EFFECTS OF CORN MILL WASTE ON MUNICIPAL SOLID WASTE DEGRADATION IN BIOREACTOR LANDFILLS

by

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Abstract

EFFECTS OF CORN MILL WASTE ON MUNICIPAL SOLID WASTE DEGRADATION IN BIOREACTOR LANDFILLS

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The Enhanced Leachate Recirculation (ELR) landfills is a sustainable disposal system of waste which facilitates faster degradation of waste, more gas generation in a short period of time, rapid waste stabilization along with energy recovery. The decomposition of waste largely depends on heterogeneity of landfilled waste composition, leachate recirculation, rainfall, and several other factors like recirculate leachate composition, ambient temperature etc. Various researches have been conducted on landfill behavior subjected to various waste composition and conditions.

Corn Mill Waste, a crop residue and a refuse from corn milling industries, is a major source of crop waste in US. A significant amount of corn waste is being utilized by producing corn ethanol which contributes to the total biofuel generation although there is a mentionable portion which does not have any proper disposal facility. Bioreactor landfills could be an appropriate solution regarding this problem. However, the effects of Corn Mill Waste on waste degradation in ELR landfills are unknown and need to be investigated.

The objectives of the current study is to determine the effects of Corn Mill Waste on municipal solid waste degradation and gas generation potential. To accomplish this objective, physical characteristics of collected Municipal Solid Waste (MSW) and Corn Mill

Waste were determined. Four laboratory scale reactors were prepared with selected MSW-Corn Mill Waste ratios to simulate the bioreactor condition. The reactors were operated in favorable microbial growth condition and monitored on a periodic basis. The pH level, COD, and BOD_5 tests were conducted on generated leachate to assess the ongoing level of degradation.

Based on the experimental results, it was observed that REACTOR-C 100 which had 100 % Corn Mill Waste by weight suffered a lag phase of methanogenesis as the pH level was acidic and generation of meathane was negligible compared to other reactors. BOD and COD results also complied with the lag phase. Gas generation from reactors containing 10% and 20% Corn Mill Waste was similar to the reactor which contains 100% MSW. The degradation levels in these three reactors maintained resemblance in their period of operation.

Considering the experimental results, it can be summarized that Corn Mill Waste not more than 20% by weight if disposed in landfills would not affect the leachate quality, gas generation, and overall degradation phases in municipal solid waste landfills and if 10% Corn Mill Waste is disposed two times methane generation can be achieved from the landfills.

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Chapter 1

Introduction

1.1 Background

Corn Waste is one of the major crop residues generated every year in United States. According to US Department of Energy, 111 million tons of agricultural waste is generated in 2011 as shown in Figure 1.1 among which three fourth of the crop residues is corn stovers. It is estimated that in 2030, this quantity will exceed 250 million per year.

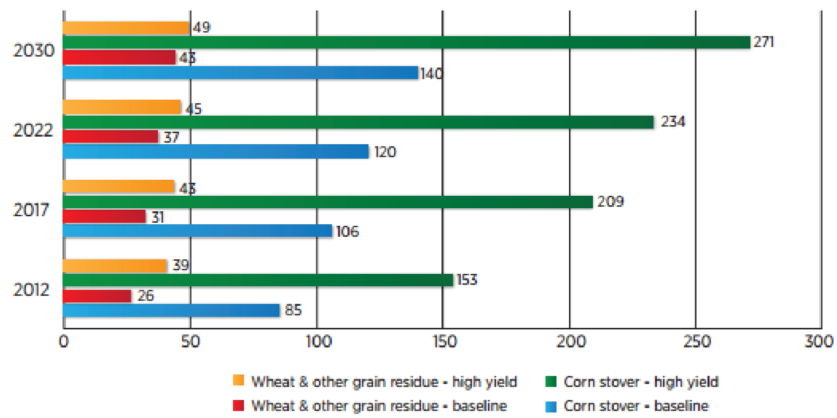


Figure 1.1 Supplies of primary crop residues (US DOE, 2012)

A major use of corn residues is cellulosic ethanol production which is mainly used as an oxygenate in low level blends of gasoline although recent researches of Young (2008) found that burning Corn Ethanol instead of gasoline releases 1.7 times Carbon-dioxide for every vehicle mile traveled. Moreover, in terms of energy efficiency Corn Ethanol can only provide 62% of thermal energy compared to gasoline. Although corn waste is a significant contributor to ethanol production, a huge amount of corn waste are left in the field sites which does not have proper disposal facility.

1.2 Bioreactor Landfill for Municipal Solid Waste Decomposition

A bioreactor landfill is an engineered waste disposal site which has several advantages over conventional dry tomb landfills. In the conventional dry tomb landfills, no external moisture intrusion is allowed. As a result the initial moisture content of the disposed waste is the only source of moisture for waste degradation. This causes a slower rate of biodegradation taking a long time, sometimes more than 50 years. Moisture intrusion is allowed in ELR landfills. This type of landfills is operated to enhance the microbial activity which leads to faster degradation of waste. Moreover, bioreactor landfills have rapid settlement of waste which leads to increased disposal capacity. Recirculation of leachate reduces the cost of waste water treatment and increase microbial activity which results in increased gas generation and ensuing energy conversion. The generated gas in bioreactor landfills have high methane flow rate which is currently utilized in several parts in United States to produce electricity. The schematic of a bioreactor landfill is shown in Figure 1.2.

Figure 1.2 Schematic of Bioreactor Landfill

1.3 Problem Statement

The largest quantities of agricultural wastes derive from the commodity crops such as corn, wheat, barley etc. according to U.S. Department of Energy. A fraction of this residue are subjected to incineration which is a major source of greenhouse gas emission. Currently burning corn residue is a common practice in all of the states which leaves a deep impact on climate change. The alternative of corn residue incineration is incorporating residues back into soils which sometimes is not also considered as a solution. Leftovers of corn residue after harvesting in fields cause mentionable gas emission and each year a large amount of Corn Mill Waste from food industries and corn fields are generated which do not have any proper disposal facility.

If a significant amount of Corn Mill Waste gets disposed in bioreactor landfills the degradation of waste might be affected and which in terms may influence the gas generation rate and the overall performance. However, no research to date has been conducted to determine the effects of crop residue such as corn waste disposal in bioreactor landfills. Therefore, a study is important to evaluate the effects of corn mill waste on municipal solid waste degradation in bioreactor landfills.

1.4 Research Objectives

The main objective of the current study is to determine the effects of Corn Mill Waste on municipal solid waste degradation in bioreactor landfills. A systematic experimental program was undertaken and gas and leachate data were collected and analyzed.

The specific objectives of the current study are the following –

1. To evaluate the effects of Corn Mill Waste on bio-degradation of Municipal Solid Waste (MSW) in a bioreactor landfill.

2. To determine the effects of Corn Mill Waste on gas generation of Municipal Solid Waste (MSW) in a bioreactor landfill.
3. To evaluate the optimum ratio of Corn Mill Waste for the maximum gas generation from a bioreactor landfill.

1.5 Thesis Organization

The thesis is organized in the following manner

The first chapter presents general information of the study, problem statement, research objectives and a brief outline of the thesis organization.

The second chapter offers the literatures on municipal solid waste properties, landfilling method and operation, and biodegradation of solid waste.

The third chapter describes the location of area of study, experimental setups, and required laboratory test methodologies to address the research objective.

The fourth chapter discusses about the test results obtained from leachate and gas data.

The fifth chapter summarizes the main conclusions of the present study and some recommendations for future research work.

Chapter 2

Literature Review

2.1 Introduction

This chapter includes the literature review on Municipal Solid Waste (MSW), landfills, degradation of waste in landfills, gas generation from landfills, and effects on gas generation of the landfills.

2.1.1 Municipal Solid Waste (MSW)

Municipal solid waste (MSW), commonly known as trash or garbage, consists of paper, plastic, food waste, package wrappings, glass, wood, textile, metal etc. The heterogeneous nature of MSW is the outcome of the diverse source of waste flow from residential, commercial, and institutional sources (US-EPA, 2011). Wastes from industrial, hazardous, and construction sources are exclusive from this criteria.

2.1.1.1 Fresh MSW

Fresh MSW are those which are collected from the working face of the landfill. These are mainly the raw waste containing all initial characteristics of waste.

2.1.1.2 Landfilled MSW

Landfilled MSW are those which have been already disposed in the landfill and are undergoing biodegradation in different phases. Samples collected from different depths usually vary in their properties due to the degradation phase.

2.1.2 Corn Mill Waste

Corn Mill Waste is comprised of corn kernel, corn seed head, and corn cob as shown in Figure 2.1.

Figure 2.1 Corn Mill Waste

2.2 Composition and properties of Municipal Solid Waste

2.2.1 Composition of Municipal Solid Waste (MSW)

Composition of MSW mostly emphasizes on its biodegradability property – whether it is biodegradable or not. Landfill wastes from various sources can be primarily categorized into two major categories- biodegradable and non-biodegradable. Decomposable materials like food waste, paper, wood, and textile fall into biodegradable category whereas non degradable materials include plastic, glass, metals, and construction and demolition debris. Faster decomposition of materials can be ensured with high percentage of organic contents in the waste. Food wastes decompose quickly compared to other organic components giving a rise in landfill gas generation in the initial stage. Wood, paper, and clothes are not readily decomposable in nature but they tend to get decomposed slowly with time. Thus their contribution in landfill gas generation is insignificant in the whole life of a landfill. Landva and Clark (1990) outlined a more detailed classification for individual components of municipal solid waste which is shown in Figure 2.2.

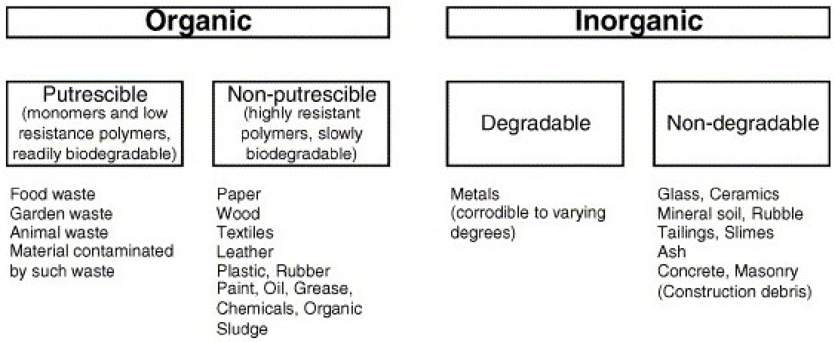


Figure 2.2 MSW Classifications by Landva and Clark (1990)

MSW composition varies from country to country as developing countries produce more biodegradable waste than plastics. In case of developed countries the situation is different. Countries where recycling and reuse of materials are more common practice tend to produce less organic waste and more of plastic waste. Study conducted by Watts et al. (2002) shows us the variation of solid waste components in UK for 65 year (Figure 2.3).

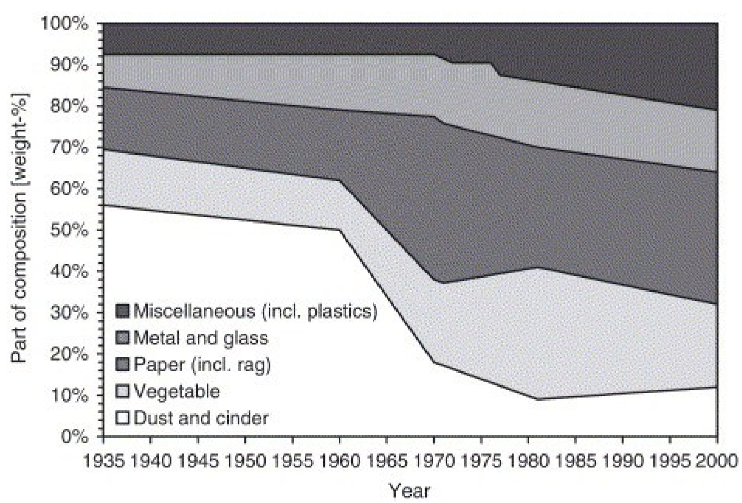


Figure 2.3 Composition of UK MSW since 1935 (Watts et al.,2002)

According to U.S. E.P.A 2012, in United States, a total of 251 million tons of solid waste was generated in 2012. Though a very good recycling rate of 34.5 percent was achieved, a large amount of waste was disposed in landfills (Table 2.1).

Table 2.1 Landfilled MSW in US in 2012 (US EPA,2012)

Material	Weight Generated	Weight Recovered	Recovery as Percent of Generation	Weight Discarded
Paper and paperboard	68.62	44.36	64.6%	24.26
Glass	11.57	3.20	27.7%	8.37
Metals				
Steel	16.80	5.55	33.0%	11.25
Aluminum	3.58	0.71	19.8%	2.87
Other nonferrous metals†	2.00	1.36	68.0%	0.64
Total metals	**22.38**	**7.62**	**34.0%**	**14.76**
Plastics	31.75	2.80	8.8%	28.95
Rubber and leather	7.53	1.35	17.9%	6.18
Textiles	14.33	2.25	15.7%	12.08
Wood	15.82	2.41	15.2%	13.41
Other materials	4.60	1.30	28.3%	3.30
Total materials in products	**176.60**	**65.29**	**37.0%**	**111.31**
Other wastes				
Food, other‡	36.43	1.74	4.8%	34.69
Yard trimmings	33.96	19.59	57.7%	14.37
Miscellaneous inorganic wastes	3.90	Negligible	Negligible	3.90
Total other wastes	**74.29**	**21.33**	**28.7%**	**52.96**
Total municipal solid waste	**250.89**	**86.62**	**34.5%**	**164.27**

* Includes waste from residential, commercial, and institutional sources.
† Includes lead from lead-acid batteries.
‡ Includes recovery of other MSW organics for composting.
Details might not add to totals due to rounding.
Negligible = Less than 5,000 tons or 0.05 percent.

In 2012, approximately 30.31 million tons of waste was landfilled in Texas according to Texas Commission on Environmental Quality (TCEQ). The ever increasing population and per capita solid waste generation in this state make landfills more appropriate solution for solid waste disposal in recent years (Figure 2.4).

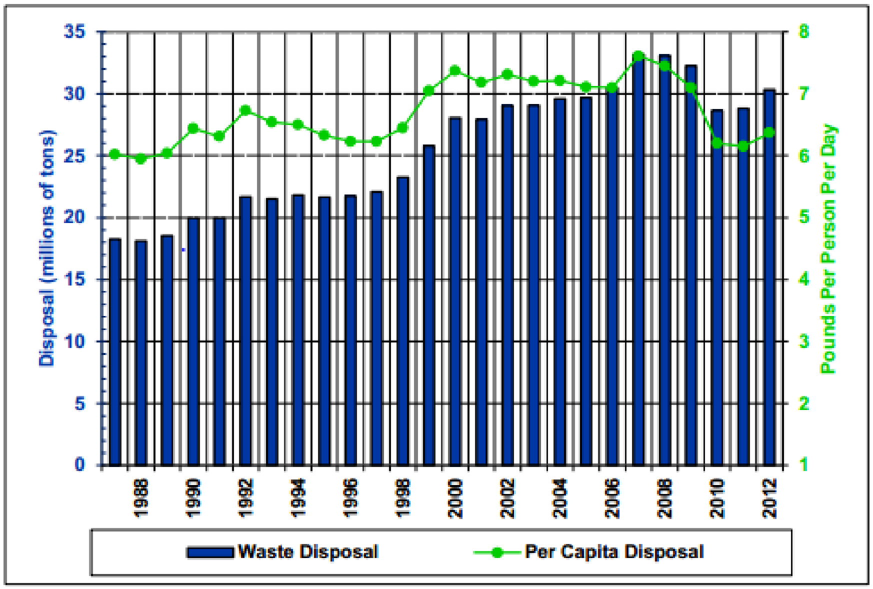


Figure 2.4 Texas total and per capita waste disposal (TCEQ Report, 2013)

2.3 Landfills

Landfills have been considered as one of the most economic and sustainable options for solid waste disposal system. Two types of landfill can be found around the US – conventional landfills and the recent one - bioreactor landfills. These two types of landfills are discussed in the following sections

2.3.1 Conventional Landfills

The design parameters and operational procedures of conventional landfills are based on the principles described in Subtitle D of the Resource Conservation and Recovery Act (Federal Register, 1991). They are also known as 'dry tomb landfills'. In conventional landfills decomposition rate of waste is low because of the absence of auspicious surroundings that is needed to enhance microbial activity. Thus it takes a long time, sometimes as long as 100 years, to complete total decomposition for landfilled waste. According to the regulation, a post-closure monitoring period of 30 years is specified which further complicates this long decomposition life span of conventional landfills (Barlaz et al., 2002). To enhance microbial decomposition minimizing the long term monitoring a novel approach in landfill designing was proposed by Pohland in the 1970s (Pohland, 1970) which is known as bioreactor landfills or ELR i.e. Enhanced Leachate Recirculaion landfills.

2.3.2 Bioreactor of ELR Landfills

Bioreactor or ELR landfills introduced the concept of adding additional water to the landfilled waste to increase microbial activities and recirculation of generated leachate afterwards. Research conducted by Barlaz showed that additional moisture will enhance microbial activities by providing better interactions among insoluable substrates, soluable nutrients, and microorganisms (Barlaz et al., 1990). In bioreactor landfills, decomposition of degradable fractions occurs rapidly and within 5-10 years the landfills get stabilized which is less than the time required for post closure of the RCRA Subtitle D landfills. An illustrative comparison between conventional and bioreactor landfills is shown in Figure 2.5.

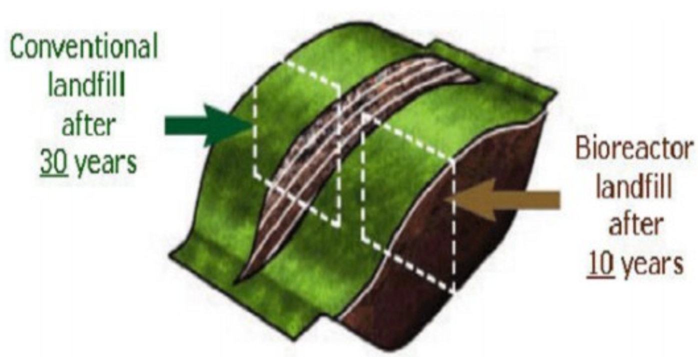


Figure 2.5 Decomposition state of waste between conventional and bioreactor landfills

Other advantages of bioreactor landfills over conventional landfills are –

1. Rapid decomposition of organic waste leads to increased gas generation rate in the initial years of landfill operation which helps in developed landfill gas recovery and utilization process;
2. Generated leachate recirculation ensures less environmental impact on ground and surface water as well as the surrounding environment;
3. Landfilling cost can be minimized as cells of bioreactor landfills can be reused in the future;
4. Decomposed end product of a bioreactor landfill does not need any mining operation as end product can be reused as compost;
5. Generated landfill gas can be used and converted into energy which complies with sustainable engineering;
6. Reduction of post closure care can be achieved.

2.4 Biodegradation of MSW and Gas Generation from Landfills

The conversion from organic content of MSW into methane can be divided into two stages – aerobic stage and anaerobic stage.

2.4.1 Stages of biodegradation of MSW in landfill

2.4.1.1 Aerobic Stage

As soon as the waste disposal, the biodegradable fraction in the waste starts reacting with oxygen from inter-waste void spaces. Organic contents get oxidized in the presence of aerobic bacteria producing carbon di oxide and water vapor. With time oxygen depletes and gradually the whole aerobic process starts shifting to anaerobic stage. The reaction time depends on availability of oxygen which is dependent on composition of the waste and permeability of the cover soil. The more permeable the cover soil, the more oxygen can intrude through the soil.

2.4.1.2 Anaerobic Stage

Hydrolysis, acetogenesis, and methanogenesis – these three subsequent steps constitute methane fermentation phenomenon. At first fermentative bacteria hydrolyze lipids, proteins, and polysachharides. This produces acetate, fatty acids, carbon di oxide, and hydrogen. Then methanogenic bacteria take the control and convert complex organic compounds into simple structured gaseous end products like methane according to Christensen et al., 1996. One of the most important facts in this methanogenesisprocess is methane molecule retains about 90% of the substrate energy. The entire process can be summarized and expressed (Perez et al., 2002) by the following equations and illustration (Figure 2.6).

$$\text{Acetogenesis : } C_6H_{12}O_6 = 2\ C_2H_5OH + 2\ CO_2$$

$$\text{Methanogenesis: } CH_3COOH = CH_4 + C0_2$$

$$C0_2 + 4H_2 = CH_4 + 2H_20$$

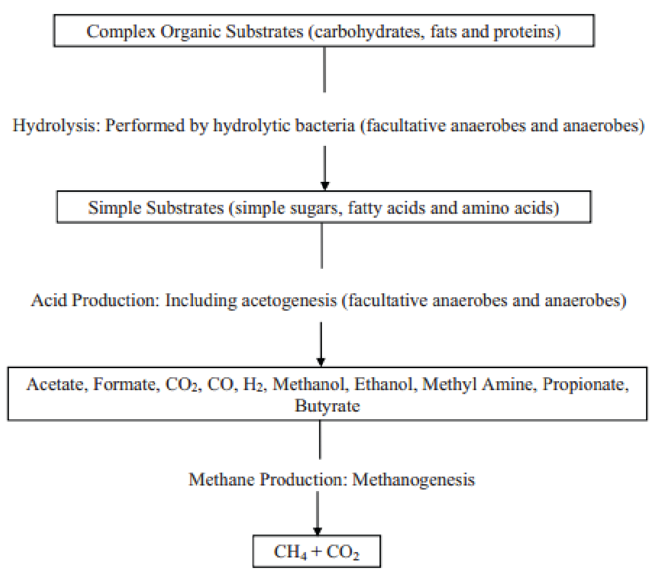


Figure 2.6 Stages of fermentation in methane production (Chandra et al. 2012)

The methanogenic bacteria i.e methantrophes are highly pH susceptible in nature as they cannot survive in acidic ambience. Low redox potential and moderate hydrogen concentration are needed to maintain the ambient surroundings for methanogenic bacteria.

2.4.2 Phases of biodegradation of MSW in landfill

Several studies on phases of biodegradation of MSW in landfill have been conducted and reported by Barlaz et al. (1989), Warith (2003), Warith et al. (2005), White et al.(2005), Zacharof et al.(2004), Al-Kaabi (2007), Kjeldsen et al. (2002), and Christensen et al. (1989). According to these studies there are five distinct phases of biodegradation of MSW exist by analyzing generated leachate quality and emitted gas composition. The phases reported in the previous literatures are described in the following sections.

- Phase I : Initial adjustment phase (Aerobic phase or lag phase)

  In this phase, the entrapped oxygen in waste is used and consumed by microbes which eventually are responsible for the oxygen depletion at the end of this phase. During this phase an initial lag phase is observed due to the absence of sufficient moisture needed to ensure proper microbial activity (Figure 2.8 and Figure 2.7).

- Phase II : Transition phase

  The already started oxygen depletion causes the whole degradation process to shift from aerobic to anaerobic phase. At the end of this phase, BOD and COD concentration of the leachate increases and organic fatty acids like acetic acid can be found in the leachate.

- Phase III: Acid formation phase

  The pH levels of leachate drop significantly in this phase due to the rapid degradation of organic content of MSW. BOD and COD reaches at their peak in this phase (Figure 2.8 and Figure 2.7).

- Phase IV: Methane fermentation phase

  In this phase, methanogenic bacteria vigorously transform the accumulated acids, carbon di oxide, and hydrogen of Phase II into methane gas. The pH value bumps up to 7 or more and then start showing a stabilizing trend which continues for the rest of the biodegradation process (Figure 2.8 and Figure 2.7).

- Phase V: Maturation phase

  In this last phase, methane concentration drops down continuing a steady state as decomposition of organic contents along with the microbial activity cease with time. This phase is known as maturation phase (Figure 2.8 and Figure 2.7).

All the phase activities are shown in the following Figure 2.7 and Figure 2.8.

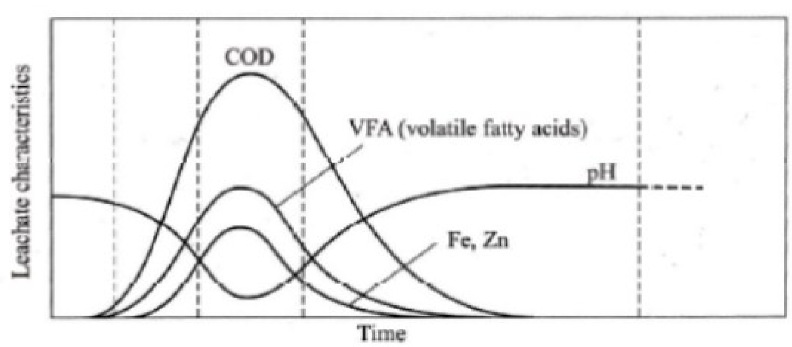


Figure 2.7 Degradation phases in landfills (for leachate)

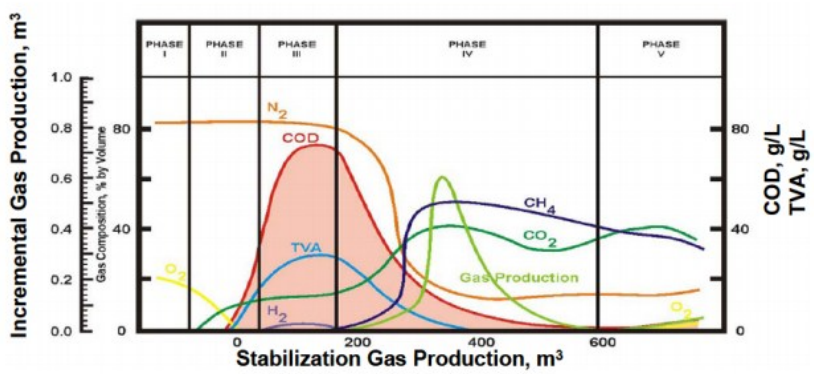


Figure 2.8 Degradation phases in landfills (for gas)

2.4.3 Factors affecting biodegradation in landfills

Moisture content, pH, alkalinity, temperature, and available nutrients significantly affect the biodegradation process in landfills. Details of these factors are given below –

i) Moisture content

Biodegradation process accelerates with the increase in moisture content of the landfilled waste. This is a fundamental and governing concept for the effective operation of bioreactor landfills. Pohland (1986) and Rees (1980) observed that for rapid waste decomposition and increased gas generation, moisture content of 60% can be considered optimum.

ii) pH

pH range from 6 – 8 is considered ideal for methane generation from the landfilled waste. pH level lower than 5 creates acidic conditions which cause inhibition of microbial activities and thus affects methane generation.

iii) Alkalinity

Alkaline environment is necessary for optimum methane generation. Studies conducted by Farquhar and Rovers (1973) reported an optimum alkalinity value of 2000 mg/L.

iv) Temperature

According to Hartz et al., (1982) the optimum temperature for methanogenesis is 41°C although the phases of decomposition are well observed in between 37°C and 41°C temperature range. In this study a temperature of 100°F (around 38°C) was maintained.

v) Nutrients

According to Christensen and Kjeldsen (1989) all sorts of nutrients are available in the landfill waste. If any kind depreciation of nutrients occur, degradation ceases which results in low methane generation.

All the influencing factors summarized by Yuen et al. 1994 are presented in a tabular form below (Table 2.2).

Table 2.2 Factors affecting biodegradation in MSW landfills (Yuen et al. 1994)

Sl.No.	Influencing factors	Criteria/Comments	Reference
1.	Moisture	Optimum: 60% and above	Pohland (1986); Rees (1980)
2.	Oxygen	Optimum redox potential for methanogens: -200 mv -300 mv < -100 mv	 Farquhar & Rovers (1973) Christensen & Kjelden (1989) Pohland (1980)
3.	pH	Optimum pH for methanogenesis: 6 to 8 6.4 to 7.2	 Ehrig (1983) Farquhar & Rovers (1973)
4.	Alkalinity	Optimum alkalinity for methanogenesis: 2000 mg/L. Maximum organic acid concentration for methanogenesis: 3000 mg/L Maximum acetic acid/alkalinity ratio for methanogenesis: 0.8	Farquhar & Rovers (1973) Farquhar & Rovers (1973) Ehrig (1983)
5.	Temperature	Optimum temperature for methanogenesis; 40°C 41°C 45 (34 – 38°C)	 Rees (1980) Hartz *et al* (1982) Mata-Alvarez *et al* (1986)
6.	Hydrogen	Partial hydrogen pressure for acetogenesis: $<10^{-6}$ atm	Barlaz *et al* (1987)
7.	Nutreints	Generally adequate	Christensen & Kjelden (1989)
8.	Sulphate	Increase in sulphate decrease in methanogenesis	Christensen & Kjelden (1989)
9.	Inhibitors	Cation concentration producing moderate inhibition (ppm) Ammonium (Total) : 1500 – 3000 Sodium : 3500 - 5500 Potassium : 2500 – 4500 Calcium : 2500 – 4500 Magnesium : 1000 – 1500 Heavy metals: No significance influence Organic compounds: Inhibitory effect only in significant amount.	McCarty & McKinney (1961) Ehrig (1983) Christensen & Kjelden (1989)

Source: (Yuen *et al.*, 1994)[7]

2.4.4 *Landfill gas generation with biodegradation of waste*

Landfill gases are the byproducts of methanogenesis in the anaerobic degradation phase. In the first aerobic phase, amount of carbon di oxide is greater due to the oxidation of organic compounds. In Phase II, carbon di oxide along with hydrogen is produced. In Phase III, oxygen gets depleted which gives rise to the anaerobic phase. From this phase, methane generation starts and carbon di oxide and hydrogen decreases because of the absence of oxygen. In Phase IV, amount of methane exceeds the amount of carbon di oxide as methane: carbon di oxide becomes more than 1. In the final phase, overall gas production drops suddenly. Methane production is decreased and stabilized with time in the maturation phase. The following reaction can explain the whole process of decomposition of cellulose content of solid waste.

$$C_6H_{10}O_5 + H_2O \rightarrow 3CH_4 + 3\ CO_2$$

Typically a landfill can generate gases for 10-80 years or more. Aerobic degradation phase remains for first 6 months and can continue up to 18 months. According to EMCON (1998) summary of landfill gas generation is presented in the following Table 2.3 and Figure 2.8.

Table 2.3 Landfill gas generation phases and time duration

Phase No.	Phase name	Activities	Phase duration
I	Aerobic	No oxygen	Several hours to 1 week
II	Acid formation	Formation of fatty acids, methane generation begins	1-6 months
III	Transition	Methane and Carbon-di-oxide stabilization, no nitrogen	3 months to 3 years
IV	Anaerobic	Methane and Carbon-di-oxide concentrations reduce, a small amount of nitrogen	8 to 40 years
V	Maturation	Final stabilization of methane and Carbon-di-oxide, all anaerobic decomposition ends	1-40 or more years

2.4.5 Composition of landfill gas

Landfill gases can be divided into two groups – principal gases and trace gases. Principal gases include methane, carbon di oxide, and oxygenwhereas trace gases are toxic gases such as hydrogen sulfide. The principal gases are mainly the dominant kind of gases in total gas composition.

Methane (CH_4)

Methane is byproduct of the anaerobic degradation of solid waste. It is one of the greenhouse gases, highly explosive when present in high concentration and generally colorless and tasteless.

Carbon Dioxide (CO_2)

Carbon Dioxide is also colorless and odorless in nature. It is the byproduct of both aerobic and anaerobic decomposition phases and present in relatively high concentrations in the primary phases which lowers the pH level of leachate. As the decomposition level shifts from aerobic to anaerobic its concentration decreases and stabilized in the final maturation phase.

Oxygen (O_2)

Concentration of oxygen depletes as the decomposition phases move to aerobic to anaerobic. The typical amount of oxygen in landfills is less than 5 percent. Increased volume of oxygen is an indication of air leak in the gas collection system.

Hydrogen (H_2)

Hydrogen is produced in low concentration in aerobic decomposition phase and also can be found in the anaerobic phase.

Trace gases

A total of 100 gases were identified as trace gases in landfill according to USEPA (2008). These gases are toxic and harmful for living things. There are some other constituents of landfill trace elements such as Non Methane Organic Compounds (NMOCs) and volatile organic compounds. These components exist in landfill in unpredictable quantity.

Study conducted by Tchobanoglous et al. (1993) reported landfill gases and their percentage in landfill which is presented in the following Table 2.4.

Table 2.4 Landfill gas percentages

Landfill Gases	Percentage (on the basis of dry volume)
Methane	45-60
Carbon Dioxide	40-60
Oxygen	2-5
Sulfides, disulfides, mercaptans etc.	0.1-1.0
Ammonia	0.1-1.0
Hydrogen	0-0.2
Carbon monoxide	0-0.2
Other trace constituents	0.01-0.6

2.5 Landfill leachate

Landfill leachate quantity largely depends on the field moisture capacity. If the field moisture capacity exceeds, leachate is produced. Studies conducted by Reinhart (1996), Rees (1980), Kjeldsen et al. (2002), and El-Fadel et al., (1997) reported that generation of leachate largely depends on initial moisture content, amount of recirculated leachate into landfill, climate, and density of weight.

2.5.1 Lechate composition

Waste composition, waste age, phase of degradation are some of the factors that affect leachate composition. Study conducted by Kjeldsen et al., (2002) revealed that major components of leachate are dissolved organic matter, macro nutrients such as calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}), ammonium (NH^{4+}), iron (Fe^{2+}), manganese (Mn^{2+}), chloride (Cl^{-}), and sulfate (SO_4^{2-}). There are some heavy metals that can be present in leachate like cadmium (Cd^{2+}), chromimum (Cr^{3+}), copper (Cu^{2+}), lead (Pb^{2+}), nickel (Ni^{2+}), and zinc (Zn^{2+}). That study also reported the leachate composition with different biodegradation phase which is presented in the following Table 2.5.

Table 2.5 Leachate composition for different biodegradation phases (Kjeldsen et al., 2002)

Parameter	Acid phase		Methanogenic phase		Average
	Average	Range	Average	Range	
pH	6.1	4.5-7.5	8	7.5-9	
Biological Oxygen Demand (BOD_5)	13000	4000-40000	180	20-550	
Chemical Oxygen Demand (COD)	22000	6000-60000	3000	500-4500	
BOD_5/COD (ratio)	0.58		0.06		
Sulfate	500	70-1750	80	10-420	
Calcium	1200	10-2500	60	20-600	
Magnesium	470	50-1150	180	40-350	
Iron	780	20-2100	15	3-280	
Manganese	25	0.3-65	0.7	0.03-45	
Ammonia-N					740
Chloride					2120
Potassium					1085
Sodium					1340
Total phosphorus					6
Cadmium					0.005
Chromium					0.28
Cobalt					0.05
Copper					0.065
Lead					0.09
Nickel					0.17
Zinc	5	0.1-120	0.6	0.03-4	

Hazardous waste component could be found in landfill leachate if it is more than 30 years old as there were fewer restrictions on landfilling of hazardous waste. This hazardous waste content includes monoaromatic hydrocarbons like benzene, toluene, ethylbenzene, and xylons and halogenated hydrocarbons like tetra-chloroethylene and trichloroethylene.

Some of the important parameters of landfill leachate are discussed in the following sections.

2.5.1.1 pH

pH of the leachate affects the methanogenesis process in landfills. Optimum pH range is considered in between (6-8). pH level less than 6 would hamper the methanogenesis process as acute acidic condition has a deterrent effect on microbial activity. This results in a low methane yield. pH level more than 8 may sometimes inhibit methane production.

2.5.1.2 BOD and COD

The BOD to COD ratio is the predictor of the proportion of biologically degradable organic matter to total organic matter. According to Reinhart et al., (1998), BOD to COD ration decreases with the aging of landfill. In the acidic phase, BOD:COD is greater than 0.1 and sulfate level varies from 70 mg/L to 1750mg/L. But in the methanogenic phase this situation is different because the conversion of sulfate into sulfide provides anaerobic condition in the landfill. BOD: COD ratio varies from 10 mg/L to 420 mg/L in this phase (Reinhart et al., 1998).

2.6 Effects on Degradation and Gas Generation

There are several factors and conditions that affects landfill waste degradation and gas generation. Some of the factors are discussed in the following subsections.

2.6.1 Effects of Moisture Content of Solid Waste

Moisture content is considered as one of the important factors of MSW as it stimulates decomposition of organic waste and gives indication about the level of degradation. Study conducted by Qian shows that there are several factors that can affect moisture content in the solid waste. They are – waste composition, precipitation, and seasonal variation i.e. wet and dry season of the year (Qian et al., 2002). Rees (1980) found that with the increase in moisture content methane generation potential increases significantly as shown in Figure 2.9 and Figure 2.10.

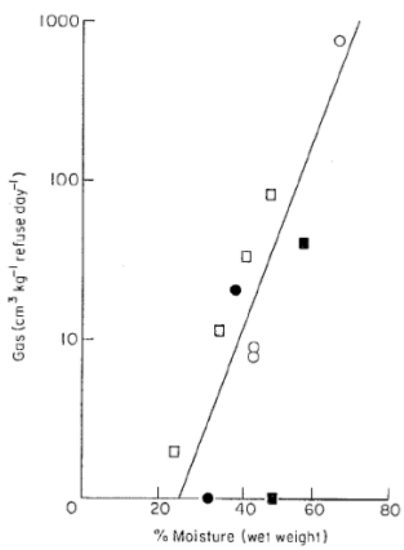


Figure 2.9 Effects of moisture content on gas generation rate (Rees, 1980)

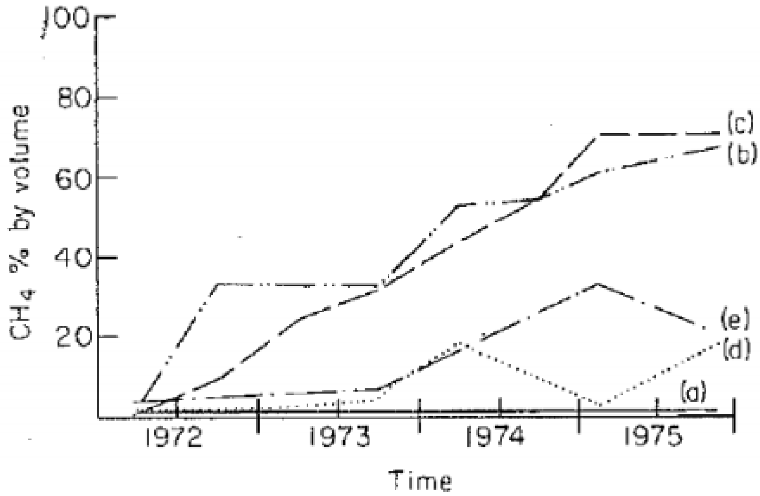


Figure 2.10 Effects of water content on methane generation a)Dry waste; b) & c) Daily liquid application; d) & e) Initially saturated(Rees,1980)

Another study conducted by Mehta & Barlaz et al. (2002) showed the performance of two test cells, one operated with and another without controlled moisture addition. The methane production rate in the control and enhanced cells are presented in Figure 2.11.

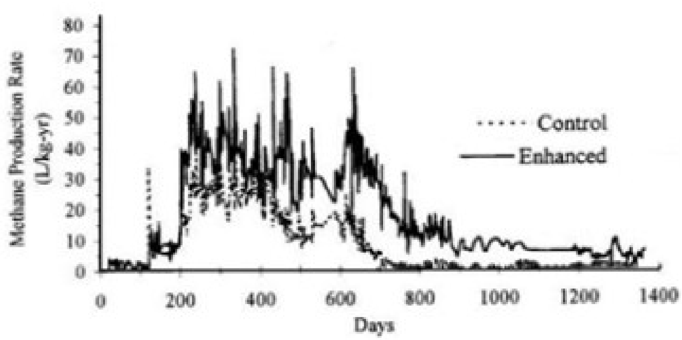


Figure 2.11 Methane production rate with increasing moisture content (Mehta & Barlaz, 2002)

2.6.2 Effects of Composition of Municipal Solid Waste

The biodegradability of landfilled waste largely depends on the composition of waste. If the waste comprises of high organic substances such as cellulosic materials - food, paper, wood or garden waste, the landfill is subjected to undergo rapid decomposition which will result in high methane yield in the initial phase. Study conducted by Eleazer et al. (1997) found that composition of waste highly affects waste degradation and methane generation. For this study, a series of reactors were prepared using different waste fractions such as - grass (G), leaves (L), branches (B), food waste (F), coated paper (CP), old newsprint (ONP), old corrugated containers (OCC), and office paper (OFF) along with mixed municipal solid waste (MSW). Four control reactors were prepared using 30% seed by volume basis except for the food waste (F) reactors in which 70% seeding was done. The reactor containing mixed MSW were not seeded. Control reactors were operated up to the dismantling of other reactors. The extent of decomposition were measured by dividing generated methane volume with methane yield assuming 100% of the cellulose and hemicellulose are converted to methane and carbon-di-oxide. The results are shown in the following Table 2.6.

Table 2.6 Methane Yield and Extent of Decomposition data (Eleazer et al. 1997)

Reactor Series	Methane Yield, (mL of CH4/dry g)	Extent of Decomposition
Seed	25.5	21.8
Seed-2	5.8	6.3
Grass	144.4	94.3
Leaves	30.6	28.3
Branch	62.6	27.8
Food	300.7	84.1
Coated Paper	84.4	39.2
Old Newsprint	74.33	31.1
Old Corrugated Container	152.3	54.4
Office Paper	217.3	54.6
MSW	92	58.4

The changing extent of decomposition of different waste components signifies varying potential of wastes for the conversion of cellulose and hemicellulose into methane and carbon-di-oxide. It was found that the methane generation from the food reactor were the maximum, as food contents are viable to rapid decomposition in the presence of moisture. The maximum value of decomposition extent in food reactors also complies with this methane generation results.

Another study conducted by Wang et al. (1997) tried to find the methane potential for food waste decomposition. For this purpose four laboratory scale reactors filled with food waste were prepared. Methane generation rate increased after 40 days of operation and then decreased with time showing a fluctuating trend as shown in Figure 2.12.

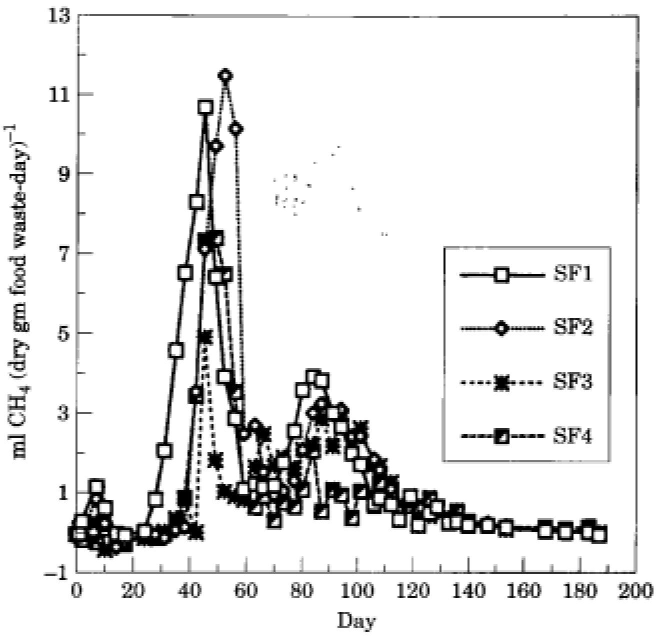


Figure 2.12 Methane production rates in reactors (Wang et al. 1997)

2.6.3 Effects of Leachate Recirculation

Bioreactors landfills are operated and maintained by recirculating generated leachate periodically to enhance the microbial growth for acceleration of waste degradation. Numerous researches have been conducted to date to determine the effects of leachate recirculation on landfilled waste degradation. According to the study of Reinhert et al. (1996), leachate recirculation has significant impacts on leachate composition, gas production, leachate stabilization rate, and waste volume reduction. San and Onay (2001) studied the effects of leachate recirculation on municipal solid waste degradation by building two reactors – with and without leachate recirculation operation. They found that in the leachate recycled reactor waste stabilized more quickly than the other one (Figure Figure 2.13). Also the removal of chemical oxygen was faster in case of leachate recirculation as shown as Figure Figure 2.13.

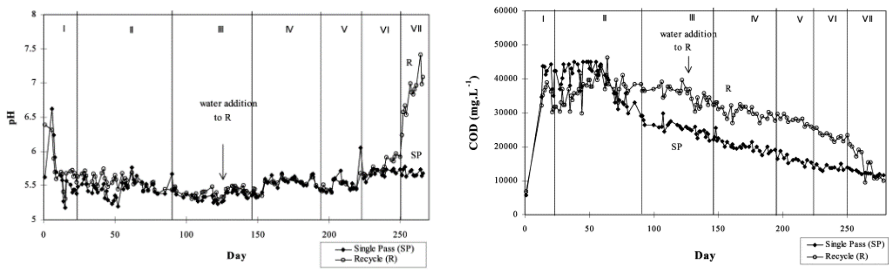


Figure 2.13 pH and COD removal in reactors with and without leachate recirculation (San and Onay, 2001)

According to Morris et al. (2003) leachate recirculation has tremendous impact on subsequent waste stabilization due to degradation in landfills. From the Figure 2.14 presented below, it can be perceived that volume reduction increased just after the initiation of leachate recirculation in landfills. This definitely gives an indication of faster degradation of solid waste due to leachate recirculation.

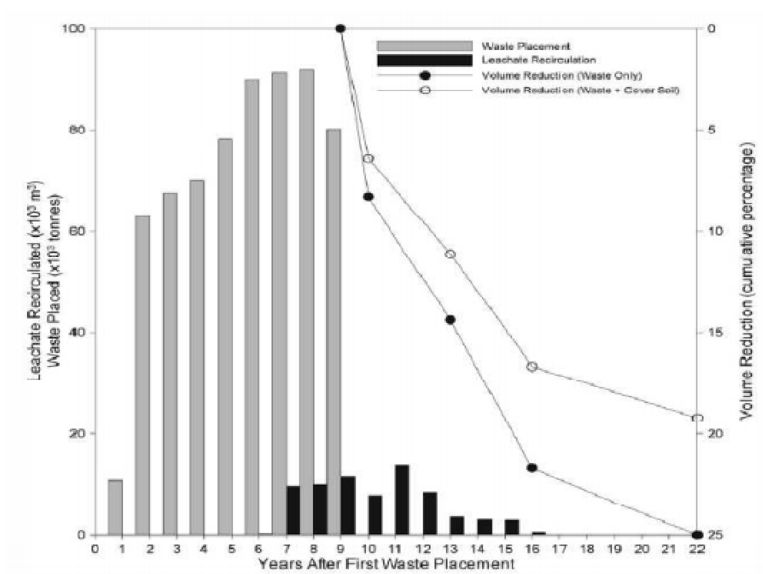


Figure 2.14 Solid waste stabilization due to leachate recirculation (Morris et al. 2003)

Study conducted by Chan et al. (1998) proved that leachate recirculation can accelerate methane generation from landfills. Gas production rate in leachate recirculated reactor was as much as 262 L/week where the reactor without leachate produced methane at a rate of only 20-40 L/week (Figure 2.15)

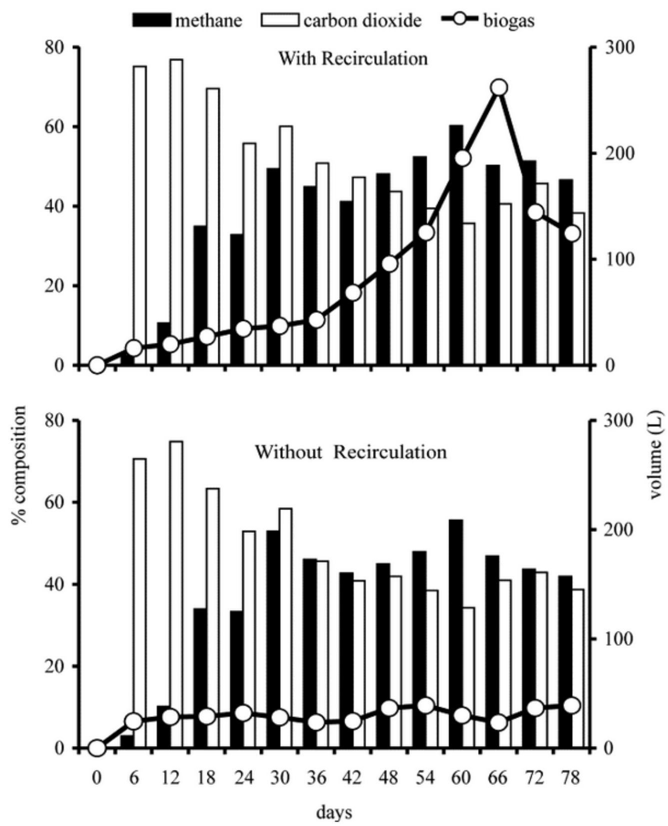


Figure 2.15 Comparison of gas generation rate due to leachate recirculation (Chan et al. 1998)

Study conducted by Hossain and Haque (2009) detected different phases of waste degradation in laboratory scale reactors by sampling destructively by maintaining intervals and based on the methane generation rate. Leachate recirculation was done in regular basis. Samples were collected after 25, 106, 225, and 253 days. Based on the pH levels of leachate and methane production rate phases of degradation were identified which is shown in Figure 2.16.

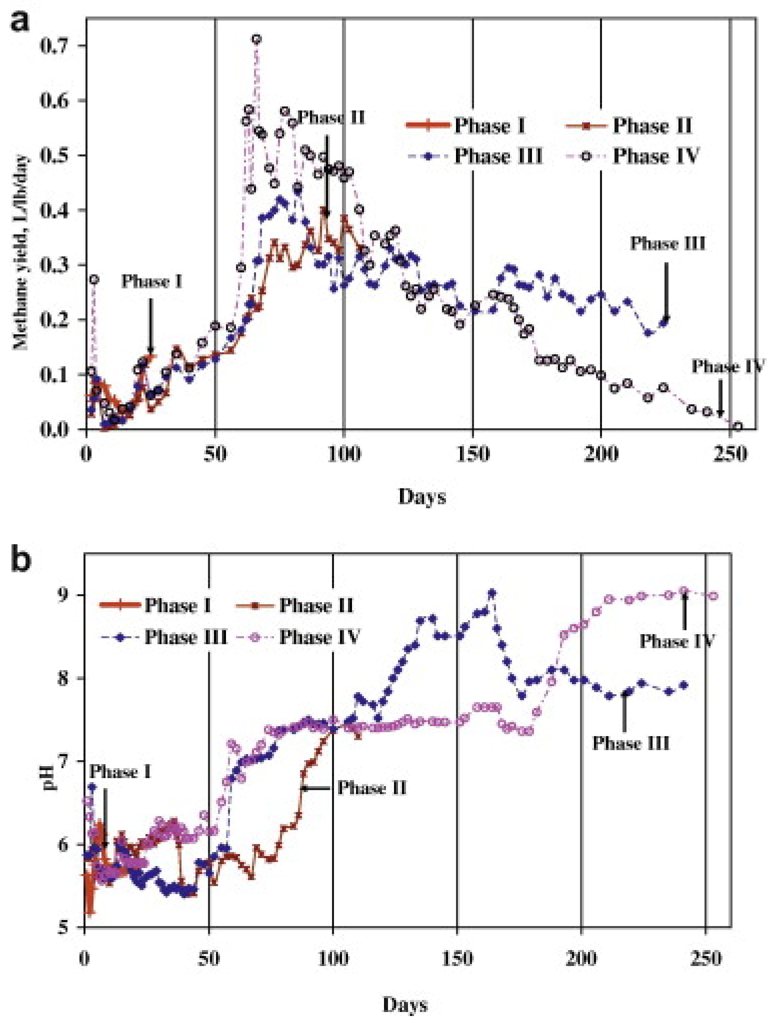


Figure 2.16 a) Rate of gas production and b) pH data at each phase of degradation (Hossain and Haque, 2009)

Temperature variation in landfills can affect the biodegradation and subsequent gas production process profoundly. Two types of bacteria – mesophilic and thermophilic, which are responsible for waste degradation, are largely dependent on temperature for their existence. Optimum temperature range for mesophilic bacteria is 30 to 35°C whereas thermophilic bacteria can survive in higher temperature range such as 45 to 65°C. Although thermophilic bacteria can produce higher gas yield from landfills, the temperature in most landfills remains in mesophilic range. Research by McBean et al. (1995) reported that optimum temperature for accelerated microbial growth and degradation lies in between 30 to 40°C. Temperature under 15°C may inhibit bacterial growth within landfill which will affect biodegradation and further gas generation.

2.6.4 Effects of Rainfall

In an extensive pilot scale study, Chiemchaisri et al. (2004) conducted a study in Bangkok to determine the effect of rainfall on municipal solid waste degradation and gas generation. In this study, four lysimeters were filled up with municipal solid waste and then were monitored under simulated rainfall for one year. The obtained methane content results are presented in the following illustrations (Figure 2.17)

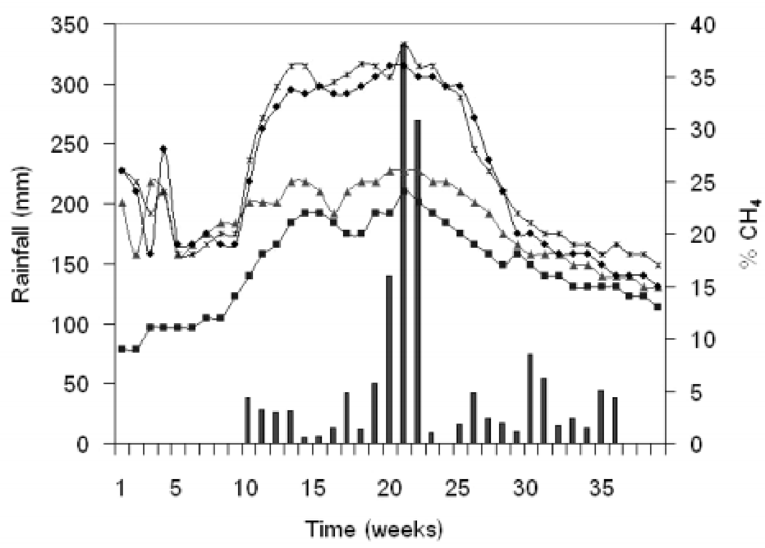


Figure 2.17 Methane content in gas from lysimeters (Chiemchaisri et al. 2004)

The methane content in total gas generation increased in the rainy season which enhanced the microbial growth inside lysimeters.

2.6.5 Effects of Salinity

Landfills may prone to saline water in coastal regions. Researches by Sadek et al. (2000), Khoury et al. (2000) reported that saline water may have some beneficial or detrimental effects on landfill waste degradation process. Khoury et al. (2000) reported that moisture and nutrients addition, and pH buffering plays to create an auspicious environment in landfills. On the other hand, compounds like sulphates has inhibitory effects on biodegradation along with high salinity and high osmotic pressure. In the study of Khoury, he prepared two reactors – one was recirculated with water, and other one was subjected to saline water recirculation. The stages of biodegradation were identified using the COD, TOC, and pH data (Figure 2.18).

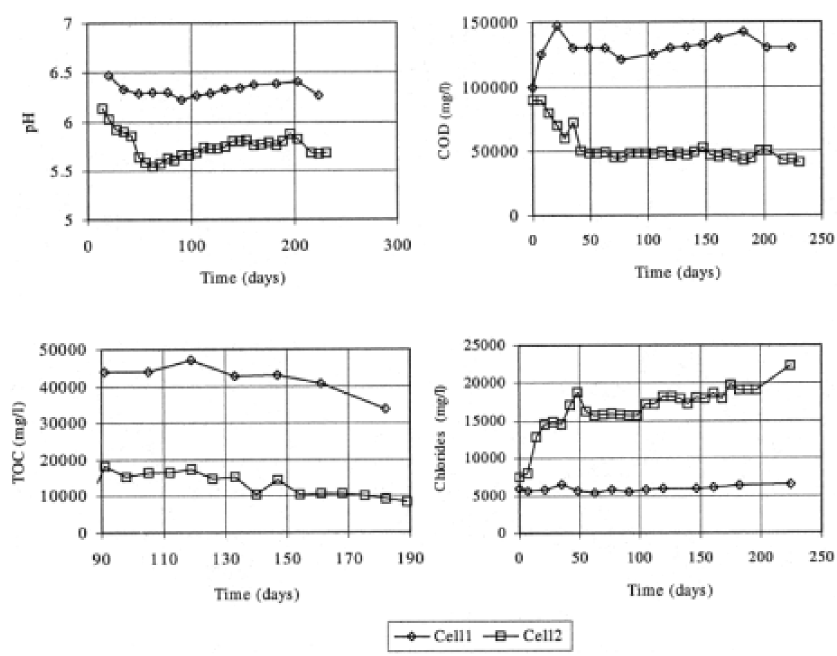


Figure 2.18 pH, COD, TOC, and Chloride variation in leachate (Khoury et al. 2000)

The pH values of both reactors had the same trend but the control reactor generated leachate have higher values than the test reactors. In case of COD, the same higher trend was observed for the control reactor but a gradual decrease in COD was found in the test reactor. The TOC values decreased with time for both reactors which indicates ongoing early stage biodegradation in those reactors. In case of chloride concentration, a high level of chloride was found in the test reactor for the salinity. This affected the overall degradation process in this reactor along with the little presence of heavy metals such as Pb, Cr, and Cd in the initial stage.

Study conducted by Sivanesan (2012) on effects of saline water on Chorpus Christi landfill showed similar kind of biodegradation. In this study, four bioreactors were prepared – two with fresh water recirculation and another two with saline water. Primarily COD values in saline reactors were lower than that of fresh water reactors which specified lower degradation state in saline reactors as shown in Figure 2.19.

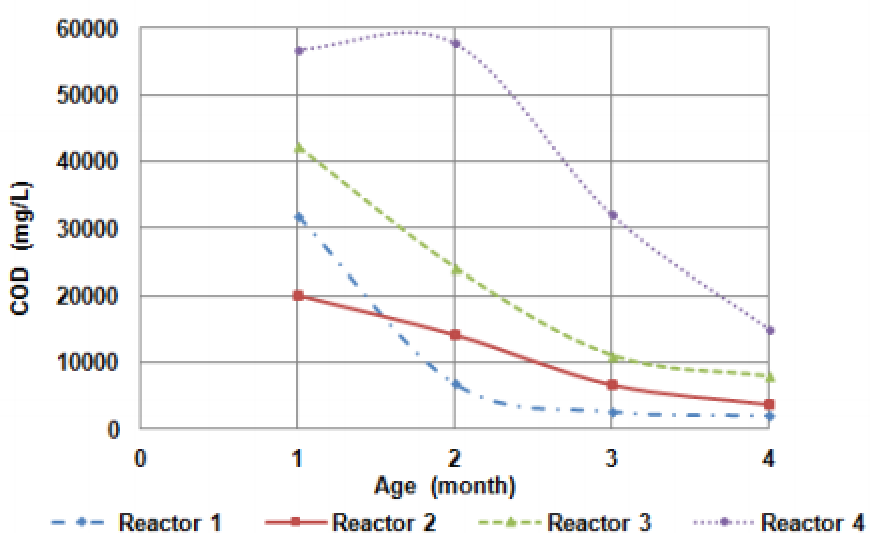


Figure 2.19 COD variation in reactors (Sivanesan 2012)

In case of gas generation salinity induces a lag phase in methane generation from landfills. Study conducted by Al-Kaabi et al. (2010) reported that there is a time lag in methane generation from laboratory scale reactors while their operation with saline water recirculation. It was found that methane production started from saline reactors after 50 days of operation as presented in Figure 2.20.

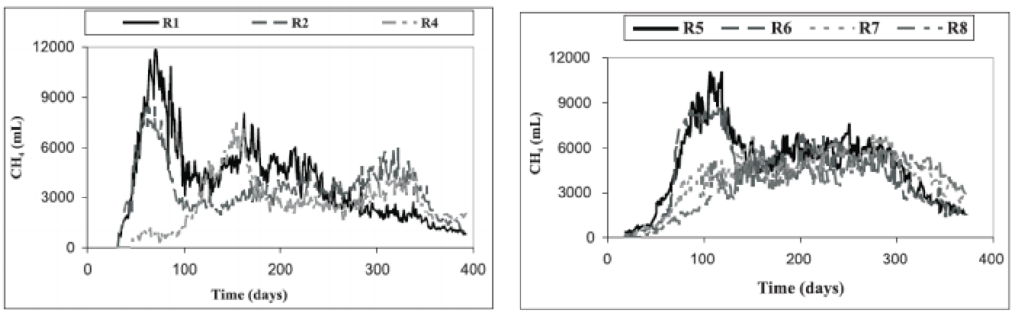


Figure 2.20 Variation of methane production (Al-Kaabi et al., 2002)

The highest gas yield was found from Reactor#5 which was operated with only sludge addition. High osmotic pressure prevailing in saline condition may induced an inhibitory effect in saline reactors which was behind the lag phase of methane production.

2.6.6 Effects of Nano-Zero Valent Iron

Iron nanoparticles are very effective to reduce pollutants like chlorinated organics, metals, and sulfides from the waste water. The effects of nano-zero valent iron was on landfill waste degradation and gas generation was first experimented by Gangopadhyay (2012). Two laboratory scale reactors were prepared in this study. One was a control reactor which was operated using leachate without nanomaterials and the test reactor was operated recirculating leachate with iron nanoparticles. It was found that there is a lag phase in methane generation in test reactor containing nanomaterials. The control reactor reached its peak methane generation after 46 days of operation where test reactor with nanomaterials took 101 days to reach its peak methane content as shown in Figure 2.21.

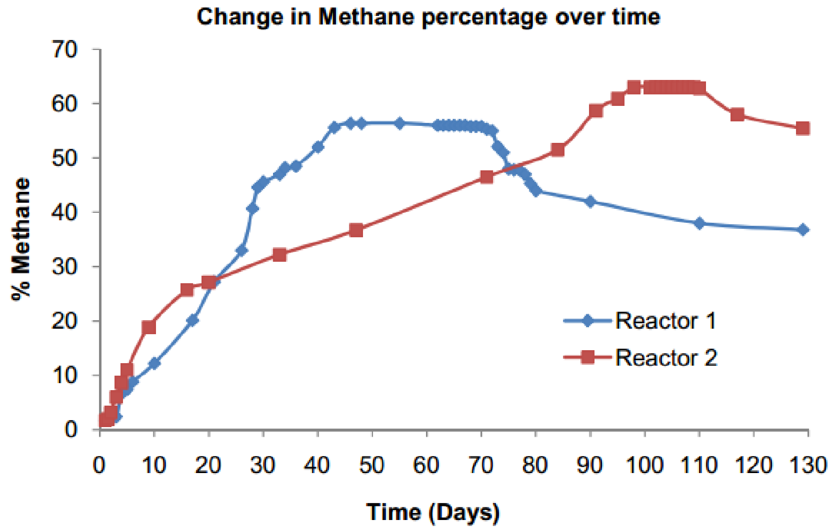


Figure 2.21 Change in methane content over time (Gangopadhyay, 2012)

In case of leachate COD, it was observed that the values were reasonably higher in the test reactor. This is because of the presence of iron nanomaterials which are high oxidation potential. The COD values of the control reactor increased in the acetogenesis phase and then decreased suddenly and got stabilized in the methanogenesis phase (Figure 2.22).

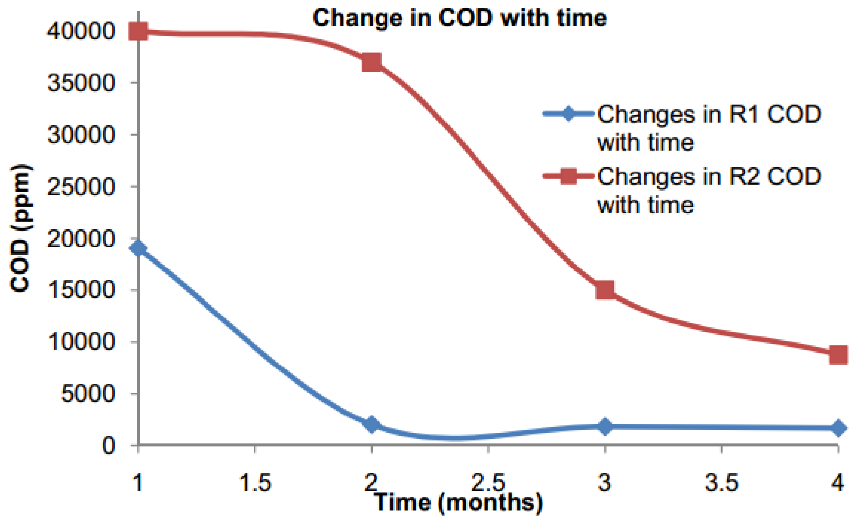


Figure 2.22 COD variation over time (Gangopadhyay, 2012)

2.6.7 Effects of Aerobic and Anaerobic Conditions

Study conducted by Erses et al. (2007) on comparison of aerobic and anaerobic degradation of municipal solid waste reported that aerobic conditions have high efficiency in removal of organic, nitrogen, alkali, and metals from landfill leachate than anaerobic conditions. Two laboratory scale reactors were operated in an insulated room at a constant temperature of 32 ˚ C. Aerobic condition was simulate with an air compressor. From the BOD curve as shown in Figure 2.23, it can be found that biochemical oxygen demand decreased with time in a faster rate for aerobic reactor than the anaerobic reactor.

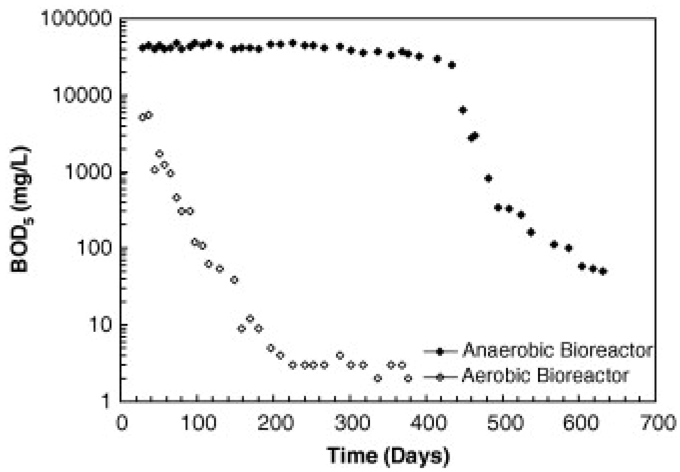


Figure 2.23 Leachate BOD concentrations for Aerobic and Anaerobic conditions (Erses et al. 2007)

Aerobic conditions led to a state where faster removal of COD happened due to the oxidation which took only 90 days. In case of anaerobic reactor, 90% removal of COD took 462 days of operation. From this study, it was found that aerobic conditions are more effective in terms of COD removal and rapid biodegradation of landfill waste.

2.7 Summary

As discussed in the above sections, there are several factors that may cause alteration in landfill waste degradation process and gas generation. A huge amount of corn mill waste is used in the plants to produce ethanol as biofuel every year in US in which a mentionable portion of corn mill waste finds its way into different disposal systems. Bioreactor landfills, as being one of the disposal options for solid waste management, may provide a sustainable solution for corn mill waste disposal. No research or study was undertaken to date to determine the individual effects of corn mill waste on bioreactor landfills operation. In the current study, the effects of processed corn mill waste on solid waste degradation and gas generation if landfilled are determined and assessed.

Chapter 3

Methodology

3.1 Introduction

The objective of the study is to determine the effects of corn waste on degradation of Municipal Solid Waste in bioreactor landfills. This required a series of extensive laboratory tests and a solid experimental setup. This chapter is basically focused on the methods of this laboratory tests and instrumentation of laboratory scale reactors. The physical and hydraulic properties such as composition of waste, permeability of municipal solid waste and corn waste were determined. To measure the degradation potential of the waste mix volatile solids test was performed.

Laboratory scale reactors were built with varying corn – municipal solid waste mix to simulate the landfill environment. pH, BOD5, and COD tests were done on reactor generated leachate.

3.2 Study Location: The City of Denton Landfill

Samples were collected from The City of Denton Landfill. The City of Denton Landfill is located at Mayhill road, Denton, Texas. An aerial view of the Landfill was presented in the following (Figure 3.1).

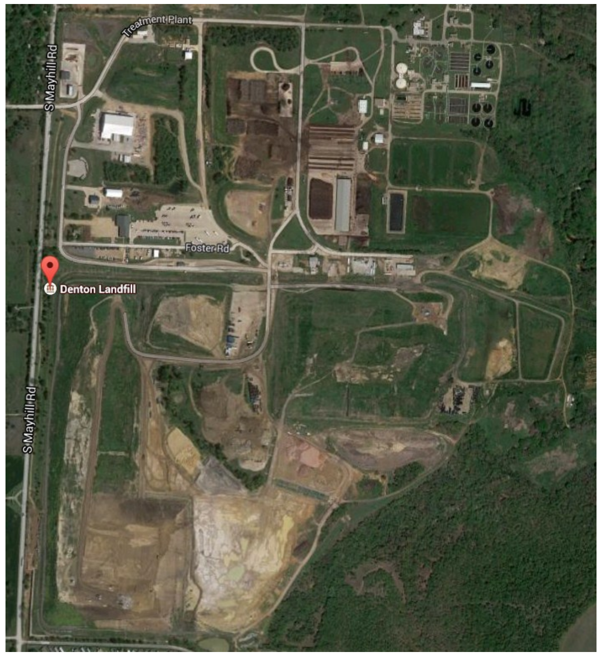


Figure 3.1 Aerial View of City of Denton Landfill

The City of Denton Landfill was built in 1983 and started receiving waste from March, 1983 according to the permit. The initial Cell 1590 which is also known as Cell 0 has an area of 32 acres. In 1998, the landfill area was extended and permit modification was completed to 1590 A. In 2009, the landfill was approved from the Texas Commission on Environmental Quality (TCEQ) for the recirculation of leachate and storm water to enhance the gas production. Every this landfill receives approximately 550 tons of municipal solid waste (MSW), 80% of which is commercial waste and rest of them is residential waste. In total it has an area of 252 acres which is divided into two parts – 152 acres area for waste disposal and 100 acres for establishments like office buildings, composting facility, and buffer zone. An effective leachate collection and recirculation system was designed and installed to operate it as a bioreactor landfill.

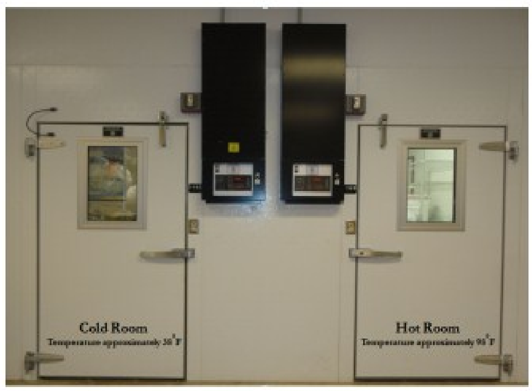
3.3 Collection of waste

Municipal solid waste was collected from the working face of The City of Denton Landfill. Total 10 bags of waste sample were collected in May, 2014.While collecting samples, it was ensured that sample collection is done from random locations. The collected bags were tagged chronologically from 1 to 10. Study conducted by Taufiq (2010) reported that collected MSW sample weight should be in between 25- 30 lb. Therefore, around 25-30 lbs of MSW were collected manually for preparing each sample bag.

Figure 3.2 Sample Collection from the working face of The City of Denton Landfill

Collected samples were brought to the Civil Engineering Laboratory Building in plastic bin bags and were kept inside the environmental growth chamber (cold room) at 4°C (38°F) for preservation of moisture and other initial properties of waste which is shown in Figure 3.2.

a)



b)

Figure 3.2 a) Stored Sample in Cold Room b) Environmental Growth Chamber (Cold Room and Hot Room)

3.4 Experimental program

Physical composition of fresh MSW and Corn Mill Waste was done at the beginning of the experiment. Reactors were prepared with selected MSW and Corn Mill Waste and monitored over time. The pH, BOD, and COD tests were performed on generated leachate in a regular basis. Gas composition and volume were measured depending on the gas production in the gas bags. Total experimental program is presented in the following flow chart (Figure 3.3).

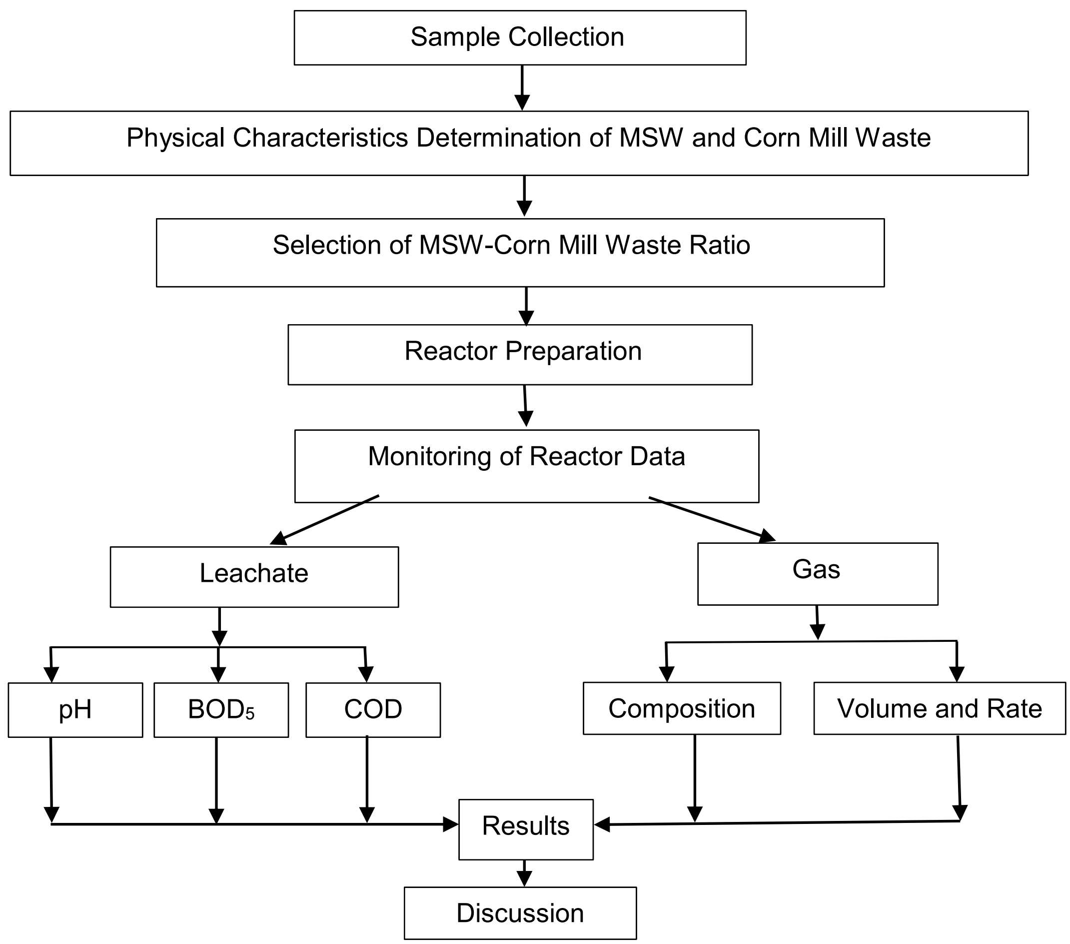


Figure 3.3 Flow chart of Experimental Program

3.5 Physical composition of MSW and Corn Mill Waste

3.5.1 Physical composition of MSW

Physical composition of MSW samples were performed on weight basis by sorting manually and categorized into different components. The components are – food waste, paper, plastic, textile, Styrofoam and sponge, yard and wood waste, metals, glass, construction debris, and others (soils and fines) as shown in Figure 3.4. They were further classified based on their degradability. Food waste, paper, yard and wood waste, and textile comprise the degradable fraction whereas plastic, metals, glass, construction debris, and others fall into non degradable waste fraction. Percentages of degradable and non-degradable portions were then determined to assess the decomposable fraction of the collected MSW.

Figure 3.4 Sorted sample of Municipal Solid Waste

3.5.2 Physical composition of Corn Mill Waste

Corn Mill Waste provided by the City of Denton Landfill was classified by visual observation into three fractions – corn kernel, corn seed heads, and corn cob as shown in Figure 3.5. Both of the fractions were sorted and mixed manually and later used to construct the laboratory reactors.

Figure 3.5 Corn Mill Waste

3.6 Selection MSW-Corn Mill Waste ratio

3.7 Selection of mix ratio of MSW and Corn Mill Waste

MSW-Corn Mill Waste mixing ratio were selected for preparation of laboratory scale reactors. For this purpose four percentages of Corn Mill Waste on weight basis were selected to determine the effects of Corn Mill Waste on MSW degradation. The following Table 3.1 presents the MSW-Corn Mill Waste ratio for reactor preparation.

Table 3.1 Selected Percentage of Corn Mill Waste with MSW

Mixing Ratio No.	Corn Mill Waste (% by weight)	Municipal Solid Waste (% by weight)
1	10	90
2	20	80
3	100	0
4	0	100

3.8 Preparation of laboratory scale reactors

Two sets of reactors were prepared simulating the landfill condition to observe the effects of Corn Mill Waste on MSW degradation. The first set comprising four reactors was prepared using Six gallon PVC buckets. Among these four reactors, three reactors have varying Corn Mill Waste ratios like 10, 20 and 100% and the remaining one was filled with only municipal solid waste. These four reactors are denoted as Reactor-1, Reactor-2, Reactor-3, and Reactor-MSW100 respectively (Table 3.2).

Table 3.2 First set of reactors

Reactor Name	Corn Mill Waste (% by weight)	MSW(% by weight)
REACTOR- 1	10	90
REACTOR- 2	20	80
REACTOR- 3	100	0
REACTOR-MSW100	0	100

The second set comprising three reactors was prepared using laboratory instrumented plastic reactors. These reactors – Reactor-C 10, Reactor-C 20, and Reactor-C 100 have varying MSW and Corn Mill Waste ratios which are presented in Table 3.3.

Table 3.3 Second set of reactors

Reactor Name	Corn Mill Waste (% by weight)	MSW(% by weight)
REACTOR –C10	10	90
REACTOR –C20	20	80
REACTOR –C100	100	0

Tubing at the top of gamma seal and at the bottom of the bucket was done for leachate collection and recirculation, and generated gas collection. At the top and bottom of the reactors geocomposite layers were attached to simulate the landfill liner system (Figure 3.6). Under the bottom geocomposite layer, a gravel layer was provided to ensure better drainage of leachate (Figure 3.7).

Figure 3.6 Geocomposite layer at the bottom of the reactor

Figure 3.7 Bottom gravel drainage layer

3.8.1 Mixing of MSW and Corn Mill Waste

Mixing Corn Mill Waste with MSW was an important step in reactor preparation. Sorted bags of MSW were spread out on the floor and mixed rigorously and then divided into three different portions (Figure 3.8). Corn Mill Waste was added maintaining the selected ratios by weight basis into those MSW samples.

Figure 3.8 Waste mixing

3.8.2 Reactor filling with waste mix

Reactors were filled by hand with waste mixes of varying ratios which is shown in Figure 3.9. While filling each lift of waste mix, water was sprayed to ensure uniform mixing and better microbial activity in the initial phase.

Figure 3.9 Filling of waste by hand

3.8.3 Sealing of reactors

Each joint of tube connectors and gamma seals was sealed with silicon sealants to negate the possibility of leakage as shown in Figure 3.10.

Figure 3.10 Sealing reactors with silicon sealants

3.8.4 Instrumentation of gas collection system

Gas collection bags were installed to collect the generated gas from the reactors. Five layer gas sampling bags were used to collected reactor produced gas which has a storage volume of 20L as shown in Figure 3.11.

Figure 3.11 Gas sampling bag

3.8.5 Instrumentation of leachate collection system

Leachate collection bags were installed at the bottom of the reactors to collect the generated leachate from reactors. For this purpose medical drainage bags (capacity 20L) were installed at the bottom of the reactors (Figure 3.12).

Figure 3.12 Leachate drainage bag

The complete reactor setup is shown schematically in Figure 3.13.

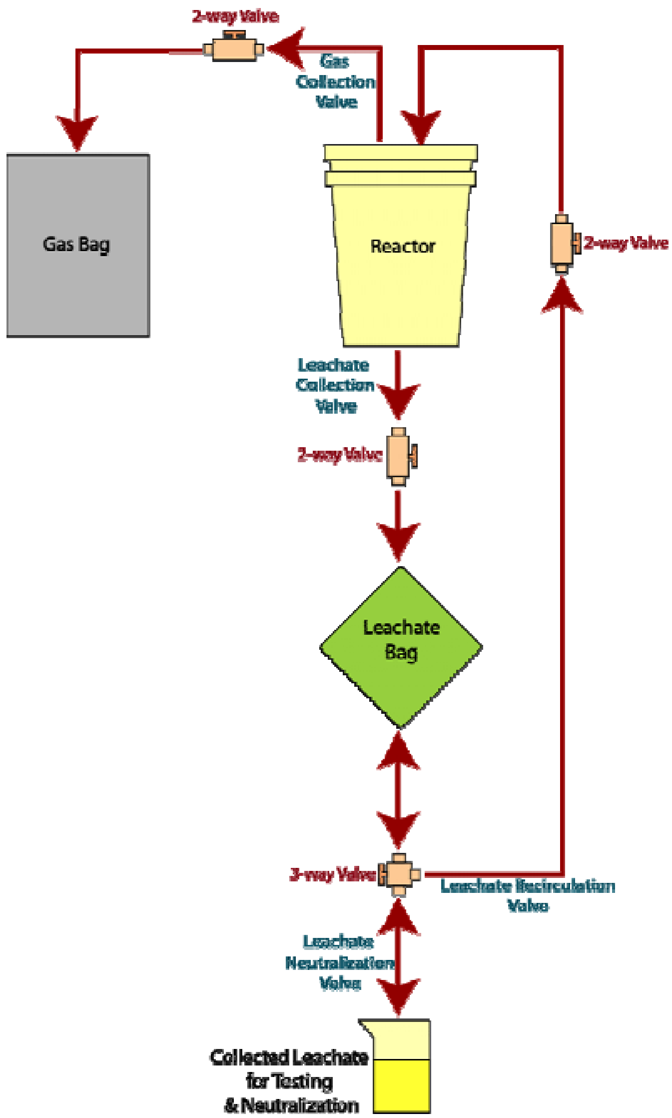


Figure 3.13 Schematic of reactor operation

These reactors are being kept in the environmental growth hot chamber for enhanced microbial activities as shown in Figure 3.14.

Figure 3.14 Reactors in environmental growth chamber (Hot room)

3.9 Reactor Monitoring

Reactors are operated and monitored in a routined way which includes several activities such as collection of generated leachate, recirculation of leachate, leachate quality monitoring, reactor produced gas collection, and measurement of gas quantity and composition. These activities are discussed in the following subsections.

3.9.1 Leachate collection and recirculation

In the initial days, water was added in each reactor to increase the moisture content to ensure higher decomposition. Reactor generated leachate was collected in a weekly basis and leachate properties such as pH, BOD, and COD were measured. Volume of the generated leachate also measured using graduated cylinder and then 1L of leachate recirculated in respective reactors. If the generated leachate is less than 1L, water was added to ensure 1L of recirculated leachate. In the initial phases pH of leachate was as low as 5. Therefore, before recirculating in the reactors, KOH was added to the leachate to ensure a basic condition which allows effective microbial activities.

3.9.2 Leachate quality monitoring

3.9.2.1 pH

The pH of the generated leachate was measured using bench top Oakton pH meter as shown in Figure 3.15. To ensure precise reading pH meter was kept inside a buffer solution to maintain a neutral pH of 7.

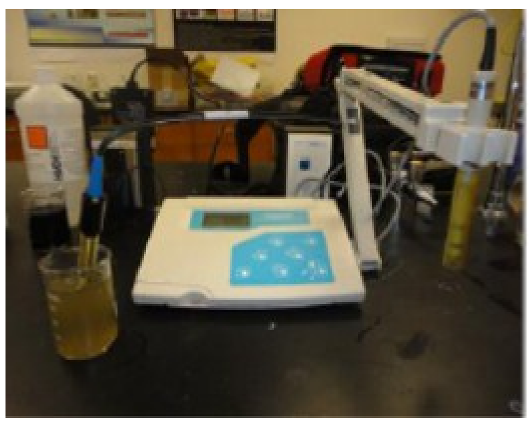


Figure 3.15 Measuring pH of collected leachate sample

3.9.2.2 Chemical Oxygen Demand (COD)

Chemical Oxygen Demand (COD) tests of leachate samples were performed in a spectrophotometer (Spectronic 200+). The main principal of spectrophotometer is that it determines the absorbance of light by each sample and gives an absorbance value. Samples were prepared by pouring 2.5 mL of diluted leachate sample into vials and putting them into the digester at 150°C temperature for 2 hours as shown in Figure 3.16 and Figure 3.17. Two trials of each sample were performed.

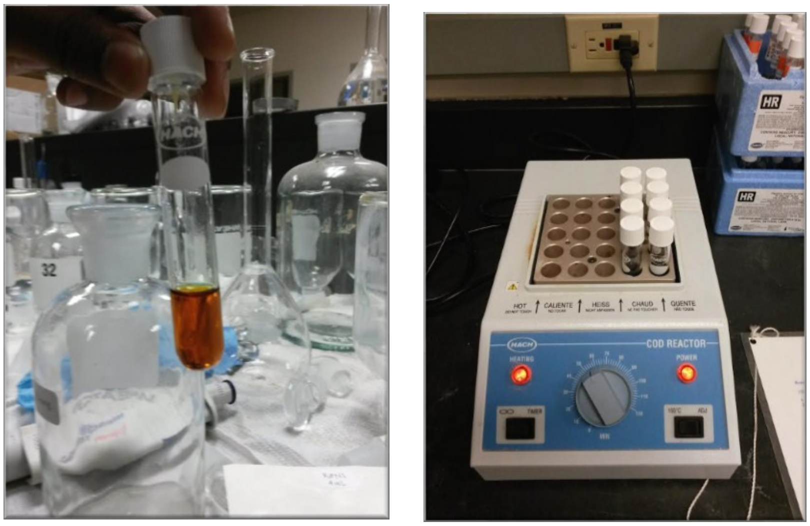


Figure 3.16 a) COD vial b) Heating of vials in digester

The heated samples were then placed into the spectrophotometer to determine the absorbance values.

Figure 3.17 Absorbance measurement in Spectrophotometer (Spectronic 200+)

To obtain the COD values a calibration curve was generated which is shown in Figure 3.18 and COD values were determined from the corresponding absorbance values. The obtained values were then adjusted according to dilution factor of the samples.

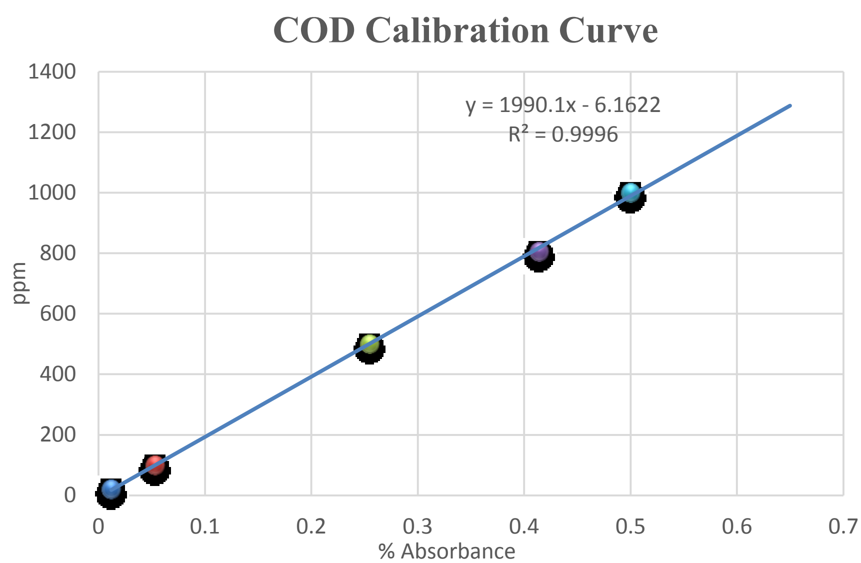
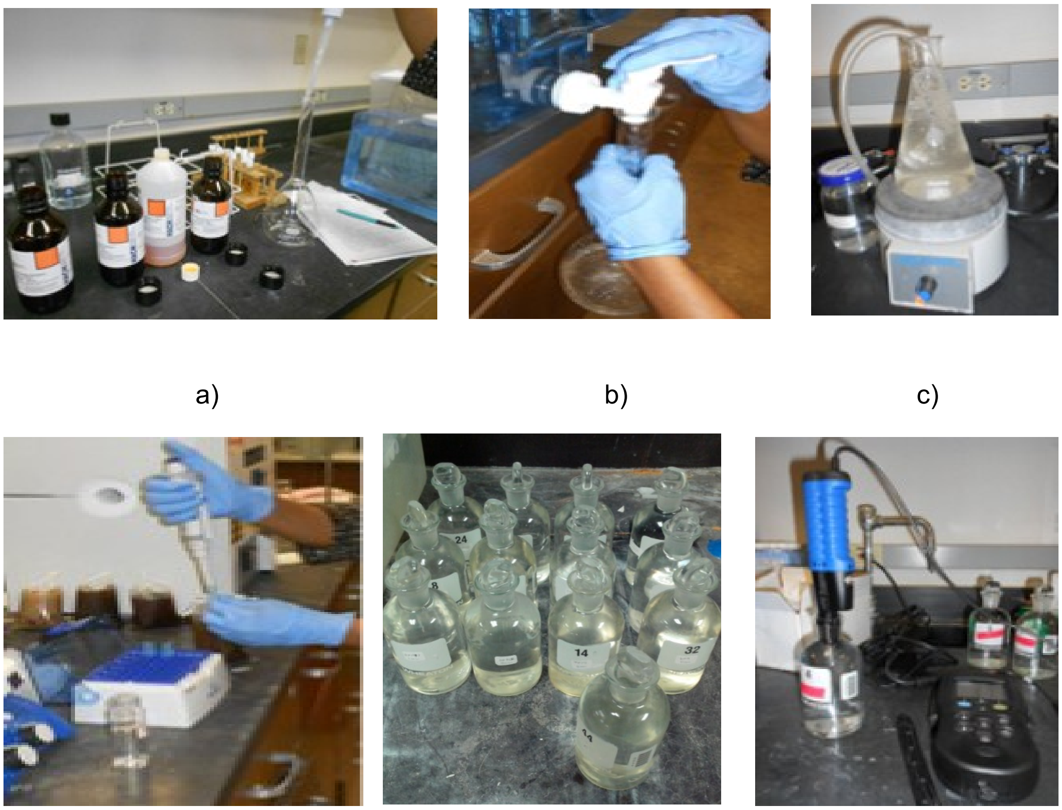


Figure 3.18 COD calibration curve

3.9.3 Biochemical Oxygen Demand (BOD)

BOD_5 tests were done following the Standard BOD Procedure 8043. Tests were conducted using seeded samples and a dilution factor of 100. Samples were triplicated and initial dissolved oxygen was measured. The samples were kept at 20 ^{0} C temperature for 5 days and after that final dissolved oxygen was measured. Anomalous results were discarded and acceptable values were averaged to obtain BOD_5 variation with time. The BOD test procedure is shown in Figure 3.19.



a) b) c)

d) e) f)

Figure 3.19 BOD Test Procedure a) Dilution water preparation, b) Deionized water addition with chemicals, c) Hydration of seed, d) Sample dilution, e) BOD bottles preparation and f) DO measurement

3.9.4 Generated gas collection and measurement

3.9.4.1 Composition of gases

Generated gas was collected and volume and composition of gases were measured in a regular basis. Five layer gas bags were used to collect the gas. Composition of the collected gases was measured using Landtec GEM 2000. This instrument measured the concentration of methane (CH_4), carbon-di-oxide (CO_2), oxygen (O_2), and trace gases in the gas bags. The procedure is shown in Figure 3.20.

Figure 3.20 Gas composition determination by Landtec GEM 2000

3.9.4.2 Volume of collected gas

Volume of collected gas was measured using an air sampling pump (Universal XR Pump Model 44XR) and Defender 330. The fixed rate of flow of gas was measured at the beginning of the sampling and time was recorded with a stopwatch until the gas bags are completely empty. The process of volume measurement is shown in Figure 3.21.

Figure 3.21 Gas sampling with Universal Sampler and Defender 330

Chapter 4

Results and Discussions

In this chapter the results obtained from laboratory instrumented reactors and tests are presented and analyzed to evaluate the effects of Corn Mill Waste in municipal solid waste degradation in landfills. A total of 10 MSW samples were collected from the working phase of The City of Denton Landfill. Among the collected 10 bags of MSW, 3 bags of sample were sorted out to determine the physical composition and moisture content of fresh waste. Corn waste was also provided by the Denton Landfill authority.

A total of seven reactors were constructed to simulate the landfill condition in laboratory. The reactors were prepared using varying Corn-MSW mix ratio to observe the degradation phase. Reactor generated leachate was studied by determining the pH and chemical properties such as BOD and COD to assess the microbial activity and respective degradation phase. Composition, volume and rate of reactor generated gases were also measured and reported accordingly.

The following subsections will discuss about the physical composition of MSW, quality of generated leachate, and composition and generation of gases.

4.1 Physical composition of MSW

A total of 10 bags of sample were collected from the working face of the City of Denton Landfill. Among those bags, 3 bags of sample were selected randomly and sorted out manually and physical composition was determined on the weight basis. Results obtained from physical composition of each bag are presented in the following Table 4.1 and Figure 4.1, Figure 4.2, and Figure 4.3.

Table 4.1 Physical Composition of MSW (% by weight)

Bag no.	Paper	Plastic	Food waste	Textile and leather	Yard and wood waste	Metals	Glass	Styrofoam and sponge	Construction and demolition debris	Others
4	36.55	18.49	6.81	1.51	3.54	5.94	2.92	2.6	0	21.65
7	32.57	29.89	0.74	8.37	8.37	3.19	0	4.51	0	12.35
10	18.5	22.61	3.93	2.53	11.25	9.2	0	4.2	6.08	21.71
Average	29.19	23.66	3.84	4.14	7.72	6.11	0.97	3.77	2.03	18.57
Standard Deviation	9.48	5.77	3.04	3.70	3.90	3.01	1.69	1.03	3.51	5.39
Maximum	36.55	29.89	6.81	8.37	11.25	9.2	2.92	4.51	6.08	21.71
Minimum	18.5	18.49	0.74	1.51	3.54	3.19	0	2.6	0	12.35

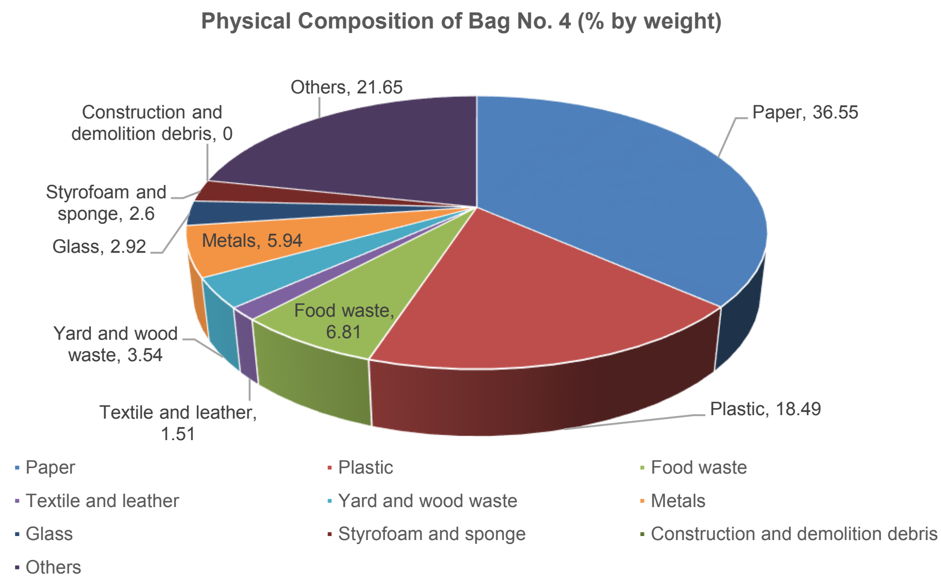


Figure 4.1 Physical Composition of Bag No. 4

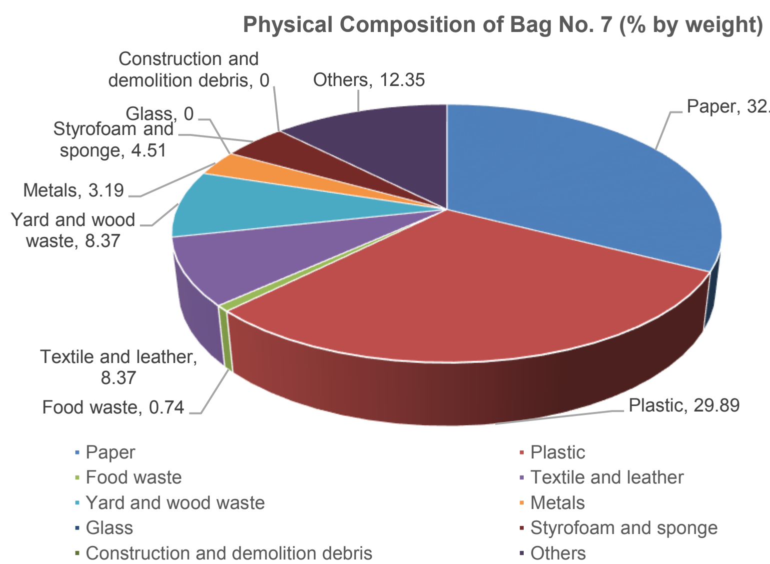


Figure 4.2 Physical Composition of Bag No.7

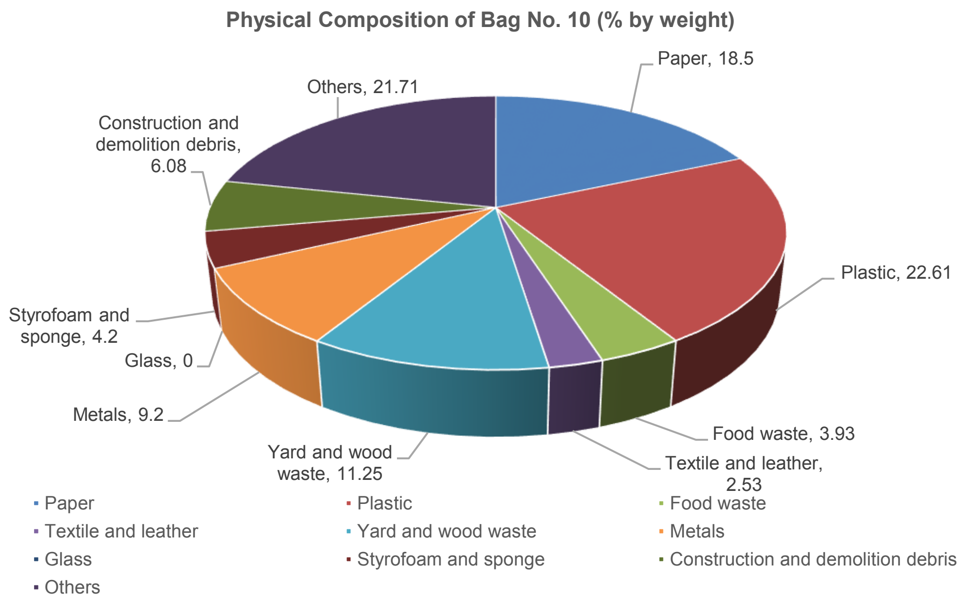


Figure 4.3 Physical Composition of Bag No.10

Based on the average physical composition in Figure 4.4, it was found that paper was the major component having a percentage of 29.19% on a weight basis. Plastic percentage was 23.66% on weight basis whereas food waste was relatively low in the sample bags.

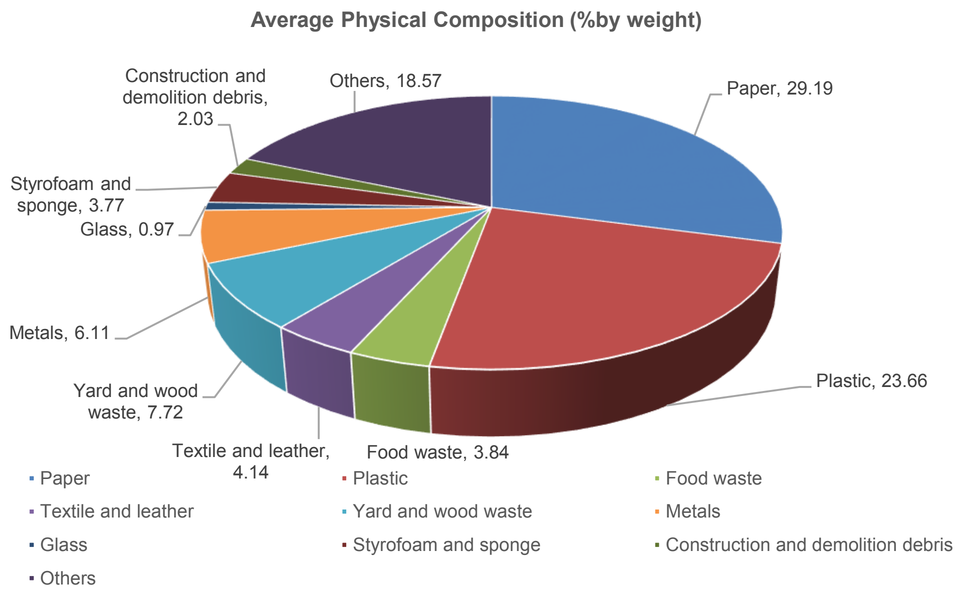


Figure 4.4 Average physical composition of MSW (%by weight)

The samples were also categorized in degradable and non-degradable sections which are presented in Table 4.2. A comparison of degradable and non-degradable components of sorted sample bags is presented in Figure 4.5.

Table 4.2 Degradable and non-degradable fractions in each sample bag

Bag No.	**Physical Composition (by degradability)**	
	Degradable (%)	**Non-degradable (%)**
4	48.41	51.6
7	50.05	49.94
10	36.21	63.79
Average	44.89	55.11

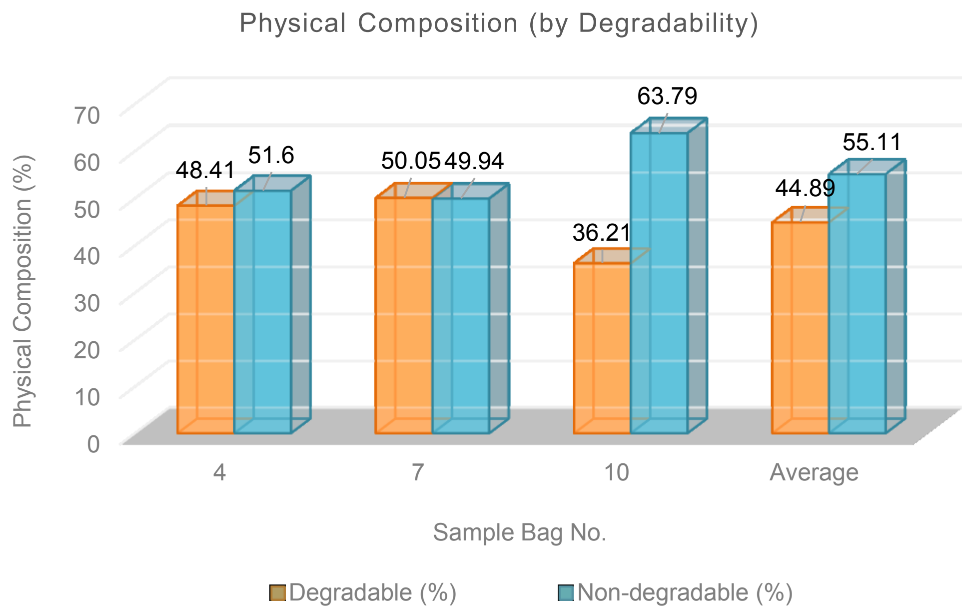


Figure 4.5 Degradable and Non-degradable component in each bag

Comparison of average physical composition of MSW among U.S.EPA, Texas (TNRCC, 2005), and the current study were done and presented in the following Table 4.3. It was found that paper percentage in the current study was higher than that of national average and close to Texas average which gives an indication of more degradation and methane generation. Plastic percentage found in current study is also higher than both of national and Texas average which implies adverse impacts on waste degradation, settlement, and gas generation as plastic is a non-degradable component. National average of food waste is way higher than Texas and the current study. More food waste indicates more rapid degradation in initial days of operation

Table 4.3 Comparison of physical composition of MSW

Components	U.S.A (U.S. EPA 2012),%	Texas (TNRCC 2005), %	Current Study, (2014),%
Paper	14.8	36	29.19
Plastic	17.6	8	23.66
Food waste	21.1	9	3.84
Textile	11.2	-	4.14
Yard trimming	8.7	20	7.72
Wood and Yard waste	8.2	6	
Metal	9	5	6.11
Glass	5.1	5	0.97
Styrofoam	-	-	3.77
C&D debris	-	-	2.03
Others	4.3	11	18.57
Total	100	100	100
%Degradable	64	71	44.89
%Non-degradable	36	29	55.11

. The total degradable fraction obtained in the current study was less than the national and Texas averages which makes non-degradable fraction higher than both of the averages. Comparison among them are shown graphically in the following Figure 4.6.

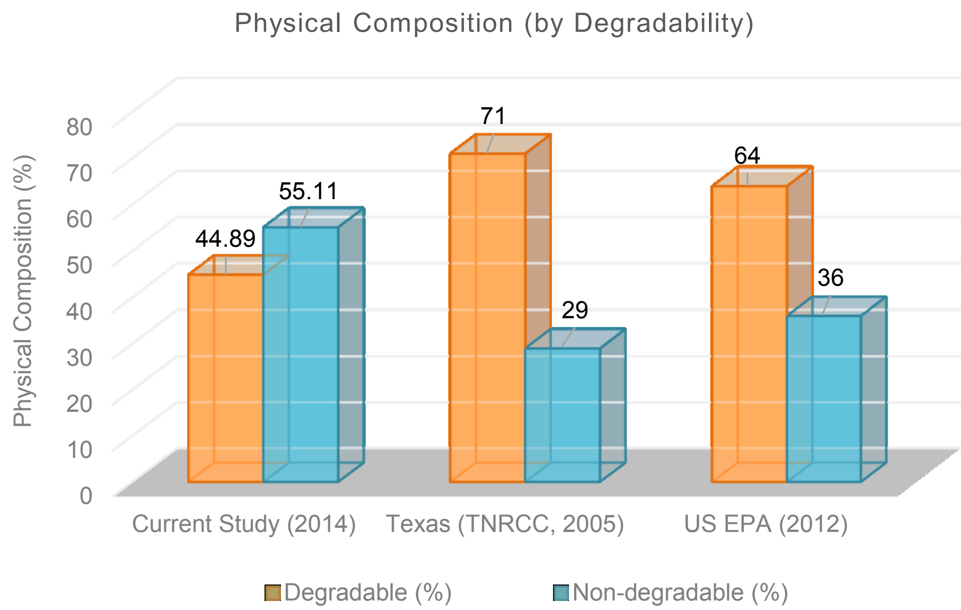


Figure 4.6 Comparison among Texas (TNRCC, 2005) and US EPA (2012) Composition with Current Study

4.2 Physical Composition of Corn Mill Waste

Corn mill waste provided by the City of Denton Landfill was classified by visual observation into three fractions – corn kernel, corn seed heads, and corn cob. These three fractions were already mixed when provided and later again mixed with municipal solid waste following selected ratios to construct the laboratory reactors.

4.3 Characteristics of generated leachate

Characteristics of the generated leachate such as pH, Biochemical oxygen demand (BOD), and chemical oxygen demand (COD) from the bioreactors are discussed in the following sections.

4.3.1 pH

Leachate generated from reactors was collected and pH was measured by Oakton pH meter. In the initial days of the reactors, the frequency of pH measurement was higher as the pH level was important to evaluate the state of degradation. Therefore for the first 30 days, pH was measured more frequently than the rest of the active time of the reactors. After first 30 days, ph was measured once in a week. The pH variation over time in all reactors are shown in Figure 4.8.

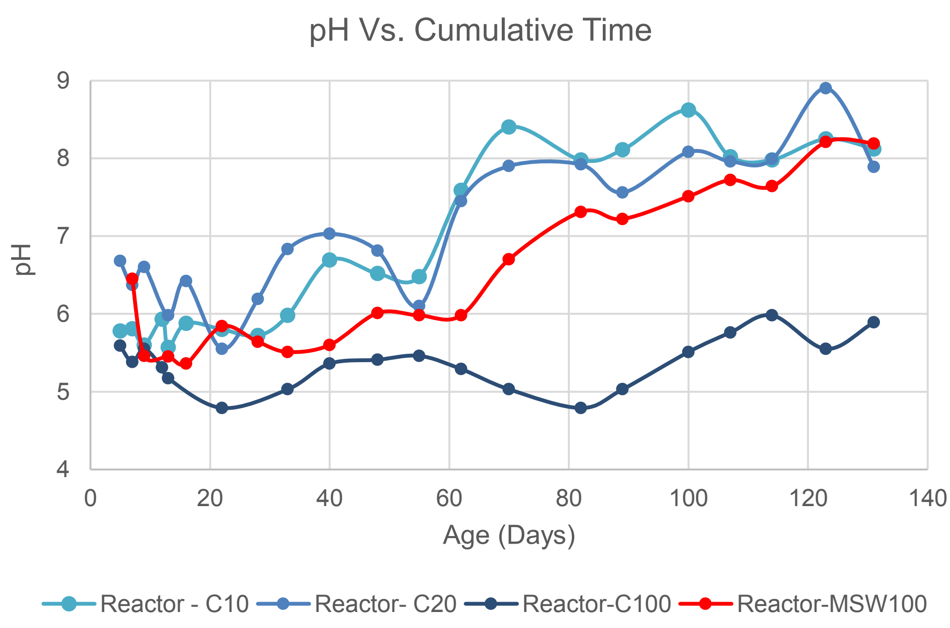


Figure 4.7 pH variation over time in laboratory reactors

In the initial days, pH level of the reactors were less than 7. This acidic phase existed because of the ongoing acid accumulation state in waste degradation. The initial pH levels of the reactors REACTOR-C10, REACTOR-C20, REACTOR-C100, and REACTOR-MSW100 are 5.78, 6.68, 5.38, and 6.84 respectively. Decreased pH level continued up to 33 days for REACTOR-C10, 28 days for REACTOR-C20, and 62 days for REACTOR-MSW100. A gradual rise in pH level was observed afterwards in these reactors which later got stabilized but fluctuated in between 7 and 8. This is due to the conversion of carboxylic acid into methane and carbon-di-oxide which is an indication of the fourth phase of biodegradation. The pH increased up to 8.62, 8.08, and 7.51 for the reactors REACTOR-C10, REACTOR-C20, and REACTOR-MSW100 respectively and got settled in the basic state for the rest of their active period.

In case of reactor REACTOR-C100 which has 100% Corn Mill Waste, pH was around 5-6 till the reactor age of 137 days. This happened due to the late degradation of Corn Mill Waste which was noticeably non-decomposed in shape. The pH value for this reactor's leachate went down up to 4.79 which were observed at the age of 82 days.

The pH variations with time of reactors REACTOR-C10, REACTOR-C20, REACTOR-C100, and REACTOR-MSW100 are shown in the following Figure 4.9.

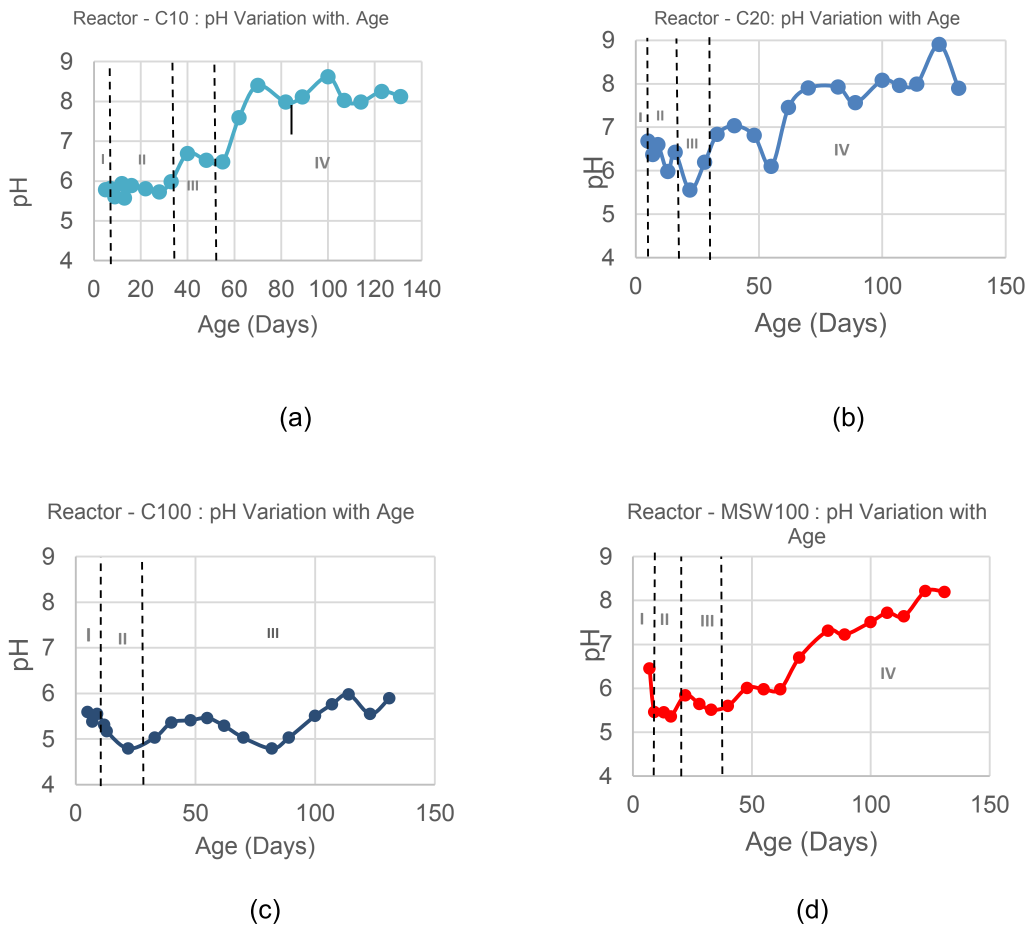


Figure 4.8 pH variation in different degradation phases with time in a) Reactor – C10 (10% Corn), b) Reactor – C20 (20% Corn); c) Reactor-C100 (100% Corn), and d) Reactor-MSW100 (100% MSW)

Degradation phases in reactors in relation to the pH level variation can be summarized in the following Table 4.4.

Table 4.4 Phases of degradation with change in pH levels

Degradation Phase	REACTOR-C 10 (10% Corn)		REACTOR-C 20 (20% Corn)		REACTOR-C 100 (100% Corn)		REACTOR-MSW100 (100% MSW)	
	pH	**Time (Days)**	**pH**	**Time (Days)**	**pH**	**Time (Days)**	**pH**	**Time (Days)**
I	6-7	0-8	6-7	0-7	5.5-6	0-9	6-7	0-8
II	5-6	8-20	5-6	7-16	5-6	9-82	5-6	8-18
III	6.5-7	20-35	5.5-7	16-25	4.5-6	82-	6.5-7.0	18-30
IV	>7	35-120	>7	25-120			>7	30-132

According to the degradation phases based on pH results, reactors containing 20% Corn reached the methanogenesis phase quicker than other reactors. It took only 25 days whereas reactors Reactor-C10 and Reactor-MSW100 took 35 and 30 days respectively. In case of Reactor-C100, the methanogenesis phase was yet to be achieved due to the lag phase.

Warith et al. (2002) recorded change in pH with time which is in accordance with the obtained results from the reactors operated this study. Reactors REACTOR-C10, REACTOR-C20, and REACTOR-MSW100 exhibited similar trends except for the 100% Corn mill reactor, REACTOR-C100. The pH variation over time in that study is presented in Figure 4.10.

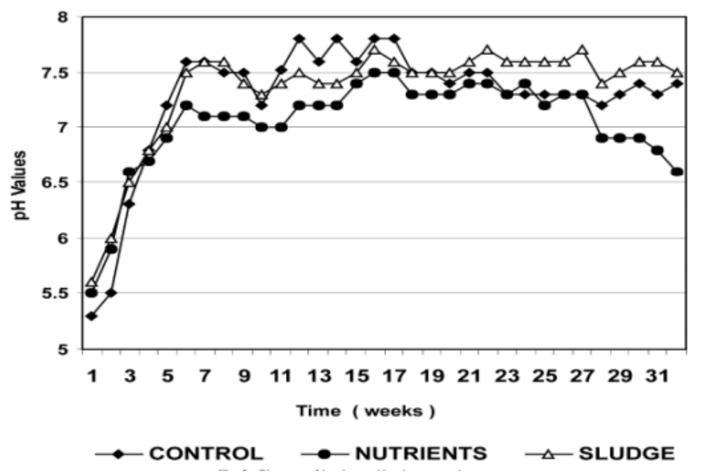


Figure 4.9 Changes in pH of leachate with time (Warith et al. 2002)

4.3.2 Chemical oxygen demand (COD)

Chemical Oxygen Demand (COD) tests were conducted in a monthly basis. Results obtained from COD tests are presented in Table 4.5 and also shown graphically in Figure 4.11.

Table 4.5 Monthly COD Test Results

Month	**COD (mg/L)**			
	REACTOR-C 10 (10% Corn)	**REACTOR-C 20 (20% Corn)**	**REACTOR-C 100 (100% Corn)**	**REACTOR-MSW100 (100% MSW)**
June	107000	92500	9100	84000
July	93600	58300	16500	74250
August	80000	33750	19750	57500
September	8750	8500	15000	31800

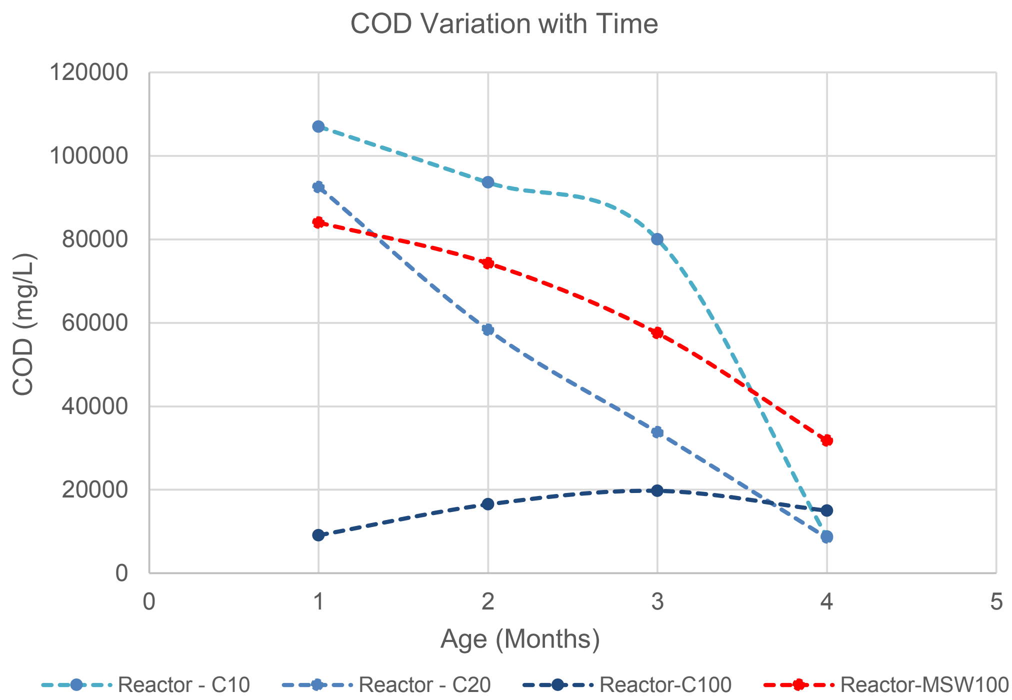


Figure 4.10 Change in leachate COD with time

At the end of the first month, COD values of REACTOR-C10, REACTOR-C20, REACTOR-C100, and REACTOR-MSW100 are 10700 mg/L, 92500 mg/L, 9100 mg/L, and 84000 mg/L respectively. Thereafter the COD values started to decrease for REACTOR-C10, REACTOR-C20, and REACTOR-C100 reactors and at the end of the fourth month, COD values of these reactors are 8750 mg/L, 8500 mg/L, and 31800 mg/L. In case of REACTOR-C100, the COD values were always in the lower side as the initial COD was 9100 mg/L. COD values increased gradually in after 2nd and 3rd month and then decreased again at the end of 4th month. The COD value of this reactor after 4th month was 15000 mg/L.

4.3.3 Biochemical Oxygen Demand (BOD)

Biochemical Oxygen Demand (BOD_5) tests were performed on a monthly basis to measure the microbial concentration to oxidize carbon and nitrogenous compounds in leachate. The results are presented in Table 4.6 and plotted in Figure 4.12.

Table 4.6 BOD variation with time

Month	**BOD (mg/L)**			
	REACTOR-C 10	**REACTOR-C 20**	**REACTOR-C 100**	**REACTOR-MSW100**
	(10% Corn)	**(20% Corn)**	**(100% Corn)**	**(100% MSW)**
June	72418.75	76783.3	27325	60525
`	42142.71	45050	12978.57	48675
August	30504.02	32946.43	15383.52	31842.86
September	16959.4	21766.7	8697	7958

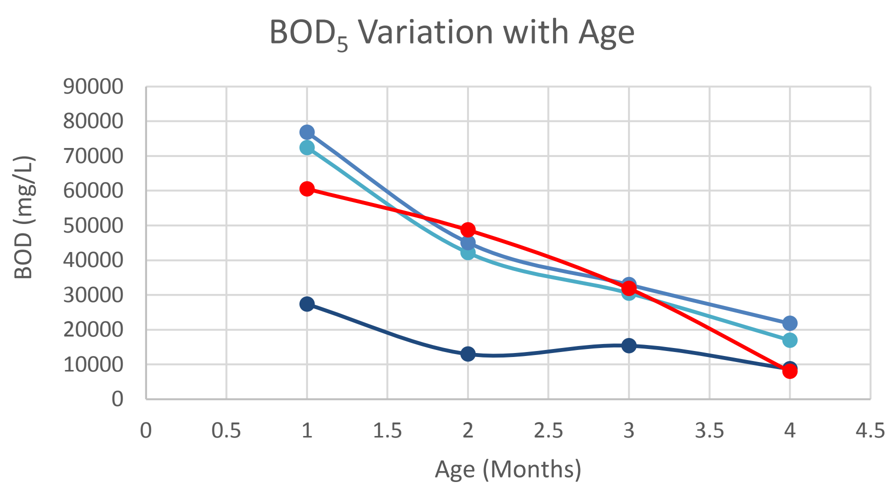


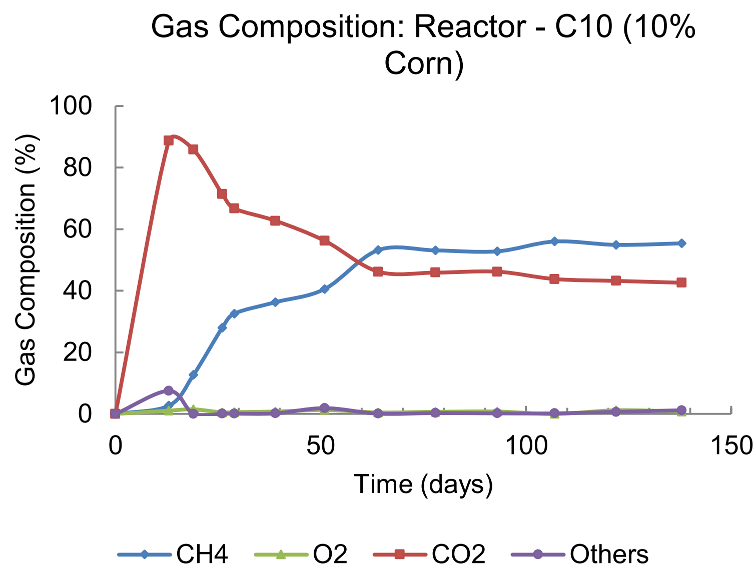
Figure 4.11 BOD variation over time

From the obtained results it was found that BOD_5 decreased gradually for each reactor with time. The maximum BOD_5 values were 72418.75 mg/L, 76783.3 mg/L, 29291.67 mg/L, and 60525 mg/L for REACTOR – C10, REACTOR – C20, REACTOR – C100, and REACTOR – MSW100 respectively. From the study of Barlaz et al. (1993) highest BOD values are reported in acetogenic phase. In the current study, it was found that after one month of operation each and every reactor was in acetogenesis degradation phase which complies with the study results of Barlaz et al. (1993). The BOD values were always on the lower side for REACTOR-C100.

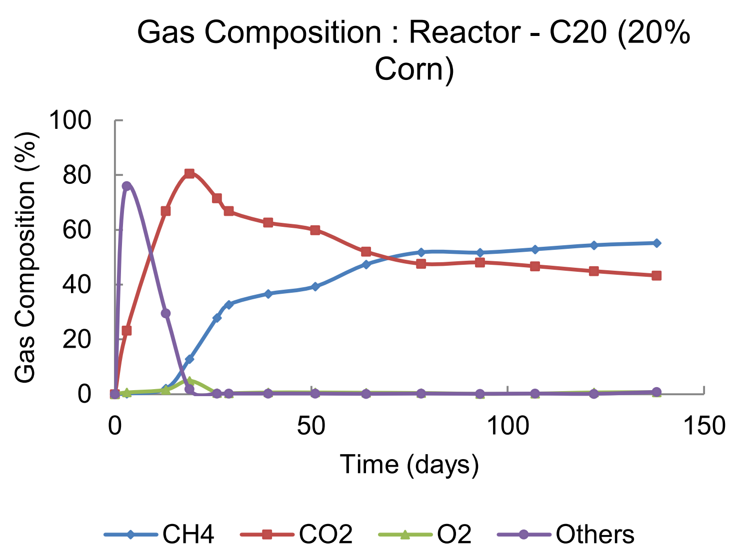
4.4 Gas data from the Reactors

4.4.1 Gas composition

In the initial days, oxygen depleted severely leading to an anaerobic condition inside reactors and amount of carbon-di-oxide increased over time. Three reactors – REACTOR-C10, REACTOR-C20, and REACTOR-MSW100 showed similar trends except the REACTOR-C 100 reactor which contained 100% Corn Mill Waste. Increasing carbon-di-oxide reached the peak at 13, 19, 13, and 26 days for REACTOR-C10, REACTOR-C20, REACTOR-C100, and REACTOR-MSW100 reactors respectively and then decreased gradually for all reactors. This increase in volume of carbon-di-oxide was due to the acetogenesis phase where degradable organic compounds were broken into simpler compounds like carbon-di-oxide and water vapor. Over time carbon-di-oxide percentage decreased and methane percentage increased simultaneously for all of the reactors except REACTOR-C100 (100% Corn Mill Waste) reactors. In this specific reactor methane percentage was always lower than carbon-di-oxide percentage although a noticeable increasing trend of methane was observed from 107 days of reactor age. Compositions of gases generated from the reactors REACTOR-C10, REACTOR-C20, REACTOR-C100, and REACTOR-MSW100 are shown in Figure 4.13 .



a)



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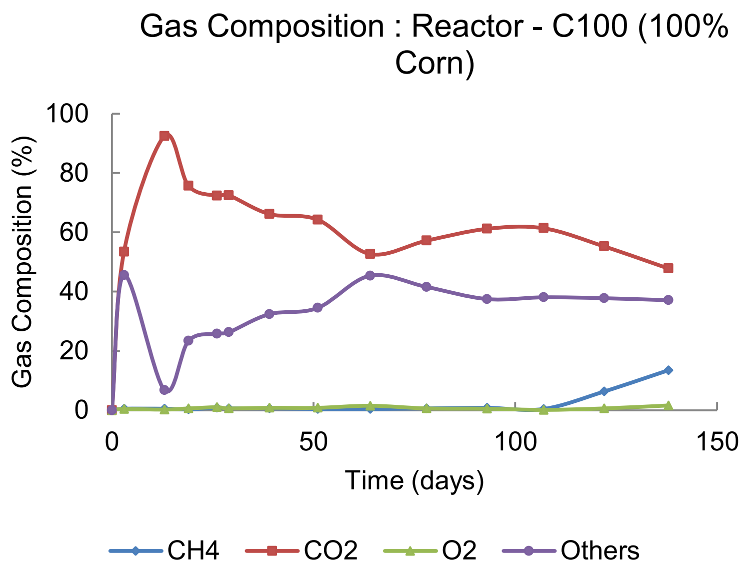

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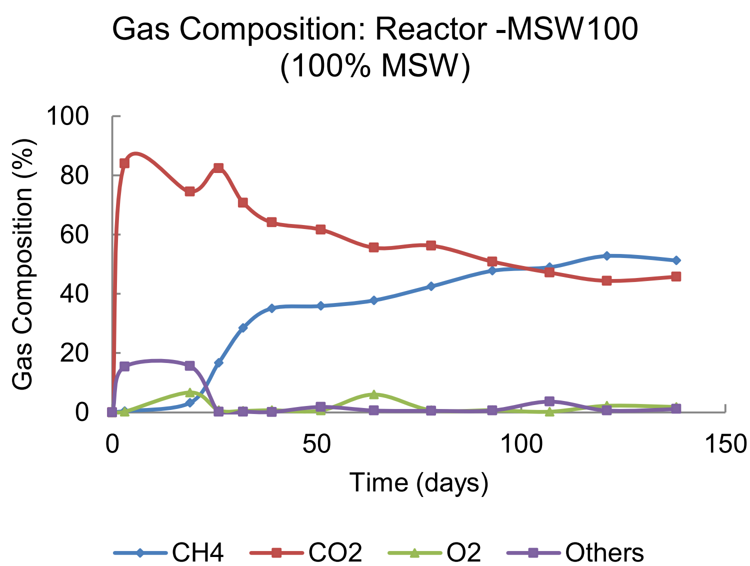

d)

Figure 4.12 Gas compositions of a) REACTOR-C 10, b)REACTOR-C 20, c) REACTOR-C 100, and d) REACTOR-MSW100

This increasing methane and decreasing carbon-di-oxide scenario can be easily conceived after observing the trend of CH_4: CO_2 curve with time as shown in Figure 4.14. The ratio between methane and carbon-di-oxide increased gradually for all reactors except REACTOR-C100 which showed a flat trend up to 107 days and a sudden rise afterwards.

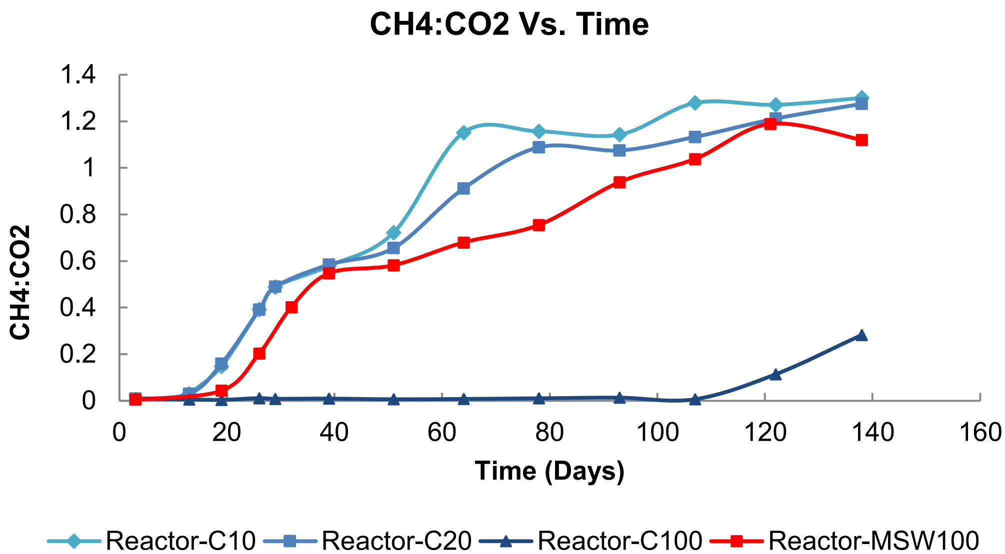

Figure 4.13 Methane to Carbon-di-oxide ratio over time

4.4.2 Volume of generated gas

Total gas generated from reactors REACTOR-C 10, REACTOR-C 20, REACTOR-C 100, and REACTOR-MSW100 with time is shown in Figure 4.15. It was observed that Reactor-C 10 containing 10% Corn Mill Waste (weight basis) generated highest amount of gas than others. Reactor-MSW100 which was filled with 100% MSW generated less amount of gas in compared to others.

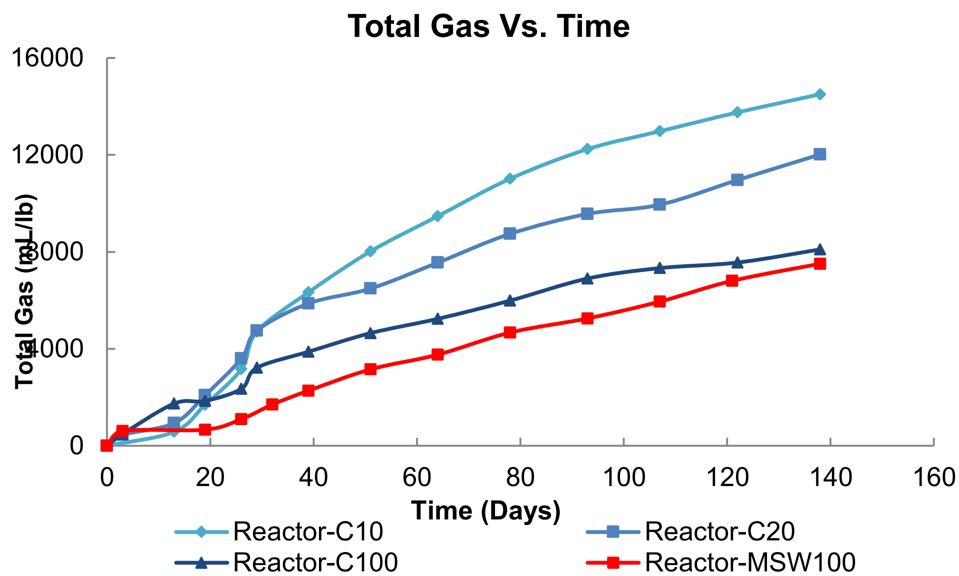

Figure 4.14 Total gas generated in reactors with time

At the very beginning, it took 13 days for REACTOR-C 10 to generate some gas while other reactors started producing gas just after 3 days of operation. At the age of 20 days, reactors REACTOR-C 10, REACTOR-C 20, REACTOR-C 100, and REACTOR-MSW100 produced 1.7 L/lb, 2.1 L/lb, 1.8L/lb, and 0.6 L/lb gas respectively. After 20 days, there was a rise in gas generation observed in all reactors which later was stabilized after 40 days of operation.

Cumulative methane generation with time shows almost a similar trend like total gas with time apart from Reactor-C 100 (Figure 4.16). Methane generation in this reactor was very low compared to other reactors. Only 1929 mL methane gas was produced by REACTOR-C 100 up to the age of 140 days. This is due to a long lag phase of methanogenesis in this reactor. There was a sudden rise in methane gas generation after 107 days of operation.

Comparison of methane concentration among reactors in different reactors are shown in Figure 4.17.

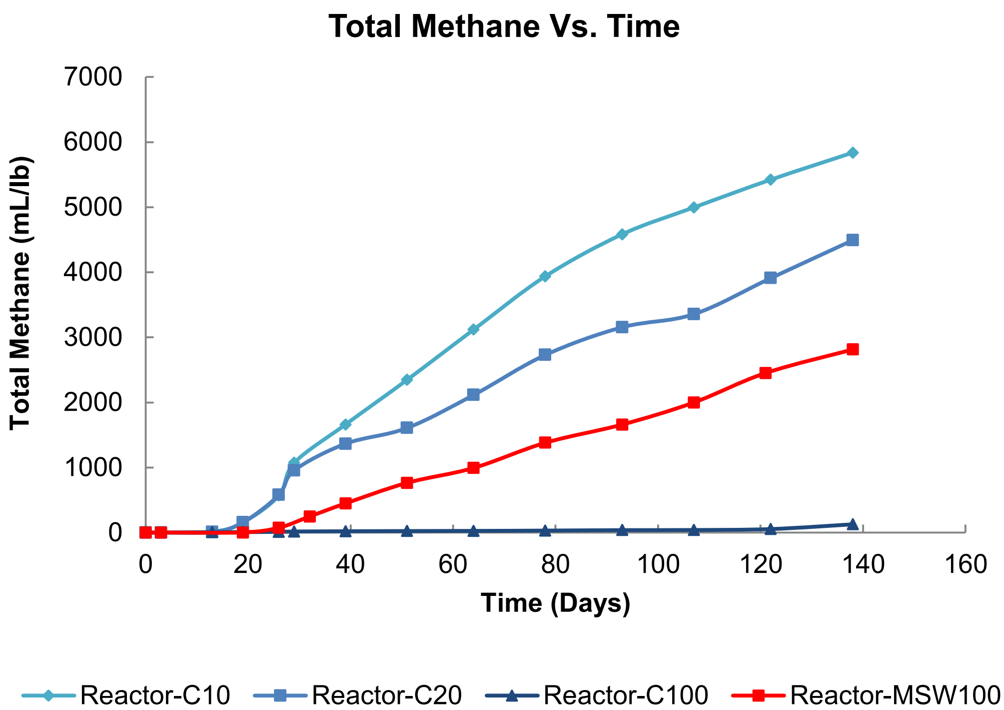

Figure 4.15 Cumulative methane generation with time

Based on the cumulative methane production results, it was found that after 138 days of operation 5838 L/lb methane gas was produced from the Reactor-C10 which was more than the other reactors. The reactor containing 20% Corn waste produced 4492 L of gas from per pound of waste. Therefore, it can be said the presence of Corn Mill Waste increased the cumulative methane production from reactors.

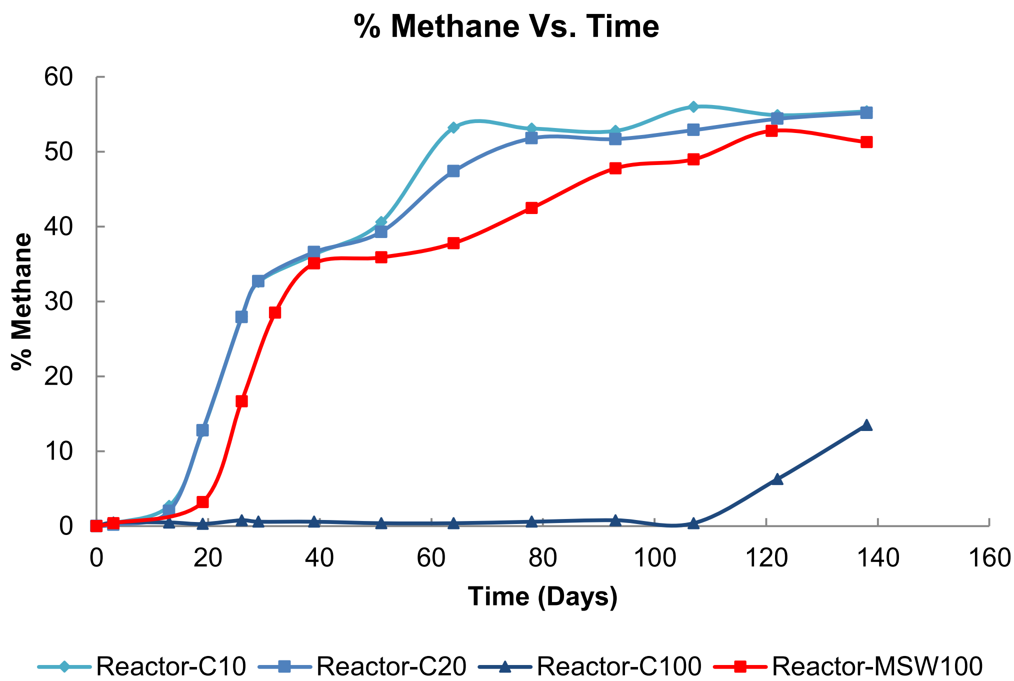

Figure 4.16 Methane percentage in generated gas with time

Rate of methane and total gas generation are shown graphically in Figure 4.18 and Figure 4.19.

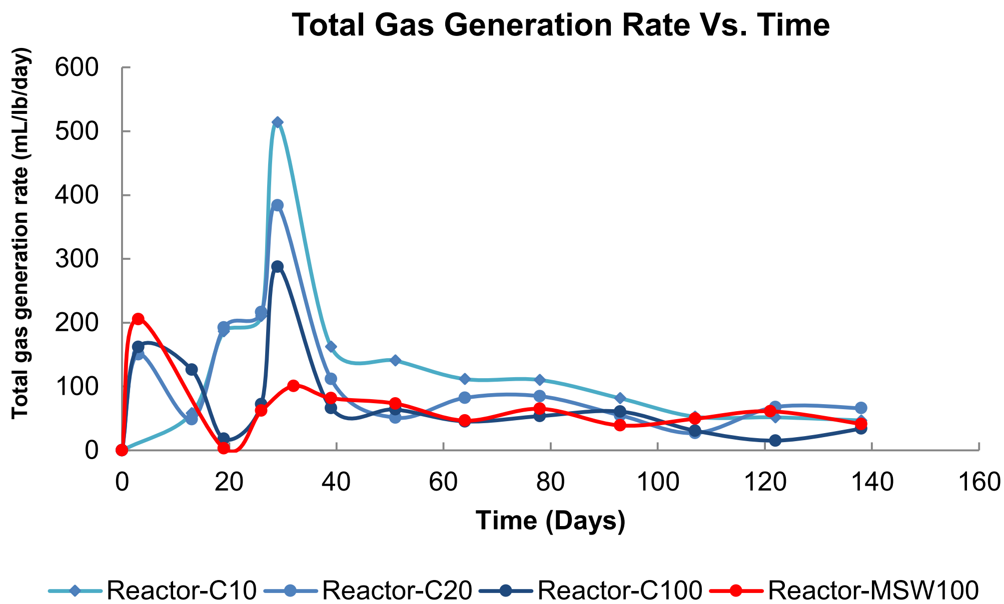

Figure 4.17 Total gas generation rate with time

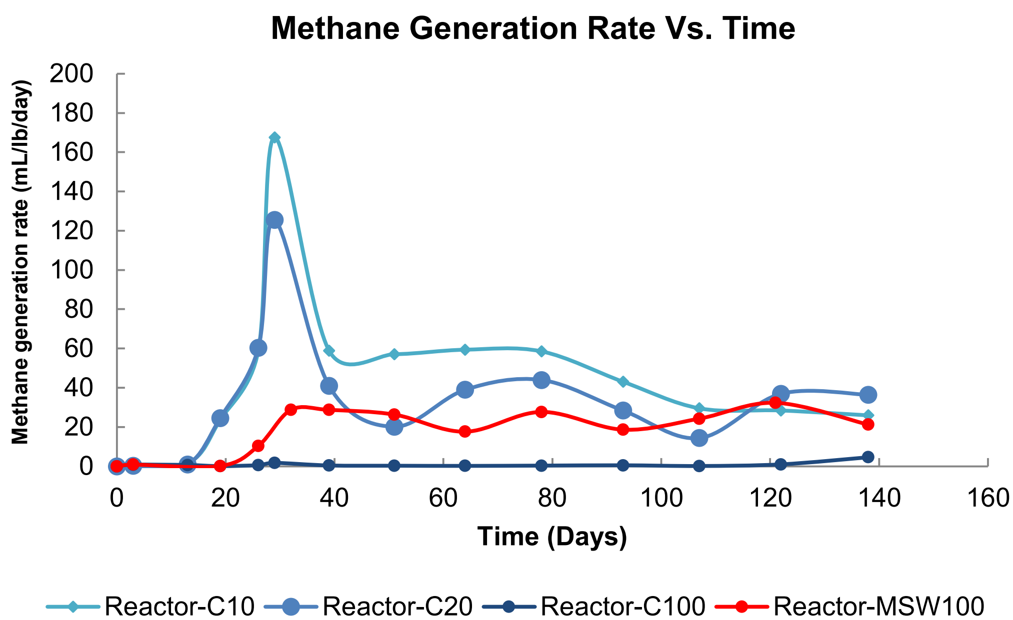

Figure 4.18 Methane generation rate with time

Gas generation rate was highest for REACTOR-C10, REACTOR-C20, and REACTOR-C100 reactors in between 20 – 40 days of operation. Rest of the time the rates fluctuated over time. In case of methane generation rate of reactor REACTOR-C100 did not show any observable peak or fluctuation as methane percentage of that reactor was the lowest. The maximum total gas generation rate of all reactors were in between the first 70 days. Study conducted by Barlaz et al. (2006) showed that maximum methane generation rate was found in between the first 100 days of reactor operation as shown in Figure 4.20 which is in good agreement of the obtained results of this study.

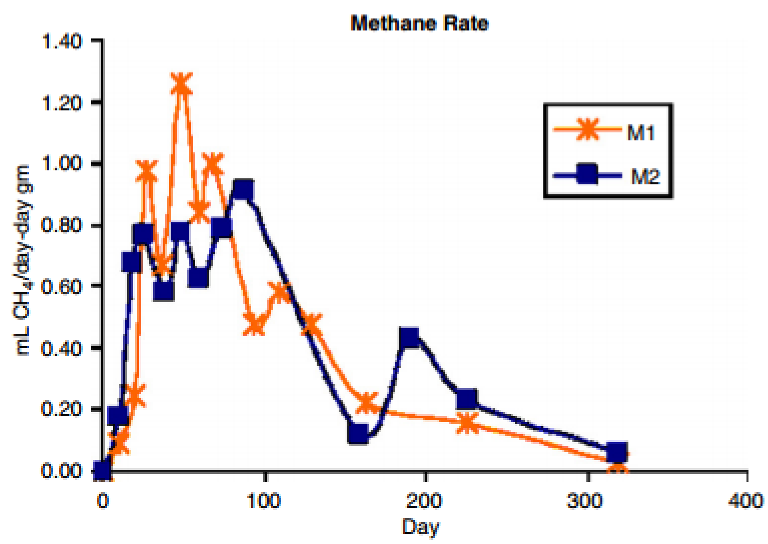

Figure 4.19 Generation of methane in experimental apparatus (Barlaz et al. 2006)

4.5 Summary of Results

The curves obtained from pH, percent methane content, and COD results are incorporated in Figure 4.21 to detect and have a better understanding of the change in degradation phase in reactors.

In REACTOR-C10 which have 10% Corn Mill Waste, Phase – I and Phase – II ended within the first 20 days. The duration of Phase – III was till 35 days in which maximum COD removal value and minimum pH level was observed because of the acetogenesis phenomenon. After that, methanogenic phase (Phase – IV) continued up to the end of the operational period where increased pH level and methane content, and decreasing COD trend were observed.

In case of REACTOR-C20, the acid formation phase (Phase – III) ended at the end of 25 days and the methanogenic phase continued up to the rest of the monitoring period. In this phase, decreasing trend of COD and a stabilized pH level were observed. Methane content increased up to 55 percent in the total gas composition in this phase.

In REACTOR-C100, Phase – I ended at the end of 9 days. Phase – II continued up to 80 days as the COD removal values showed an increasing trend in this duration. COD was maximum in Phase – III and then decreased gradually with time. Percent methane content was very low all through this reactor life. This decreased methane content and pH levels and high COD value proves that this reactor going through an acetogenic phase.

In REACTOR-MSW100, similar trends were observed like REACTOR-C10 and REACTOR-C20. Maximum COD was observed in Phase-III which continued up to 30 days. The COD then started to decrease and methane content started to increase gradually along with pH level.

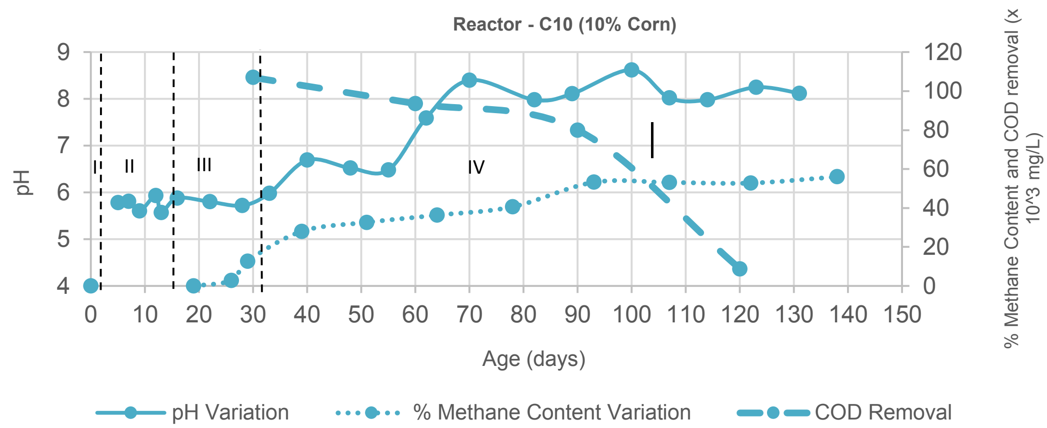

Figure 4.20 Degradation Phases based on pH, COD, and %Methane Content of Reactor-C10

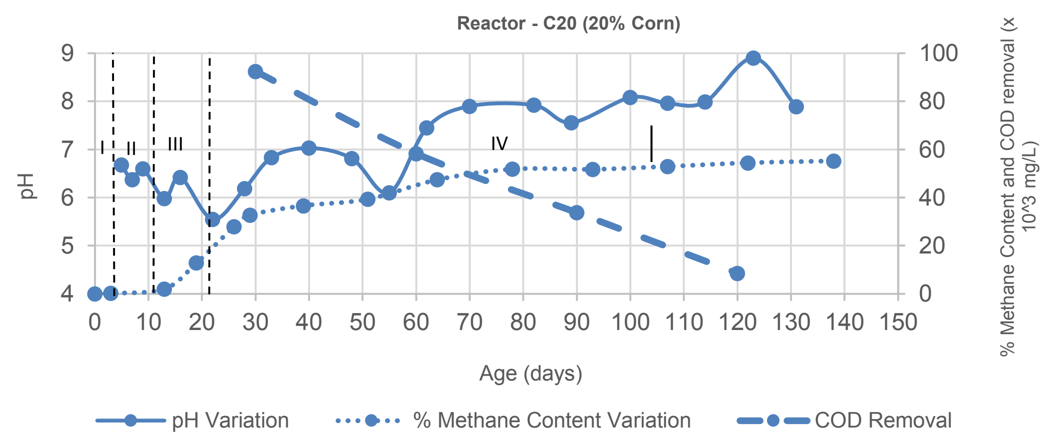

Figure 4.21 Degradation Phases based on pH, COD, and %Methane Content of Reactor-C20

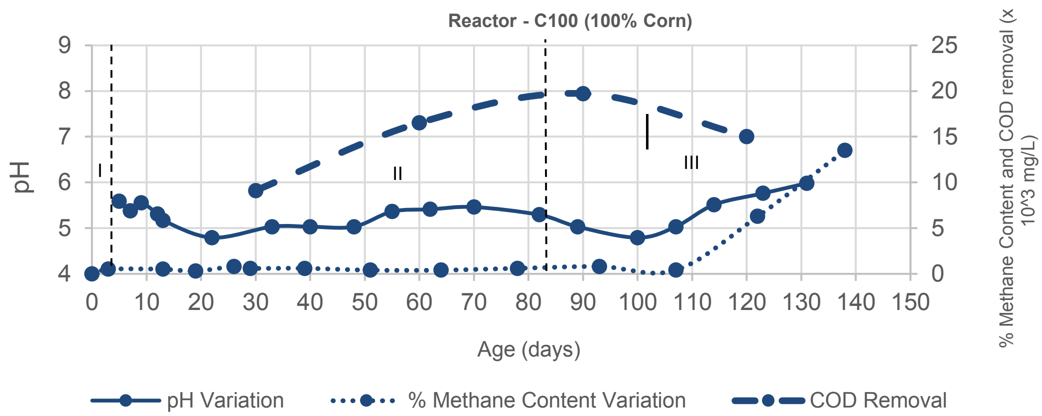

Figure 4.22 Degradation Phases based on pH, COD, and %Methane Content of Reactor-C20

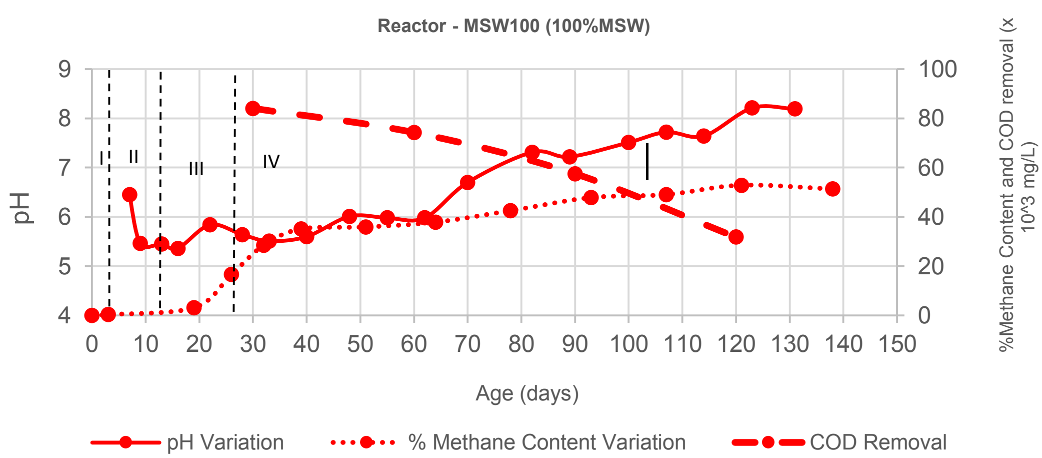

Figure 4.23 Degradation Phases based on pH, COD, and %Methane Content of Reactor-MSW100

Chapter 5

Conclusions and Recommendations

The main objective of this study was to determine the effects of Corn Mill Waste on municipal solid waste degradation and generation of landfill gas. To achieve that goal a total of 10 bags of samples of MSW were collected from the working phase of the City of Denton Landfil and 3 buckets of Corn Mill Waste were provided by the same authority. Physical composition of municipal solid waste and corn waste were determined. Laboratory scale reactors were constructed with varying MSW-Corn Mill Waste ratio to observe the effects of Corn mill on degradation. Recirculation and monitoring of leachate were done periodically along with measurement of reactor generated gas composition and gas volume. The pH, COD, and BOD_5 tests were done periodically to analyze the degradation condition in reactors.

The results obtained from the current study can be summarized as follow:

- Fresh MSW samples were collected from the working face of the City of Denton Landfill. A total of 10 bags were collected and from them 3 bags were randomly selected and sorted manually. Each sample bag weighed in between 25 to 30 Ibs. Paper (29.19%), plastic (23.66%), and soils and fine materials (18.57%) were found to be major components in the waste samples.
- A total of 3 buckets of Corn Mill Waste was provided by the City of Denton authority. The physical characteristics of Corn mill sample were done by visual observation and were found that the Corn mill samples consist of corn kernel, corn cob, and corn seed heads.
- The average degradable and non-degradable portions of MSW samples were 44.89% and 55.11% respectively which are comparatively less than the national

(U.S. EPA, 2012) and Texas state average values. Presence of plastic component and inert soils and fines in greater percentage were responsible for this lower average.

- Three of the reactors which were built for repeatability purpose (REACTOR-1, REACTOR-2, and REACTOR-3) stopped working after one month as no gases were coming out of those reactors. Relentless attempts were made for fixing those reactors, but no positive outcome could be achieved. This might happen due to leakage for machine compaction in the reactors.
- The initial pH levels of the reactors were less than 7. This happened because of the ongoing acid accumulation phase of degradation. pH values started to rise and got stabilized in between 7 and 8 for three reactors REACTOR-C10, REACTOR-C20, and REACTOR-MSW100. Conversion of fatty acids into methane and carbon-di-oxide in methanogenesis phase was the main reason behind it. In case of the 100% Corn mill reactor, the pH value remained less than 6 till the end of the current study. This is due to a prominent lag phase in Corn mill reactor which inhibits degradation progress to methanogenesis.
- According to the degradation phases based on pH results, reactors containing 20% Corn reached the methanogenesis phase quicker than other reactors. It took only 25 days whereas reactors Reactor-C10 and Reactor-MSW100 took 35 and 30 days respectively.
- Based on the COD test results, it was found that COD values for REACTOR-C10, REACTOR-C20, and REACTOR-MSW100 decreased gradually over time except for the REACTOR-C100 which contains 100% corn mill samples. Initial COD values of this reactor were lower and did not decrease like others. The capacity of oxygen consumption during decomposition of corn waste showed an unchanging trend.

- Biochemical Oxygen Demand or BOD_5 test results showed that for every reactor its value decreased with time. This decreasing trend was not promising in REACTOR-C100 which contains 100% Corn Mill Waste. Besides that, BOD_5 value of this reactor was always on the lower side which indicates low microbial activities all through the reactor's operation period.
- Initially Carbon-di-oxide concentration in total gas composition was higher in all reactors. This situation changed in three reactors – REACTOR-C10, REACTOR-C20, and REACTOR-MSW100 with the decrease in carbon-di-oxide and increase in methane concentration. In case of 100% Corn mill reactor CH_4:CO_2 was always less than 1 which ensured the presence of a lag phase of methanogenesis in that specific reactor.
- Gas generation rate in REACTOR-C10, REACTOR-C20, REACTOR-C100, and REACTOR-MSW100 showed similar fluctuation all through their operational period. Volume of methane generated from REACTOR-C100 was too low in compared to other reactors due to the lag phase. REACTOR-MSW100 which contained 100% MSW did not produce significant amount of gas like REACTOR-C10 and REACTOR-C20. This might happened due to the high compaction effort used to fill this reactor with waste. REACTOR-C10 and REACTOR-C20 were constructed using hand compaction and produced sufficient amount of gas in their active life.
- Based on the cumulative methane production results, it was found that after 138 days of operation 5838 L/lb methane gas was produced from the Reactor-C10 which was more than the other reactors. The reactor containing 20% Corn waste produced 4492 L of gas from per pound of waste. Therefore, it can be concluded that the presence of Corn Mill Waste increased the cumulative methane production from reactors.

- Based on the experimental results, it can be seen reactors containing 10% and 20% Corn Mill Waste showed similar trends with 100% MSW reactor in leachate characteristics, gas generation performance and degradation phases. Reactors containing 10% corn produced the highest amount of gas in the days of its operation. Therefore, it can be concluded that 10% Corn Mill Waste by weight would be the optimum disposal rate for optimum gas generation and faster waste stabilization in bioreactor landfills.

5.1 Recommendations for future studies

On the basis of results obtained in the current study and to increase its reliability some recommendations can be made for the future study.

- To identify the optimum Corn Mill Waste percentage that can be disposed in landfills without affecting leachate quality and gas generation, reactors can be constructed with different MSW-Corn Mill Waste ratios such as 30%, 50% etc.
- To accelerate the gas generation, sludge can be added to the reactors.
- To determine the organic carbon content TOC tests could be done on leachate.
- Corn mill samples can be pulverized before constructing reactors.
- Chemical pretreatment of corn samples can be done before disposing them in landfills.

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