stepping-- CV:      8: 00:00:00
Forward Stepwise Knot Placement-- CV:      9: 00:00:00
                  Back Stepping-- CV:      9: 00:00:00
Forward Stepwise Knot Placement-- CV:     10: 00:00:00
                  Back Stepping-- CV:     10: 00:00:00
             Forward Stepwise Knot Placement: 00:00:00
                              Back Stepping: 00:00:01
                              Writing Grove: 00:00:00
```

This launch supports up to 32768 variables.

Random seeds: 13579 12345 131

VARIABLES IN RECT FILE ARE:

LOGCOD	TIME	LEACHVOL	FOOD	TEXTILE
PAPER	YARD	RAIN	TEMP	

C:\Arpita_PhD\PhD Landfill Project\leachate Parameters Analysis\COD Data\MARS COD\Log COD_Data.xlsx: 433 records.

Model reset.
Model reset: LOGCOD

Salford Predictive Modeler: MARS(R) version 6.6.0.091

Records Read: 432
Records Kept in Learning sample: 432

CV Results
==========

10-fold cross validation used to find the optimal model.

Optimal Model Nr = 33, DF = 3.00000, Estimated PSE = 0.03269

Forward Stepwise Knot Placement
===============================

BasFn(s)	GCV	IndBsFns	EfPrms	Variable	Knot	Parent	BsF
0	0.48161	0.0	1.0				
2 1	0.25276	2.0	6.0	TIME	96.00000		
4 3	0.12806	4.0	11.0	RAIN	6.00000		
6 5	0.08597	6.0	16.0	PAPER	60.00000		
7	0.07344	7.0	20.0	TEMP	70.00000		
9 8	0.06532	9.0	25.0	FOOD	10.00000		
11 10	0.05910	11.0	30.0	TIME	179.00000	FOOD	8
13 12	0.05774	13.0	35.0	RAIN	6.00000	FOOD	8
15 14	0.05698	15.0	40.0	TIME	53.99999	FOOD	9
17 16	0.05625	17.0	45.0	TEMP	85.00000	FOOD	8
19 18	0.05185	19.0	50.0	TIME	55.99999	RAIN	3
21 20	0.04949	21.0	55.0	RAIN	6.00000	TIME	2
23 22	0.04583	23.0	60.0	TIME	172.00000	RAIN	4
25 24	0.04322	25.0	65.0	YARD	60.00000	RAIN	3
27 26	0.04170	27.0	70.0	TIME	141.00000	TEMP	7
29 28	0.04030	29.0	75.0	TEXTILE	30.00000	TIME	1
31 30	0.03849	31.0	80.0	PAPER	10.00000	RAIN	3
33 32	0.03757	33.0	85.0	FOOD	10.00000	TIME	2
35 34	0.03763	35.0	90.0	YARD	60.00000	PAPER	6
37 36	0.03695	37.0	95.0	TIME	47.99999	PAPER	6
39 38	0.03712	38.0	99.0	TIME	225.99998	PAPER	6
41 40	0.03737	39.0	103.0	TIME	74.99999	TEMP	7
43 42	0.03791	40.0	107.0	TIME	235.99998	FOOD	8
45 44	0.03806	41.0	111.0	TIME	210.00000	RAIN	3
46	0.03868	42.0	115.0	TEXTILE	0.00000	TIME	2

Final Model (After Backward Stepwise Elimination)
===

```
Basis Fun  Coefficient Variable     Parent         Knot
-------------------------------------------------------------------------
       0      2.72530
       1     -0.00233 TIME                          96.00000
       2      0.02028 TIME                          96.00000
       3     -0.13976 RAIN                           6.00000
       4      0.14532 RAIN                           6.00000
       6      0.01888 PAPER                         60.00000
       7     -0.02399 TEMP                          70.00000
       8     -0.00639 FOOD                          10.00000
       9     -0.01538 FOOD                          10.00000
      11      0.00008 TIME         FOOD            179.00000
      12      0.00125 RAIN         FOOD              6.00000
      13      0.00193 RAIN         FOOD              6.00000
      14      0.00030 TIME         FOOD             53.99999
      18      0.00028 TIME         RAIN             55.99999
      19      0.00274 TIME         RAIN             55.99999
      20     -0.00109 RAIN         TIME              6.00000
      21     -0.00404 RAIN         TIME              6.00000
      23      0.00101 TIME         RAIN            172.00000
      24      0.00204 YARD         RAIN             60.00000
      25      0.00254 YARD         RAIN             60.00000
      27      0.00011 TIME         TEMP            141.00000
      28     -0.00006 TEXTILE      TIME             30.00000
      29     -0.00012 TEXTILE      TIME             30.00000
      30     -0.00163 PAPER        RAIN             10.00000
      31     -0.00745 PAPER        RAIN             10.00000
      32     -0.00008 FOOD         TIME             10.00000
      34     -0.00020 YARD         PAPER            60.00000
      35     -0.00016 YARD         PAPER            60.00000
      36     -0.00001 TIME         PAPER            47.99999
      37     -0.00018 TIME         PAPER            47.99999
      38      0.00008 TIME         PAPER           225.99998
      40      0.00009 TIME         TEMP             74.99999
      42     -0.00008 TIME         FOOD            235.99998
      44     -0.00055 TIME         RAIN            210.00000

Piecewise Linear GCV = 0.03514, #efprms = 90.57142
```



```
ANOVA Decomposition on 33 Basis Functions
=========================================

 fun    std. dev.         -gcv #bsfns  #efprms variable
-------------------------------------------------------
   1      0.56340      0.08105   2     5.42857 TIME
   2      0.58260      0.06826   2     5.42857 RAIN
   3      0.46631      0.05374   1     2.71429 PAPER
   4      0.27598      0.04821   1     2.71429 TEMP
   5      0.14156      0.03654   2     5.42857 FOOD
   6      0.24708      0.05049   4    10.85714 TIME
                                               FOOD
   7      0.20251      0.03879   2     5.42857 FOOD
                                               RAIN
   8      0.12827      0.04663   6    16.28571 TIME
                                               RAIN
   9      0.38863      0.04186   2     5.42857 YARD
                                               RAIN
  10      0.13607      0.03727   2     5.42857 TIME
                                               TEMP
  11      0.26487      0.04120   2     5.42857 TIME
                                               TEXTILE
  12      0.19681      0.03723   2     5.42857 PAPER
                                               RAIN
  13      0.23283      0.04120   2     5.42857 PAPER
                                               YARD
  14      0.09463      0.03699   3     8.14286 TIME
```

PAPER

Piecewise Cubic Fit on 33 Basis Functions, GCV = 0.03978

Relative Variable Importance
============================

Variable	Importance	-gcv
TIME	100.00000	0.39962
RAIN	67.15488	0.19951
PAPER	32.06890	0.07262
TEMP	26.31967	0.06039
FOOD	21.06512	0.05131
YARD	13.65524	0.04193
TEXTILE	12.89321	0.04120

MARS Regression: Training Data
==============================

N: 432.00 R-SQUARED: 0.95421
MEAN DEP VAR: 2.94144 ADJ R-SQUARED: 0.95042
UNCENTERED R-SQUARED = R-0 SQUARED: 0.99760

Parameter	Estimate	S.E.	T-Ratio	P-Value
Constant	2.72530	0.05512	49.43904	0.00000
Basis Function 1	-0.00233	0.00042	-5.53967	0.00000
Basis Function 2	0.02028	0.00096	21.16230	0.00000
Basis Function 3	-0.13976	0.01371	-10.19515	0.00000
Basis Function 4	0.14532	0.00859	16.91451	0.00000
Basis Function 6	0.01888	0.00127	14.84821	0.00000
Basis Function 7	-0.02399	0.00192	-12.52012	0.00000
Basis Function 8	-0.00639	0.00122	-5.23956	0.00000
Basis Function 9	-0.01538	0.00502	-3.06545	0.00232
Basis Function 11	0.00008	0.00001	5.97371	0.00000
Basis Function 12	0.00125	0.00028	4.47014	0.00001
Basis Function 13	0.00193	0.00026	7.44144	0.00000
Basis Function 14	0.00030	0.00003	8.96098	0.00000
Basis Function 18	0.00028	0.00009	3.03590	0.00256
Basis Function 19	0.00274	0.00053	5.16852	0.00000
Basis Function 20	-0.00109	0.00031	-3.46107	0.00060
Basis Function 21	-0.00404	0.00046	-8.84786	0.00000
Basis Function 23	0.00101	0.00020	5.14192	0.00000
Basis Function 24	0.00204	0.00055	3.70981	0.00024
Basis Function 25	0.00254	0.00028	9.09182	0.00000
Basis Function 27	0.00011	0.00003	4.20318	0.00003
Basis Function 28	-0.00006	0.00001	-7.72818	0.00000
Basis Function 29	-0.00012	0.00001	-8.67956	0.00000
Basis Function 30	-0.00163	0.00032	-5.10537	0.00000
Basis Function 31	-0.00745	0.00144	-5.16804	0.00000
Basis Function 32	-0.00008	0.00003	-3.26061	0.00121
Basis Function 34	-0.00020	0.00003	-6.82156	0.00000
Basis Function 35	-0.00016	0.00002	-9.14063	0.00000
Basis Function 36	-0.00001	0.00001	-2.18657	0.02936
Basis Function 37	-0.00018	0.00004	-4.34373	0.00002
Basis Function 38	0.00008	0.00002	4.87052	0.00000
Basis Function 40	0.00009	0.00001	6.13622	0.00000
Basis Function 42	-0.00008	0.00002	-3.35529	0.00087
Basis Function 44	-0.00055	0.00017	-3.26127	0.00120

F-STATISTIC = 251.35579 S.E. OF REGRESSION = 0.15435
P-VALUE = 0.00000 RESIDUAL SUM OF SQUARES = 9.48189
[MDF,NDF] = [33, 398] REGRESSION SUM OF SQUARES = 197.61257

```
 -----------------------------------------------------------------------------

<a name="6"></a>
 Basis Functions
 ===============

 BF1 = max( 0, TIME - 96);
 BF2 = max( 0, 96 - TIME);
 BF3 = max( 0, RAIN - 6);
 BF4 = max( 0, 6 - RAIN);
 BF6 = max( 0, 60 - PAPER);
 BF7 = max( 0, TEMP - 70);
 BF8 = max( 0, FOOD - 10);
 BF9 = max( 0, 10 - FOOD);
 BF11 = max( 0, 179 - TIME) * BF8;
 BF12 = max( 0, RAIN - 6) * BF8;
 BF13 = max( 0, 6 - RAIN) * BF8;
 BF14 = max( 0, TIME - 54) * BF9;
 BF18 = max( 0, TIME - 56) * BF3;
 BF19 = max( 0, 56 - TIME) * BF3;
 BF20 = max( 0, RAIN - 6) * BF2;
 BF21 = max( 0, 6 - RAIN) * BF2;
 BF23 = max( 0, 172 - TIME) * BF4;
 BF24 = max( 0, YARD - 60) * BF3;
 BF25 = max( 0, 60 - YARD) * BF3;
 BF27 = max( 0, 141 - TIME) * BF7;
 BF28 = max( 0, TEXTILE - 30) * BF1;
 BF29 = max( 0, 30 - TEXTILE) * BF1;
 BF30 = max( 0, PAPER - 10) * BF3;
 BF31 = max( 0, 10 - PAPER) * BF3;
 BF32 = max( 0, FOOD - 10) * BF2;
 BF34 = max( 0, YARD - 60) * BF6;
 BF35 = max( 0, 60 - YARD) * BF6;
 BF36 = max( 0, TIME - 48) * BF6;
 BF37 = max( 0, 48 - TIME) * BF6;
 BF38 = max( 0, TIME - 226) * BF6;
 BF40 = max( 0, TIME - 75) * BF7;
 BF42 = max( 0, TIME - 236) * BF8;
 BF44 = max( 0, TIME - 210) * BF3;

 Y = 2.7253 - 0.00233253 * BF1 + 0.0202826 * BF2 - 0.139758 * BF3
           + 0.145319 * BF4 + 0.0188766 * BF6 - 0.0239861 * BF7
           - 0.00638596 * BF8 - 0.0153806 * BF9 + 7.59442e-005 * BF11
           + 0.00125096 * BF12 + 0.00193323 * BF13 + 0.000303856 * BF14
           + 0.000276475 * BF18 + 0.00273979 * BF19 - 0.00108569 * BF20
           - 0.00404448 * BF21 + 0.00100837 * BF23 + 0.00203763 * BF24
           + 0.00253754 * BF25 + 0.000109849 * BF27 - 6.48613e-005 * BF28
           - 0.000123034 * BF29 - 0.00162816 * BF30 - 0.00744808 * BF31
           - 8.1569e-005 * BF32 - 0.000200359 * BF34 - 0.000158906 * BF35
           - 1.43964e-005 * BF36 - 0.000181155 * BF37 + 8.31104e-005 * BF38
           + 9.03464e-005 * BF40 - 8.06951e-005 * BF42 - 0.000554588 * BF44;

 MODEL LOGCOD = BF1 BF2 BF3 BF4 BF6 BF7 BF8 BF9 BF11 BF12 BF13 BF14
               BF18 BF19 BF20 BF21 BF23 BF24 BF25 BF27 BF28 BF29
               BF30 BF31 BF32 BF34 BF35 BF36 BF37 BF38 BF40 BF42
               BF44;

 Grove file created: C:\Users\Hetal\AppData\Local\Temp\s8r451: 70 kb

 Grove file created containing:
      1 Mars model

                Examining and Preparing Data: 00:00:00
 Forward Stepwise Knot Placement-- CV:      1: 00:00:01
                  Back Stepping-- CV:      1: 00:00:00
 Forward Stepwise Knot Placement-- CV:      2: 00:00:00
                  Back Stepping-- CV:      2: 00:00:00
 Forward Stepwise Knot Placement-- CV:      3: 00:00:00
```

```
                  Back Stepping-- CV:      3: 00:00:00
Forward Stepwise Knot Placement-- CV:      4: 00:00:00
                  Back Stepping-- CV:      4: 00:00:00
Forward Stepwise Knot Placement-- CV:      5: 00:00:00
                  Back Stepping-- CV:      5: 00:00:00
Forward Stepwise Knot Placement-- CV:      6: 00:00:00
                  Back Stepping-- CV:      6: 00:00:00
Forward Stepwise Knot Placement-- CV:      7: 00:00:00
                  Back Stepping-- CV:      7: 00:00:00
Forward Stepwise Knot Placement-- CV:      8: 00:00:00
                  Back Stepping-- CV:      8: 00:00:00
Forward Stepwise Knot Placement-- CV:      9: 00:00:00
                  Back Stepping-- CV:      9: 00:00:00
Forward Stepwise Knot Placement-- CV:     10: 00:00:00
                  Back Stepping-- CV:     10: 00:00:00
             Forward Stepwise Knot Placement: 00:00:00
                              Back Stepping: 00:00:00
                              Writing Grove: 00:00:00
```

This launch supports up to 32768 variables.

Random seeds: 13579 12345 131

VARIABLES IN RECT FILE ARE:

LOGCL	TIME	LEACHVOL	FOOD	TEXTILE
PAPER	YARD	RAIN	TEMP	

C:\Arpita_PhD\PhD Landfill Project\leachate Parameters Analysis\Cl Data\MARS Analysis_Log Cl\Log Cl data.xlsx: 431 records.

Model reset.
Model reset: LOGCL

Salford Predictive Modeler: MARS(R) version 6.6.0.091

Records Read: 430
Records Kept in Learning sample: 430

CV Results
==========

10-fold cross validation used to find the optimal model.

Optimal Model Nr = 18, DF = 3.00000, Estimated PSE = 0.06466

Forward Stepwise Knot Placement
===============================

BasFn(s)	GCV	IndBsFns	EfPrms	Variable	Knot	Parent	BsF
0	0.39636	0.0	1.0				
2 1	0.20856	2.0	6.0	TIME	95.99999		
4 3	0.11617	4.0	11.0	RAIN	6.00000		
6 5	0.10337	6.0	16.0	PAPER	60.00000	TIME	2
8 7	0.09273	8.0	21.0	YARD	60.00000	RAIN	4
9	0.08666	9.0	25.0	FOOD	-0.00000	RAIN	4
11 10	0.08101	11.0	30.0	TEMP	85.00000	RAIN	3
13 12	0.07815	13.0	35.0	TIME	77.99999	RAIN	4
15 14	0.07464	14.0	39.0	TIME	222.99998	RAIN	4
17 16	0.07447	16.0	44.0	TIME	37.99999	RAIN	3
19 18	0.07286	18.0	49.0	LEACHVOL	555.00000	TIME	1
21 20	0.07169	20.0	54.0	FOOD	60.00000	RAIN	3
23 22	0.07130	22.0	59.0	YARD	20.00000	TIME	1
25 24	0.07140	24.0	64.0	RAIN	6.00000	TIME	1
27 26	0.07224	26.0	69.0	TEXTILE	20.00000	TIME	1
29 28	0.07316	27.0	73.0	TIME	180.00000	RAIN	3
30	0.07391	28.0	77.0	TEMP	70.00000		
32 31	0.07223	30.0	82.0	FOOD	10.00000	TEMP	30
34 33	0.07307	32.0	87.0	YARD	20.00000	RAIN	3

Final Model (After Backward Stepwise Elimination)
===

Basis Fun	Coefficient	Variable	Parent	Knot
0	1.76611			
1	-0.00457	TIME		95.99999
2	0.01056	TIME		95.99999
3	-0.09037	RAIN		6.00000
4	0.29760	RAIN		6.00000
6	0.00016	PAPER	TIME	60.00000

8	-0.00228	YARD	RAIN	60.00000
9	0.00112	FOOD	RAIN	-0.00000
11	0.00275	TEMP	RAIN	85.00000
13	-0.00353	TIME	RAIN	77.99999
14	0.00142	TIME	RAIN	222.99998
16	0.00042	TIME	RAIN	37.99999
18	0.00000	LEACHVOL	TIME	555.00000
20	0.00116	FOOD	RAIN	60.00000
22	0.00003	YARD	TIME	20.00000
23	0.00005	YARD	TIME	20.00000
25	-0.00107	RAIN	TIME	6.00000
28	-0.00053	TIME	RAIN	180.00000
32	-0.00062	FOOD	TEMP	10.00000

Piecewise Linear GCV = 0.06546, #efprms = 49.37500

ANOVA Decomposition on 18 Basis Functions
===

fun	std. dev.	-gcv	#bsfns	#efprms	variable
1	0.50237	0.09918	2	5.37500	TIME
2	0.70275	0.12639	2	5.37500	RAIN
3	0.16975	0.07538	1	2.68750	TIME PAPER
4	0.20873	0.07491	1	2.68750	YARD RAIN
5	0.09962	0.07298	2	5.37500	FOOD RAIN
6	0.07730	0.06936	1	2.68750	RAIN TEMP
7	0.24689	0.07460	5	13.43750	TIME RAIN
8	0.04672	0.06678	1	2.68750	TIME LEACHVOL
9	0.07812	0.06567	2	5.37500	TIME YARD
10	0.06804	0.06821	1	2.68750	FOOD TEMP

Piecewise Cubic Fit on 18 Basis Functions, GCV = 0.06573

Relative Variable Importance
============================

Variable	Importance	-gcv
TIME	100.00000	0.35522
RAIN	65.14143	0.18842
YARD	24.40121	0.08271
FOOD	21.93067	0.07940
PAPER	18.50021	0.07538
TEMP	16.54688	0.07339
LEACHVOL	6.74909	0.06678

MARS Regression: Training Data
==============================

N: 430.00 R-SQUARED: 0.86999
MEAN DEP VAR: 1.74558 ADJ R-SQUARED: 0.86430
UNCENTERED R-SQUARED = R-0 SQUARED: 0.98510

Parameter		Estimate	S.E.	T-Ratio	P-Value
Constant	|	1.76611	0.03453	51.14001	0.00000
Basis Function 1	|	-0.00457	0.00051	-8.98947	0.00000
Basis Function 2	|	0.01056	0.00101	10.46597	0.00000
Basis Function 3	|	-0.09037	0.00854	-10.58259	0.00000
Basis Function 4	|	0.29760	0.01843	16.14615	0.00000
Basis Function 6	|	0.00016	0.00002	8.30500	0.00000
Basis Function 8	|	-0.00228	0.00028	-8.12331	0.00000
Basis Function 9	|	0.00112	0.00018	6.36901	0.00000
Basis Function 11	|	0.00275	0.00050	5.53841	0.00000
Basis Function 13	|	-0.00353	0.00056	-6.27989	0.00000
Basis Function 14	|	0.00142	0.00025	5.70530	0.00000
Basis Function 16	|	0.00042	0.00009	4.84952	0.00000
Basis Function 18	|	0.00000	0.00000	3.77211	0.00019
Basis Function 20	|	0.00116	0.00025	4.57947	0.00001
Basis Function 22	|	0.00003	0.00001	3.61254	0.00034
Basis Function 23	|	0.00005	0.00002	2.15459	0.03177
Basis Function 25	|	-0.00107	0.00016	-6.58274	0.00000
Basis Function 28	|	-0.00053	0.00016	-3.24406	0.00127
Basis Function 32	|	-0.00062	0.00013	-4.83095	0.00000

```
F-STATISTIC =  152.79546                  S.E. OF REGRESSION =  0.23165
    P-VALUE =  0.00000              RESIDUAL SUM OF SQUARES =  22.05509
  [MDF,NDF] = [ 18, 411 ]         REGRESSION SUM OF SQUARES =  147.58761
```



```
Basis Functions
===============

BF1 = max( 0, TIME - 96);
BF2 = max( 0, 96 - TIME);
BF3 = max( 0, RAIN - 6);
BF4 = max( 0, 6 - RAIN);
BF6 = max( 0, 60 - PAPER) * BF2;
BF8 = max( 0, 60 - YARD) * BF4;
BF9 = max( 0, FOOD + 1.33476e-006) * BF4;
BF11 = max( 0, 85 - TEMP) * BF3;
BF13 = max( 0, 78 - TIME) * BF4;
BF14 = max( 0, TIME - 223) * BF4;
BF16 = max( 0, TIME - 38) * BF3;
BF18 = max( 0, LEACHVOL - 555) * BF1;
BF20 = max( 0, FOOD - 60) * BF3;
BF22 = max( 0, YARD - 20) * BF1;
BF23 = max( 0, 20 - YARD) * BF1;
BF25 = max( 0, 6 - RAIN) * BF1;
BF28 = max( 0, TIME - 180) * BF3;
BF30 = max( 0, TEMP - 70);
BF32 = max( 0, 10 - FOOD) * BF30;

Y = 1.76611 - 0.00456675 * BF1 + 0.0105642 * BF2 - 0.0903672 * BF3
            + 0.297602 * BF4 + 0.000155298 * BF6 - 0.00227787 * BF8
            + 0.00111781 * BF9 + 0.00275275 * BF11 - 0.00352966 * BF13
            + 0.00142161 * BF14 + 0.000416858 * BF16 + 2.33094e-006 * BF18
            + 0.00115751 * BF20 + 2.65993e-005 * BF22 + 4.59232e-005 * BF23
            - 0.00107268 * BF25 - 0.000529058 * BF28 - 0.000623637 * BF32;

MODEL LOGCL = BF1 BF2 BF3 BF4 BF6 BF8 BF9 BF11 BF13 BF14 BF16 BF18
              BF20 BF22 BF23 BF25 BF28 BF32;

Grove file created: C:\Users\Hetal\AppData\Local\Temp\s6ic51: 58 kb

Grove file created containing:
     1 Mars model

                Examining and Preparing Data: 00:00:00
Forward Stepwise Knot Placement-- CV:      1: 00:00:00
```

```
                 Back Stepping-- CV:      1: 00:00:00
Forward Stepwise Knot Placement-- CV:      2: 00:00:00
                 Back Stepping-- CV:      2: 00:00:00
Forward Stepwise Knot Placement-- CV:      3: 00:00:00
                 Back Stepping-- CV:      3: 00:00:00
Forward Stepwise Knot Placement-- CV:      4: 00:00:00
                 Back Stepping-- CV:      4: 00:00:00
Forward Stepwise Knot Placement-- CV:      5: 00:00:00
                 Back Stepping-- CV:      5: 00:00:00
Forward Stepwise Knot Placement-- CV:      6: 00:00:00
                 Back Stepping-- CV:      6: 00:00:00
Forward Stepwise Knot Placement-- CV:      7: 00:00:00
                 Back Stepping-- CV:      7: 00:00:00
Forward Stepwise Knot Placement-- CV:      8: 00:00:00
                 Back Stepping-- CV:      8: 00:00:00
Forward Stepwise Knot Placement-- CV:      9: 00:00:00
                 Back Stepping-- CV:      9: 00:00:00
Forward Stepwise Knot Placement-- CV:     10: 00:00:00
                 Back Stepping-- CV:     10: 00:00:00
            Forward Stepwise Knot Placement: 00:00:00
                              Back Stepping: 00:00:00
                             Writing Grove: 00:00:00
```

```
This launch supports up to  32768 variables.


 Random seeds:            13579           12345            131
 VARIABLES IN RECT FILE ARE:
  LOG10NH3N            TIME        LEACHVOL            FOOD         TEXTILE
      PAPER            YARD            RAIN            TEMP

 C:\Arpita_PhD\PhD Landfill Project\leachate Parameters Analysis\NH3-N Data\MARS_NH3-
N\Log NH3N data_wo inorg.xlsx: 416 records.

 Model reset.
 Model reset: LOG10NH3N

 Salford Predictive Modeler: MARS(R) version 6.6.0.091

 Records Read: 415
 Records Kept in Learning sample: 415
<a name="0"></a>


 CV Results
 ==========

 10-fold cross validation used to find the optimal model.

 Optimal Model Nr = 26, DF = 3.00000, Estimated PSE = 0.19998
<a name="1"></a>


 Forward Stepwise Knot Placement
 ===============================

 BasFn(s)      GCV  IndBsFns EfPrms Variable            Knot       Parent  BsF
 ------------------------------------------------------------------------------
     0        0.64934    0.0    1.0
   2   1      0.49191    2.0    6.0 YARD            60.00000
   4   3      0.39767    4.0   11.0 FOOD            60.00000
     5        0.33493    5.0   15.0 RAIN             2.00000
   7   6      0.26191    7.0   20.0 TIME           104.00001
   9   8      0.23385    9.0   25.0 FOOD            60.00000 TIME            7
  11  10      0.23190   11.0   30.0 LEACHVOL       219.99998 TIME            7
    12        0.22768   12.0   34.0 TEMP            70.00000
    13        0.22031   13.0   38.0 FOOD            -0.00000 TEMP           12
  15  14      0.21537   15.0   43.0 TEMP            85.00000 TIME            7
    16        0.21429   16.0   47.0 LEACHVOL        49.99999 RAIN            5
  18  17      0.21483   18.0   52.0 YARD            20.00000 TIME            6
  20  19      0.21685   20.0   57.0 TEXTILE         60.00000 TIME            6
  22  21      0.21960   22.0   62.0 LEACHVOL       310.00000 YARD            2
  24  23      0.22023   24.0   67.0 TEXTILE         30.00000
    25        0.22281   25.0   71.0 YARD            -0.00000 TEMP           12
    26        0.22549   26.0   75.0 LEACHVOL        49.99999 FOOD            3
<a name="2"></a>


 Final Model (After Backward Stepwise Elimination)
 ================================================

 Basis Fun  Coefficient Variable     Parent         Knot
 -----------------------------------------------------------------------
        0      2.15084
        1      0.01189 YARD                           60.00000
        2     -0.01125 YARD                           60.00000
        3      0.04522 FOOD                           60.00000
```

4	-0.00827	FOOD		60.00000
5	-0.07244	RAIN		2.00000
6	0.00134	TIME		104.00001
7	0.02711	TIME		104.00001
8	-0.00037	FOOD	TIME	60.00000
9	-0.00034	FOOD	TIME	60.00000
10	-0.00001	LEACHVOL	TIME	219.99998
11	-0.00011	LEACHVOL	TIME	219.99998
12	-0.00699	TEMP		70.00000
13	-0.00031	FOOD	TEMP	-0.00000
14	0.00041	TEMP	TIME	85.00000
15	0.00029	TEMP	TIME	85.00000
16	0.00004	LEACHVOL	RAIN	49.99999
17	-0.00007	YARD	TIME	20.00000
18	-0.00019	YARD	TIME	20.00000
19	0.00002	TEXTILE	TIME	60.00000
20	0.00005	TEXTILE	TIME	60.00000
21	0.00000	LEACHVOL	YARD	310.00000
22	-0.00003	LEACHVOL	YARD	310.00000
23	0.00871	TEXTILE		30.00000
24	0.00838	TEXTILE		30.00000
25	0.00014	YARD	TEMP	-0.00000
26	-0.00002	LEACHVOL	FOOD	49.99999

Piecewise Linear GCV = 0.22549, #efprms = 75.00000

ANOVA Decomposition on 26 Basis Functions
===

fun	std. dev.	-gcv	#bsfns	#efprms	variable
1	0.37781	0.25410	2	5.69231	YARD
2	0.60359	0.27949	2	5.69231	FOOD
3	0.29607	0.24291	1	2.84615	RAIN
4	0.65333	0.31229	2	5.69231	TIME
5	0.08005	0.22421	1	2.84615	TEMP
6	0.16063	0.22557	2	5.69231	TEXTILE
7	0.41835	0.26037	2	5.69231	TIME FOOD
8	0.15016	0.22873	2	5.69231	TIME LEACHVOL
9	0.23936	0.23087	1	2.84615	FOOD TEMP
10	0.10819	0.22706	2	5.69231	TIME TEMP
11	0.11181	0.22342	1	2.84615	LEACHVOL RAIN
12	0.25211	0.23062	2	5.69231	TIME YARD
13	0.17486	0.22334	2	5.69231	TIME TEXTILE
14	0.06734	0.22240	2	5.69231	LEACHVOL YARD
15	0.08648	0.22439	1	2.84615	YARD TEMP
16	0.10783	0.22431	1	2.84615	LEACHVOL FOOD

Piecewise Cubic Fit on 26 Basis Functions, GCV = 0.23089

Relative Variable Importance
============================

Variable	Importance	-gcv

```
-------------------------------------------------------------
FOOD                                       100.00000      0.39646
YARD                                        98.33926      0.39082
TIME                                        87.32211      0.35585
RAIN                                        44.70255      0.25965
TEMP                                        25.59730      0.23669
```


MARS Regression: Training Data

```
==============================

N: 415.00                                 R-SQUARED: 0.76579
MEAN DEP VAR: 1.41195                 ADJ R-SQUARED: 0.75009
                 UNCENTERED R-SQUARED = R-0 SQUARED: 0.94267
```

Parameter	Estimate	S.E.	T-Ratio	P-Value
Constant	2.15084	0.14738	14.59366	0.00000
Basis Function 1	0.01189	0.00307	3.86674	0.00013
Basis Function 2	-0.01125	0.00242	-4.64356	0.00000
Basis Function 3	0.04522	0.00632	7.16001	0.00000
Basis Function 4	-0.00827	0.00282	-2.93633	0.00352
Basis Function 5	-0.07244	0.01191	-6.08321	0.00000
Basis Function 6	0.00134	0.00105	1.26646	0.20611
Basis Function 7	0.02711	0.00215	12.60684	0.00000
Basis Function 8	-0.00037	0.00008	-4.63676	0.00000
Basis Function 9	-0.00034	0.00004	-8.66763	0.00000
Basis Function 10	-0.00001	0.00000	-4.27460	0.00002
Basis Function 11	-0.00011	0.00006	-1.82798	0.06832
Basis Function 12	-0.00699	0.00338	-2.07009	0.03911
Basis Function 13	-0.00031	0.00008	-3.99245	0.00008
Basis Function 14	0.00041	0.00011	3.74189	0.00021
Basis Function 15	0.00029	0.00018	1.62051	0.10593
Basis Function 16	0.00004	0.00002	1.70250	0.08946
Basis Function 17	-0.00007	0.00002	-4.20680	0.00003
Basis Function 18	-0.00019	0.00004	-4.21298	0.00003
Basis Function 19	0.00002	0.00003	0.59518	0.55207
Basis Function 20	0.00005	0.00002	2.87756	0.00423
Basis Function 21	0.00000	0.00000	0.20612	0.83680
Basis Function 22	-0.00003	0.00001	-2.65082	0.00836
Basis Function 23	0.00871	0.00265	3.28405	0.00112
Basis Function 24	0.00838	0.00494	1.69774	0.09036
Basis Function 25	0.00014	0.00006	2.14488	0.03258
Basis Function 26	-0.00002	0.00001	-2.11329	0.03521

```
---------------------------------------------------------------------------
F-STATISTIC =  48.79260                     S.E. OF REGRESSION =  0.40235
    P-VALUE =  0.00000                RESIDUAL SUM OF SQUARES =  62.81100
  [MDF,NDF] = [ 26, 388 ]           REGRESSION SUM OF SQUARES =  205.36728
---------------------------------------------------------------------------
```


Basis Functions

```
===============

BF1 = max( 0, YARD - 60);
BF2 = max( 0, 60 - YARD);
BF3 = max( 0, FOOD - 60);
BF4 = max( 0, 60 - FOOD);
BF5 = max( 0, RAIN - 2);
BF6 = max( 0, TIME - 104);
BF7 = max( 0, 104 - TIME);
BF8 = max( 0, FOOD - 60) * BF7;
BF9 = max( 0, 60 - FOOD) * BF7;
BF10 = max( 0, LEACHVOL - 220) * BF7;
BF11 = max( 0, 220 - LEACHVOL) * BF7;
BF12 = max( 0, TEMP - 70);
BF13 = max( 0, FOOD + 3.74098e-007) * BF12;
```

```
BF14 = max( 0, TEMP - 85) * BF7;
BF15 = max( 0, 85 - TEMP) * BF7;
BF16 = max( 0, LEACHVOL - 50) * BF5;
BF17 = max( 0, YARD - 20) * BF6;
BF18 = max( 0, 20 - YARD) * BF6;
BF19 = max( 0, TEXTILE - 60) * BF6;
BF20 = max( 0, 60 - TEXTILE) * BF6;
BF21 = max( 0, LEACHVOL - 310) * BF2;
BF22 = max( 0, 310 - LEACHVOL) * BF2;
BF23 = max( 0, TEXTILE - 30);
BF24 = max( 0, 30 - TEXTILE);
BF25 = max( 0, YARD + 1.21251e-006) * BF12;
BF26 = max( 0, LEACHVOL - 50) * BF3;

Y = 2.15084 + 0.0118899 * BF1 - 0.0112459 * BF2 + 0.0452198 * BF3
            - 0.00826714 * BF4 - 0.0724418 * BF5 + 0.00133542 * BF6
            + 0.0271093 * BF7 - 0.000369377 * BF8 - 0.000336708 * BF9
            - 1.31386e-005 * BF10 - 0.000113766 * BF11 - 0.00698821 * BF12
            - 0.000310514 * BF13 + 0.000405255 * BF14 + 0.000293399 * BF15
            + 3.61778e-005 * BF16 - 7.12088e-005 * BF17 - 0.000188725 * BF18
            + 1.79401e-005 * BF19 + 4.74529e-005 * BF20 + 6.68061e-007 * BF21
            - 3.4045e-005 * BF22 + 0.00871295 * BF23 + 0.00838417 * BF24
            + 0.000136876 * BF25 - 2.19872e-005 * BF26;

MODEL LOG10NH3N = BF1 BF2 BF3 BF4 BF5 BF6 BF7 BF8 BF9 BF10 BF11
                  BF12 BF13 BF14 BF15 BF16 BF17 BF18 BF19 BF20
                  BF21 BF22 BF23 BF24 BF25 BF26;

Grove file created: C:\Users\Hetal\AppData\Local\Temp\s54051: 64 kb

Grove file created containing:
     1 Mars model

                Examining and Preparing Data: 00:00:00
Forward Stepwise Knot Placement-- CV:      1: 00:00:00
                  Back Stepping-- CV:      1: 00:00:00
Forward Stepwise Knot Placement-- CV:      2: 00:00:00
                  Back Stepping-- CV:      2: 00:00:00
Forward Stepwise Knot Placement-- CV:      3: 00:00:00
                  Back Stepping-- CV:      3: 00:00:00
Forward Stepwise Knot Placement-- CV:      4: 00:00:00
                  Back Stepping-- CV:      4: 00:00:00
Forward Stepwise Knot Placement-- CV:      5: 00:00:00
                  Back Stepping-- CV:      5: 00:00:00
Forward Stepwise Knot Placement-- CV:      6: 00:00:00
                  Back Stepping-- CV:      6: 00:00:00
Forward Stepwise Knot Placement-- CV:      7: 00:00:00
                  Back Stepping-- CV:      7: 00:00:00
Forward Stepwise Knot Placement-- CV:      8: 00:00:00
                  Back Stepping-- CV:      8: 00:00:00
Forward Stepwise Knot Placement-- CV:      9: 00:00:00
                  Back Stepping-- CV:      9: 00:00:00
Forward Stepwise Knot Placement-- CV:     10: 00:00:00
                  Back Stepping-- CV:     10: 00:00:00
             Forward Stepwise Knot Placement: 00:00:00
                              Back Stepping: 00:00:00
                              Writing Grove: 00:00:00
```

```
This launch supports up to  32768 variables.


 Random seeds:            13579           12345             131
 VARIABLES IN RECT FILE ARE:
        PH           TIME       LEACHVOL           FOOD        TEXTILE
     PAPER           YARD           RAIN           TEMP

 C:\Arpita_PhD\PhD Landfill Project\leachate Parameters Analysis\pH Data\MARS pH\pH
data.xlsx: 429 records.

 Model reset.
 Model reset: PH

 Salford Predictive Modeler: MARS(R) version 6.6.0.091

 Records Read: 428
 Records Kept in Learning sample: 428
<a name="0"></a>


 CV Results
 ==========

 10-fold cross validation used to find the optimal model.

 Optimal Model Nr = 26, DF = 3.00000, Estimated PSE = 0.15910
<a name="1"></a>


 Forward Stepwise Knot Placement
 ===============================

 BasFn(s)      GCV  IndBsFns EfPrms Variable            Knot       Parent  BsF
 ------------------------------------------------------------------------------
     0        0.39130    0.0    1.0
   2   1      0.33952    2.0    6.0 RAIN              6.00000
   4   3      0.29154    4.0   11.0 TIME             60.00000
   6   5      0.27391    6.0   16.0 TIME            172.00000 RAIN           2
   8   7      0.25857    8.0   21.0 TEMP             85.00000
  10   9      0.23820   10.0   26.0 TEXTILE          60.00000 TEMP           7
    11        0.22368   11.0   30.0 YARD             -0.00000
    12        0.21447   12.0   34.0 FOOD             -0.00000 TEMP           8
  14  13      0.20959   14.0   39.0 FOOD             60.00000
  16  15      0.19694   16.0   44.0 TIME             89.00000 FOOD          13
  18  17      0.18244   18.0   49.0 RAIN              6.00000 FOOD          14
  20  19      0.16976   19.0   53.0 TIME            151.00000 FOOD          13
  22  21      0.15833   21.0   58.0 TIME            320.00000 TEMP           8
  24  23      0.15380   23.0   63.0 YARD             20.00000 TIME           4
  26  25      0.14789   25.0   68.0 TIME             38.00000 YARD          11
  28  27      0.14494   27.0   73.0 LEACHVOL        250.00002
  30  29      0.13786   29.0   78.0 LEACHVOL        270.00003 TIME           4
  32  31      0.13502   30.0   82.0 YARD             20.00000 TIME           3
  34  33      0.13521   32.0   87.0 TEMP             85.00000 TIME           3
<a name="2"></a>


 Final Model (After Backward Stepwise Elimination)
 =================================================

 Basis Fun  Coefficient Variable     Parent         Knot
 -----------------------------------------------------------------------
        0      7.96748
        1     -0.10976 RAIN                           6.00000
```

2	-0.12213	RAIN		6.00000
3	-0.00344	TIME		60.00000
4	-0.03896	TIME		60.00000
6	-0.00160	TIME	RAIN	172.00000
8	-0.04333	TEMP		85.00000
9	-0.00100	TEXTILE	TEMP	60.00000
12	-0.00052	FOOD	TEMP	-0.00000
13	-0.02432	FOOD		60.00000
14	-0.00511	FOOD		60.00000
15	0.00075	TIME	FOOD	89.00000
16	0.00030	TIME	FOOD	89.00000
17	0.00194	RAIN	FOOD	6.00000
18	0.00533	RAIN	FOOD	6.00000
19	-0.00073	TIME	FOOD	151.00000
21	-0.00035	TIME	TEMP	320.00000
23	0.00069	YARD	TIME	20.00000
24	0.00045	YARD	TIME	20.00000
25	0.00011	TIME	YARD	38.00000
26	-0.00116	TIME	YARD	38.00000
27	-0.00037	LEACHVOL		250.00002
29	0.00004	LEACHVOL	TIME	270.00003
30	0.00015	LEACHVOL	TIME	270.00003
31	-0.00013	YARD	TIME	20.00000
33	0.00012	TEMP	TIME	85.00000
34	0.00027	TEMP	TIME	85.00000

Piecewise Linear GCV = 0.12603, #efprms = 70.87500

ANOVA Decomposition on 26 Basis Functions
===

fun	std. dev.	-gcv	#bsfns	#efprms	variable
1	0.28636	0.14084	2	5.37500	RAIN
2	0.38435	0.16357	2	5.37500	TIME
3	0.28485	0.14937	1	2.68750	TEMP
4	0.22708	0.14108	2	5.37500	FOOD
5	0.09364	0.13189	1	2.68750	LEACHVOL
6	0.17687	0.14646	1	2.68750	TIME RAIN
7	0.14780	0.14052	1	2.68750	TEXTILE TEMP
8	0.10017	0.12965	1	2.68750	FOOD TEMP
9	0.34523	0.16567	3	8.06250	TIME FOOD
10	0.46184	0.14856	2	5.37500	FOOD RAIN
11	0.30283	0.13933	3	8.06250	TIME TEMP
12	0.17413	0.14836	5	13.43750	TIME YARD
13	0.13609	0.13247	2	5.37500	TIME LEACHVOL

Piecewise Cubic Fit on 26 Basis Functions, GCV = 0.14797

Relative Variable Importance
============================

Variable	Importance	-gcv
TIME	100.00000	0.29212
FOOD	71.20448	0.21024

RAIN	62.27167	0.19043
TEMP	57.94884	0.18180
YARD	36.66952	0.14836
TEXTILE	29.53841	0.14052
LEACHVOL	21.38526	0.13362

MARS Regression: Training Data
==============================

N: 428.00 R-SQUARED: 0.77471
MEAN DEP VAR: 7.27206 ADJ R-SQUARED: 0.76010
UNCENTERED R-SQUARED = R-0 SQUARED: 0.99835

Parameter	Estimate	S.E.	T-Ratio	P-Value
Constant	7.96749	0.06822	116.78787	0.00000
Basis Function 1	-0.10976	0.01412	-7.77313	0.00000
Basis Function 2	-0.12213	0.03196	-3.82176	0.00015
Basis Function 3	-0.00344	0.00038	-9.12525	0.00000
Basis Function 4	-0.03896	0.00458	-8.51200	0.00000
Basis Function 6	-0.00160	0.00019	-8.48920	0.00000
Basis Function 8	-0.04333	0.00480	-9.02564	0.00000
Basis Function 9	-0.00100	0.00014	-7.27090	0.00000
Basis Function 12	-0.00052	0.00012	-4.21400	0.00003
Basis Function 13	-0.02432	0.00360	-6.75323	0.00000
Basis Function 14	-0.00511	0.00121	-4.22280	0.00003
Basis Function 15	0.00075	0.00007	10.19746	0.00000
Basis Function 16	0.00030	0.00008	3.67928	0.00027
Basis Function 17	0.00194	0.00029	6.63423	0.00000
Basis Function 18	0.00533	0.00059	8.96643	0.00000
Basis Function 19	-0.00073	0.00011	-6.89066	0.00000
Basis Function 21	-0.00035	0.00016	-2.11452	0.03509
Basis Function 23	0.00069	0.00010	6.85403	0.00000
Basis Function 24	0.00045	0.00024	1.89094	0.05935
Basis Function 25	0.00011	0.00002	5.90760	0.00000
Basis Function 26	-0.00116	0.00020	-5.68305	0.00000
Basis Function 27	-0.00037	0.00007	-5.00052	0.00000
Basis Function 29	0.00004	0.00001	5.68741	0.00000
Basis Function 30	0.00015	0.00005	2.95898	0.00327
Basis Function 31	-0.00013	0.00003	-5.00951	0.00000
Basis Function 33	0.00012	0.00003	4.07321	0.00006
Basis Function 34	0.00027	0.00004	7.75529	0.00000

F-STATISTIC = 53.03592 S.E. OF REGRESSION = 0.30603
P-VALUE = 0.00000 RESIDUAL SUM OF SQUARES = 37.55459
[MDF,NDF] = [26, 401] REGRESSION SUM OF SQUARES = 129.14040

Basis Functions
===============

```
BF1 = max( 0, RAIN - 6);
BF2 = max( 0, 6 - RAIN);
BF3 = max( 0, TIME - 60);
BF4 = max( 0, 60 - TIME);
BF6 = max( 0, 172 - TIME) * BF2;
BF7 = max( 0, TEMP - 85);
BF8 = max( 0, 85 - TEMP);
BF9 = max( 0, TEXTILE - 60) * BF7;
BF11 = max( 0, YARD + 1.07638e-006);
BF12 = max( 0, FOOD + 7.81104e-007) * BF8;
BF13 = max( 0, FOOD - 60);
BF14 = max( 0, 60 - FOOD);
BF15 = max( 0, TIME - 89) * BF13;
BF16 = max( 0, 89 - TIME) * BF13;
```

```
BF17 = max( 0, RAIN - 6) * BF14;
BF18 = max( 0, 6 - RAIN) * BF14;
BF19 = max( 0, TIME - 151) * BF13;
BF21 = max( 0, TIME - 320) * BF8;
BF23 = max( 0, YARD - 20) * BF4;
BF24 = max( 0, 20 - YARD) * BF4;
BF25 = max( 0, TIME - 38) * BF11;
BF26 = max( 0, 38 - TIME) * BF11;
BF27 = max( 0, LEACHVOL - 250);
BF29 = max( 0, LEACHVOL - 270) * BF4;
BF30 = max( 0, 270 - LEACHVOL) * BF4;
BF31 = max( 0, YARD - 20) * BF3;
BF33 = max( 0, TEMP - 85) * BF3;
BF34 = max( 0, 85 - TEMP) * BF3;

Y = 7.96748 - 0.109756 * BF1 - 0.122133 * BF2 - 0.00343849 * BF3
            - 0.0389607 * BF4 - 0.00160046 * BF6 - 0.0433295 * BF8
            - 0.000996241 * BF9 - 0.000517144 * BF12 - 0.0243159 * BF13
            - 0.00510772 * BF14 + 0.000754425 * BF15 + 0.000300999 * BF16
            + 0.00194321 * BF17 + 0.0053259 * BF18 - 0.000732156 * BF19
            - 0.000348103 * BF21 + 0.000687358 * BF23 + 0.000452001 * BF24
            + 0.000110059 * BF25 - 0.00115817 * BF26 - 0.000365713 * BF27
            + 3.84477e-005 * BF29 + 0.000149192 * BF30 - 0.000134269 * BF31
            + 0.000117481 * BF33 + 0.000271561 * BF34;

MODEL PH = BF1 BF2 BF3 BF4 BF6 BF8 BF9 BF12 BF13 BF14 BF15 BF16
           BF17 BF18 BF19 BF21 BF23 BF24 BF25 BF26 BF27 BF29 BF30
           BF31 BF33 BF34;

Grove file created: C:\Users\Hetal\AppData\Local\Temp\s4a851: 62 kb

Grove file created containing:
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Forward Stepwise Knot Placement-- CV:      1: 00:00:00
                  Back Stepping-- CV:      1: 00:00:00
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                  Back Stepping-- CV:      2: 00:00:00
Forward Stepwise Knot Placement-- CV:      3: 00:00:00
                  Back Stepping-- CV:      3: 00:00:00
Forward Stepwise Knot Placement-- CV:      4: 00:00:00
                  Back Stepping-- CV:      4: 00:00:00
Forward Stepwise Knot Placement-- CV:      5: 00:00:00
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Forward Stepwise Knot Placement-- CV:      6: 00:00:00
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Forward Stepwise Knot Placement-- CV:      7: 00:00:00
                  Back Stepping-- CV:      7: 00:00:00
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                  Back Stepping-- CV:      8: 00:00:00
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                  Back Stepping-- CV:      9: 00:00:00
Forward Stepwise Knot Placement-- CV:     10: 00:00:00
                  Back Stepping-- CV:     10: 00:00:00
             Forward Stepwise Knot Placement: 00:00:00
                              Back Stepping: 00:00:00
                              Writing Grove: 00:00:00
```

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BIOGRAPHICAL INFORMATION

Arpita Bhatt received her Bachelor’s degree in Civil Engineering from Maharaja Sayajirao University of Baroda in 2003. Then she decided to come to United States for graduate studies. She joined the University of Texas at Arlington in summer 2005 to pursue her Master’s degree in Civil Engineering, majoring in Environmental Engineering. Her Master’s project focused on air dispersion modeling software. While pursuing her degree, she worked for three months as an intern during summer 2006 at Texas Commission on Environmental Quality (TCEQ), Austin. After completing her degree, she worked as a staff engineer for SCS Engineering, Inc. and later she worked for the City of Weatherford, TX. In 2009, she decided to enroll in the doctoral program in Civil engineering, majoring Environmental engineering at the University of Texas at Arlington under the guidance of Dr. Melanie Sattler. During her graduate program, she worked as a graduate teaching assistant. She received student scholarships from Air & Waste Management Association (A&WMA), Texas Environmental Health Association (TEHA), and Solid Waste Association of North America (SWANA). She also worked as an intern at the City of Lancaster, TX for summer 2012. Her research interests include but not limited to bioreactor landfills, landfill leachate and gas, wastewater and air quality.