CHARACTERIZATION AND COMPARISON OF FRESH AND LANDFILLED SOLID WASTE

By

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Presented to the Faculty of the Graduate School of

The University of Texas at Arlington in Partial Fulfillment

Of the Requirements

For the Degree of

MASTER OF SCIENCE IN CIVIL ENGINEERING

THE UNIVERSITY OF TEXAS AT ARLINGTON

December 2015

Acknowledgements

First, I would like to express my sincere thanks to my advisor Dr. Hossain for his reassuring encouragement, inspiring personality and important words of wisdom. Without his guidance this thesis would not have been completed.

I am grateful to Dr.Sattler and Dr.Yu for spending their valuable time serving on my committee. I would like to thank all my lab members for helping me when I was in need of them and special thanks extended to Naima Rahman, Dr.Samir and Dr.Khan for their constant support and suggestions during my research work. I would like to thank my friends Rathna Mothkuri and Spoorthi Reballi for their valuable comments and constant moral support during my stay at UTA.

It will be incomplete if I don't thank my family member's father: VB Rao, Mother: Ramadevi Koganti, Sister: Tejaswi Koganti for all the love and support they have provided me with throughout my life. They have been there for me for the all the ups and downs in my life and molded me into the person I am today.

November 11, 2015

Abstract

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The understanding of the characteristics of Municipal Solid Waste (MSW) is very important in planning, designing and operating and/or upgrading the landfill operation system. It is well anticipated that the fresh MSW will be different from the landfilled MSW due to degradation. However, there is no systematic study on the comparison of physical properties of fresh and landfilled waste from bioreactor and/or enhanced leachate recirculated (ELR) landfills. The most important MSW properties to be considered while planning a landfill system are physical composition, moisture content, unit weight and volatile solids content. These properties are of particular interest especially when an enhanced leachate recirculation (ELR) landfill is operated because they help to determine the amount of moisture to be recirculated and to design the leachate recirculation and gas collection systems.

The current study presents the physical and hydraulic properties of landfilled and fresh MSW from the City of Denton Landfill from samples collected in 2014 and 2015 from cell 0, cell 2 and cell 3. The approximate age of the MSW collected from cell 0, cell 2 and cell 3 are 9 to 25 years, 5-6 years and 5-8 years respectively. According to the results of physical composition, the content of soils and fines were much higher in the landfilled waste

than the fresh waste. The range of soils and fines waste for the landfilled waste was 40% to 50% approximately, while for the fresh waste it was 35%. As the landfilled waste has a protective cover on top, it can be explained why it has more soils and fines content than the fresh waste. The content of paper and food waste is much higher in fresh waste than in the landfilled and the reason for this could be because the landfilled waste gets decomposed with time while the fresh waste is waste collected from household garbage. The paper waste for landfilled samples ranged from 13% to 20% while for the fresh waste the paper waste was 34%. The food waste for landfilled samples was almost 0% in all cases while for the fresh waste the average was 3%. The difference between the content of metals of fresh and landfilled waste was negligible. The compressible components of the MSW decreased with an increase in the age of the waste.

The average moisture content of fresh waste was higher than that of landfilled waste. The reason for higher moisture content in the fresh waste could be because of the presence of higher organic components in the waste.

The average compacted unit weight was higher for landfilled samples compared to fresh samples. This might be due to the presence of higher compaction that occurs to landfilled waste. This study of moisture content and solids content in the landfills help the design of slopes without failure because it has direct impact on the geotechnical stability of landfills according to several historic slope failures (e.g., Hendron et al. 1999; Eid et al. 2000).

The volatile solids content of landfilled samples ranged from 18% to 30% and the average volatile solids content for fresh waste was 41% which shows that the landfilled waste is more degraded than the fresh waste.

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Chapter 1

Introduction

1.1 Background

According to USEPA Municipal Solid Waste (MSW) is “any garbage or refuse, sludge from a wastewater treatment plant, water supply treatment plant, or air pollution control facility and other discarded material, including solid, liquid, semi-solid, or contained gaseous material resulting from industrial, commercial, mining, and agricultural operations, and from community activities” and the total MSW generated in the US in 2012 was 251 million tons. Since 2005, MSW generation per capita has continued to decrease. Disposal of waste to landfill has decreased from 94 percent of the amount generated in 1960 to under 54 percent of the amount in 2011.

According to USEPA in 2012, paper and paperboard made the largest component of MSW generated (27.4 percent), food waste was the second largest component (14.5 percent), and yard trimmings were the third largest (13.5 percent). Metals, plastics and wood each constituted between 8.9, 12.7 and 6.3 percent of the total MSW generated. Rubber, leather, and textiles combined made up 8.7 percent of MSW, glass made 4.6 percent, while other miscellaneous waste made up 3.4 percent of the MSW generated in 2012.

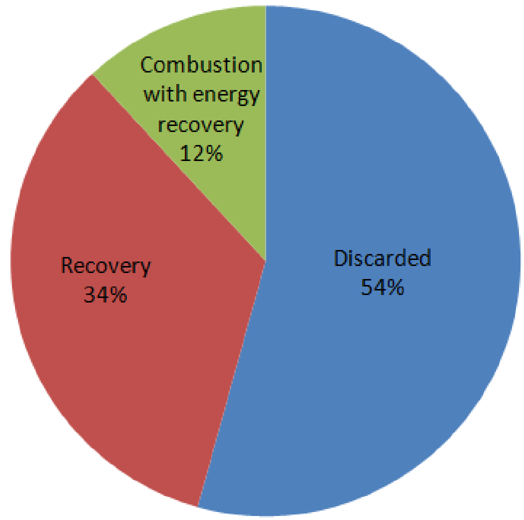

Figure 1-1 Management of MSW in United States in 2013

How a landfill works:

The waste that comes to the landfill is weighed at a scale or a weigh bridge upon arrival at the landfill site. The waste is weighed and inspected that it is in accordance with the landfill's waste acceptance criteria. After this, the vehicles travel towards the working phase of the landfill using the existing road network and where they unload their components. After the trash is deposited, compactors are used to spread and compact the waste on the working phase. While the vehicles leave the facility, they are weighed again and in this way the daily incoming waste tonnage can be calculated. In the working phase of the landfill, the waste is compacted and then covered with soil or alternate materials daily. The parts of a landfill are: Bottom liner, Cells (old and new), Leachate collection system, Storm water drainage, Methane collection system, Cover, Groundwater monitoring stations.

Therefore, the understanding of waste characterization is an extremely important process in planning, designing and operating a solid waste management system. There are no standard methods to analyze the Municipal Solid Waste (MSW). Following are some methods of determining the composition of municipal solid waste (Vesilind at al., 2002). Input methods:

(1) On a national level, data from published industry production statistics can be used for estimating waste composition. This method is known as input method.

(2) Again it can be estimated by manual sorting of representative samples.

(3) The composition can be determined by photogrammetry which involves photographing a representative portion of refuse and analyzing the photograph (Vesilind et al., 2002).

Conventional MSW landfills may take longer time for decomposition considering the growing need for air space for the waste, which might be a big disadvantage. The prohibition of moisture intrusion into the waste prolongs the decomposition and may take up to 50 to 100 years for complete decomposition. In addition, finding a new location to meet the growing need of landfills might also be challenging. Therefore, increasing the capacity of landfill and speeding up the process of decomposition is becoming a major consideration for state agencies.

The concept of an enhanced leachate recirculation (ELR) landfill has hence received increased paying attention according to Pacey et al., 1999. An ELR landfill is a sanitary landfill which uses enhanced microbiological processes to transform and stabilize the readily and moderately decomposable organic waste constituents within 5 to 10 years of bioreactor process implementation. (Pacey et al., 1991). It increases the extent of organic waste decomposition within the landfill. The idea of liquid addition differs from the conventional landfill approach, where the objective was to minimize moisture intrusion into the landfill. There are several benefits associated with the operation of landfills as ELR landfills, Including:

1. More rapid settlement which results in increased effective refuse density and air space

2. In-situ leachate treatment and the reduction of leachate handling cost,

3. The rapid stabilization of a landfill to a more environmentally benign state,

4. Increased gas production which can improve the economics of energy recovery, and

5. Acceleration of refuse decomposition which may shorten the regulated post closure monitoring period and reduce the overall cost of the landfill.

Considering all these benefits, there has been an increase in the use of ELR landfills.

1.2 Research Objective

The major objective of this research is to first characterize fresh and landfilled solid waste according to physical and hydraulic characteristics and then compare the results of both. The baseline MSW characteristics are important to evaluate the effect of leachate generation depending on the changes in physical and engineering characteristics of MSW. The specific objectives of the current study can be presented as follows:

1. Collection of landfilled solid waste and fresh solid waste from the working face of Denton Municipal Landfill.
2. Determination of Physical composition for fresh and landfilled MSW.
3. Determination of degradable and non-degradable percentage of collected wastes.
4. Determination of moisture content.
5. Determination of Unit weight of the samples.
6. Determination of volatile solids content of the samples.
7. Comparison of characteristics of conventional and ELR landfill.
8. Comparison of characteristics of fresh and landfilled waste samples.

1.3 Organization and summary

This section will provide a brief overview of the contents of the following chapters.

Chapter 2 presents previous work and studies related to the current research work. A brief introduction to landfills according to studies is given. The methodologies to characterize waste are presented in the chapter. The waste composition of different landfills according to previous chapters are discussed.

Chapter 3 describes the location of area of study and locations of sample collection. The test methodologies to characterize the fresh and landfilled waste samples are presented here.

Chapter 4 summarizes the results and discussions and present the test results for physical composition, unit weight, moisture content and Volatile solid content for both sets of samples.

Chapter 5 presents the recommendations for future studies and also the outcomes for the present study.

Chapter 2

Literature review

2.1 Introduction

According to CERCLA Solid waste is defined as garbage, refuse, sludge from a WWTP, water supply treatment plant, or air pollution control facility, other discarded material, including solid, liquid, semi-solid, or contained gaseous material resulting from industrial, commercial, mining and agricultural operations. It is not anything that is discharged into the sewage system. Also, according to Pichtel (2005) "It does not include solids or dissolved material in domestic sewage or other significant pollutants in water resources, such as silt, dissolved or suspended solids in industrial wastewater effluents, dissolves materials in irrigation return flows or other common water pollutants". So where does the solid waste go? According to Huztler (2004), the engineering method of solid waste disposal in which waste refuse is buried between layers of soil so as to fill in or reclaim low-lying ground is known as a landfill. It is important to understand the characterization of solid waste in the landfill for efficient management of Municipal Solid Waste.

2.1.1 Municipal Solid Waste (MSW)

Municipal solid waste consists of everyday waste like food waste, textile, glass, paper, electronic goods, yard waste, etc. According to US EPA "Not included are materials that also may be disposed of in landfills but are not generally considered MSW, such as construction and demolition materials, municipal wastewater treatment sludges, and non-hazardous industrial wastes."

2.1.1.1 Fresh Municipal Solid Waste

It is the waste that is collected during the working Cell of the landfill while the landfill operation is going on. It represents the initial condition at the time of placing the landfill.

2.1.1.2 Landfilled Municipal Solid waste

The waste recovered from boreholes at different depths is landfilled municipal solid waste. There is no specified age limit for the landfilled waste. They are subjected to degradation which in most cases is a function of age and depth of filling.

2.2 Physical Properties of Municipal Solid Waste

Characterization of Solid Waste must satisfy a number of conditions according to Whitlow (1983) which are:

a. It must incorporate definitive terms that are brief and yet meaningful

b. Its classes and sub-classes must be defined by parameters that are reasonably easy to measure quantitatively.

c. Its classes and sub-classes must group together soils having characteristics that will imply similar engineering properties.

2.2.1 Physical Composition

Physical composition of the waste indicates the type and percentage of waste present in the total waste stream. The waste composition can be determined by different procedures. (Vesilind et al., 2002) For example, (1) Product data published by industry on national level can be used to estimate the physical composition (known as input method), (2) Manual sorting of samples, (3) The composition can be determined by photogrammetry, where photograph of representative portion is taken and then analyzed to determine the composition.

Dixon et al. proposed a new and improved classification system to evaluate the mechanical properties of MSW. The waste is classified based on (1) material engineering properties (2) size distribution of components of the sample (3) component shape (4) degree of degradability. In this paper several other classification systems were briefed like Landva and Clark (1990) proposed a classification system that distinguishes between organic and inorganic components, Grisolia et al. which defines degradable, inert and deformable component groups and classified wastes by plotting the percentages of each group in a ternary diagram, Kolsch's classification system which includes material groups, size and dimension of components. Figure 2-1 shows the waste composition from the USA and the UK.

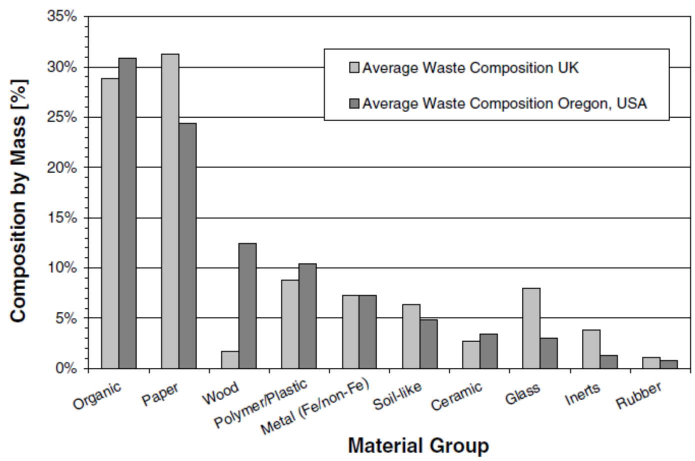

Figure 2-1 Percentage of the weight of various waste types for five different waste samples for Tri-cities waste (Kavazanjian et al., 2010)

According to Sharma & McBean (2007) the percentages of waste within individual categories are important information for planning solid waste management programs. These include evaluation of recycling programs, quantification of degree of success of exclusion of banned items from waste stream, quality of waste to be used as feedstock to an incinerator, quantification of organics to evaluate biogas possibilities, etc.

McBean and Sharma estimated the number of waste sorts for characterizing solid wastes into categories based on diminishing minimum incremental information. They have three approaches, which are 1) ASTM methodology – It provides a script for conducting a waste composition study, including a statistically based method for estimating the number of sorts for waste characterization. The number of sorts required to achieve the desired level of measurement precision is a function of the categories under consideration, and the desired confidence level.

The calculations are an iterative process, beginning with a suggested sample mean and standard deviation for waste components based on historical statistics as an initiating point. 2) USEPA Methodology - PROTOCOL is a software for estimating the number of waste sorts required to characterize waste percentages in individual categories. Currently, PROTOCOL uses waste composition data (mean and standard deviation) generated in 1972 for the US as first estimates of necessary sample sizes. 3) CIWMB (California Integrated Waste Management Board) Guidelines – It recommends the number of waste sorts, N, required for a statistically representative sampling by the following equation (Klee and Caruth, 1970):

$$N = (ZS/\delta)2$$

Where Z is the standard normal deviate, a function of statistical significance; S the standard deviation; and d is the level of precision required.

Gomes et al. conducted a study to characterize the solid wastes being disposed up at Santo Tirso landfill. Three profiles were selected (figure 2), the first one (A) in a zone still in operation, and the others (B and C) in zones already closed. The profile C is located in the zone of the coming wastes of the old dumpsite and the profile B is located in the zone of pre-selected and treated wastes disposed between 1998 and 1999.

Laboratory experiments include the determination of physical, chemical, compressibility and shear strength characteristics. In conjunction with the in-situ and laboratory measurements, a field monitoring program will be performed to measure displacements, lateral deformations, horizontal pressure and pore water pressure. The waste composition of profile B (closed zone and waste from 1998-1999) is given in Table 2.1

Table 2-1 Waste Component by Weight Percentage of Profile B from San Tirso Landfill, Portugal (Gomes et al., 2005)

Waste component (wt. %)								
Plastic	Textile	Soil	Metal	Wood	Glass	Rubber	Paper	Other organics
37.4	33.3	11.2	10.2	2.8	2.8	1.3	0.9	0.1

Saeed et al. forecasted a study of municipal solid waste generation rate and potential of its recyclable components in Kuala Lumpur (KL), the capital city of Malaysia. KL's solid waste composition from 1975 to 2000 is given in Table 2.2.

Table 2-2 MSW generated in Kuala Lumpur in 2002

Years	KL Population	Solid Waste Generated (tons/day)
1998	1446.803	2257
2000	1787.000	3070
2005	2150.000	3478

All the data related to SWG in the previous years has been obtained from previous works. All that data has been studied thoroughly and a correlation has been obtained to predict the future trend by means of excel 2003 tools:

$$(SWG)_F = [(SWG)_P/(100)^{F-P}][100+y]^{F-P}$$

Where the subscripts F and P denote ‘‘future” and ‘‘present”, respectively and y stands for yearly waste generation.

Chynoweth and Owens determined the biochemical methane potential of several MSW fractions to compare extents and rates of their conversion to methane. MSW from two different facilities were collected and three of the subsamples were chosen to compare fresh, dried and digested MSW from the same source. The characteristics of fresh samples from the facilities are shown in Table 2.3.

Table 2-3 Characteristics of fresh MSW samples as collected

MSW Characteristics:	Sumter	Levy-1	Levy-2
Date Collected	12/13/1989	3/7/1990	3/14/1990
Total Solids (%):	80.2	62.0	72.5
Volatile Solids (% of TS) :	87.9	92.5	94.1
Ash (% of TS) :	12.1	7.5	5.9
Dry Composition (%):			
Paper :	43.7	85.0	91.3
Corrugated :	4.8	7.0	7.0
Plastic :	11.2	0.8	0.0
Yard Waste :	3.0	0.0	1.6
Misc. :	37.3	7.2	1.8

Table 2-4 Solids analysis of samples after grinding and prior to BMP assay

Sample	% TS	% VS (% of TS)	% Ash (% of TS)
MSW Samples			
Sumter (f)*			
Sumter (d)*	63.6	79.7	20.3
Sumter ®*	100**	84.1	15.9
Levy-1	100	72.9	27.1
Levy-2	100	92.5	8.5
Yard Waste Samples	100	94.1	5.9
Grass			
Leaves	37.0	88.1	11.9
Branches	56.4	95.0	5.0
Blend	70.8	93.9	6.1
Paper Samples	50.4	92.0	8.0
Office			
Corrugated	96.2	92.7	7.3
News (u)***	94.8	97.7	2.3
News (p)***	91.4	97.9	2.1
Magazine	92.2	97.6	2.4
Food Packaging Samples	97.1	78.1	21.9
Cellophane			
Food Board (u)****	93.7	99.4	0.6
Food Board (c)****	95.8	98.6	1.4
Milk Carton	96.2	93.3	6.7
Wax Paper	96.1	99.4	0.6
	94.6	98.4	1.6

Vesilind et al. produced a historical trend in MSW generation in the United States from 1960 to 2008 which is shown if Figure 2-2.

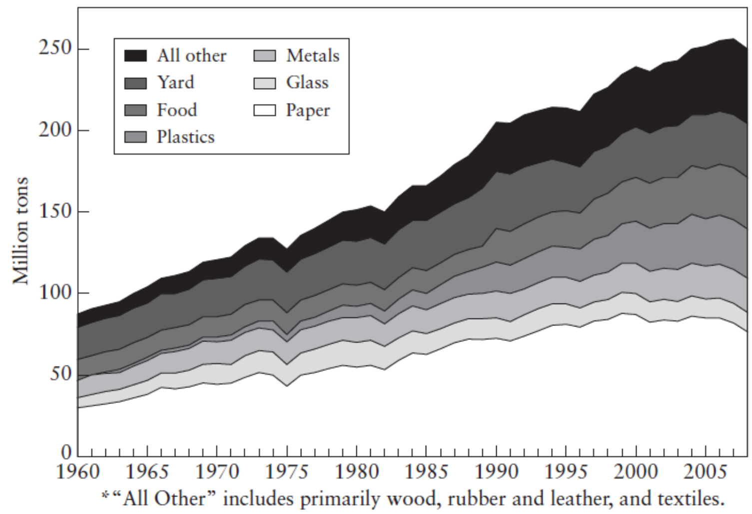

Figure 2-2 Historical trends in MSW generation in the United States from 1960 to 2008

Vesilind et al. provided with two methods to sort composition of samples. 1) Manual Sampling – A script is followed while conducting a waste composition study including a statistically based method for determining the number of samples required to characterize the waste. There is an iterative process for the calculations beginning with a suggested sample mean and standard deviation for waste components. 2) By photogrammetry- This involves photographing a representative portion of the refuse and analyzing the photograph. Table 2-5 shows the bulk densities of some refuse components.

Table 2-5 Bulk Densities of some Refuse Components

Components	Condition	Bulk Density (lb/yd^3)
Aluminum Cans	Loose	50-74
	Flattened	250
Corrugated cardboard	Loose	350
Fines (dirt, etc.)	Loose	540-1600
Food waste	Loose	220-810
	Baled	1000-1200
Glass bottles	Whole bottles	500-700
	Crushed	1800-2700
Magazines	Loose	800
Newsprint	Loose	20-55
	Baled	720-1000
Office paper	Loose	400
	Baled	700-750
Plastics	Mixed	70-220
	PETE, whole	30-40
	Baled	400-500
	HDPE, loose	24
	Flattened	65
Plastic film and bags	Baled	500-800
	Granulated	700-750
Steel cans	Unflattened	150
	Baled	850
Textiles	Loose	70-170
Yard waste	Mixed, loose	250-500
	Leaves, loose	50-250
	Grass, loose	350-500

Kavazanjian et al. (2010) reviewed existing MSW classification systems, and the field and laboratory waste characterization programs. The proposed waste characterization procedure is designed to efficiently collect information on the factors that influence geotechnical properties of MSW as well as other potentially useful information on its physical properties. The proposed procedure can be adjusted to minimize the effort required to collect relevant information on a site specific basis. According to what has been proposed, large diameter bucket auger boring was conducted to collect samples from tri-cities landfill and for the determination of in-situ weight using gravel replacement. Field logging of the boring included continuous visual description of moisture level, state of compaction, state of degradation, composition and apparent waste structure, using the classification scheme presented in Table 2-6.

Table 2-6 Landfill Field Waste Classification Scheme (Kavazanjian et al., 2010)

1 Dry dump moisture level		1 Household-paper and plastics
2 Wet moisture levels		2 Putrescible organics
3 Standing water		3 Concrete, bricks
		4 Wiring
Compaction		5 Metal
1 Slight-refuse easily falls out of bucket auger		6 Nonferrous Metal
		7 Tiers
2 Moderate-refuse falls out of bucket auger upon impact		8 Asphalt
		9 Soil
3 Heavy refuse falls out of bucket auger only after being struck multiple times		10 Medical
		11 Indistinguishable
		12 Glass
		13 Other (specify)
Degradation		
1 Non-newspaper very legible, no refuse discoloration		
		Structure
2 Slight-some newspaper still legible, discoloration		1 Layered
		2 Encapsulated
3 Moderate-newspaper partly legible, highly		3 Fibrous
		4 Interlocked
4 High-newspaper highly faded gray to black		5 Indistinguishable

Kavazanjian et al. also provided a detailed characterization of a relatively representative sample of 5-10 kg of material. The sample was separated into following categories: paper, cardboard, plastics, rubber, wood products, textiles, concrete, metals, glass, soil and miscellaneous materials. Figure 2-3 is a graphical representation of results of segregation of the > 20 mm material for the five sample groups characterized from the tri-cities landfill.

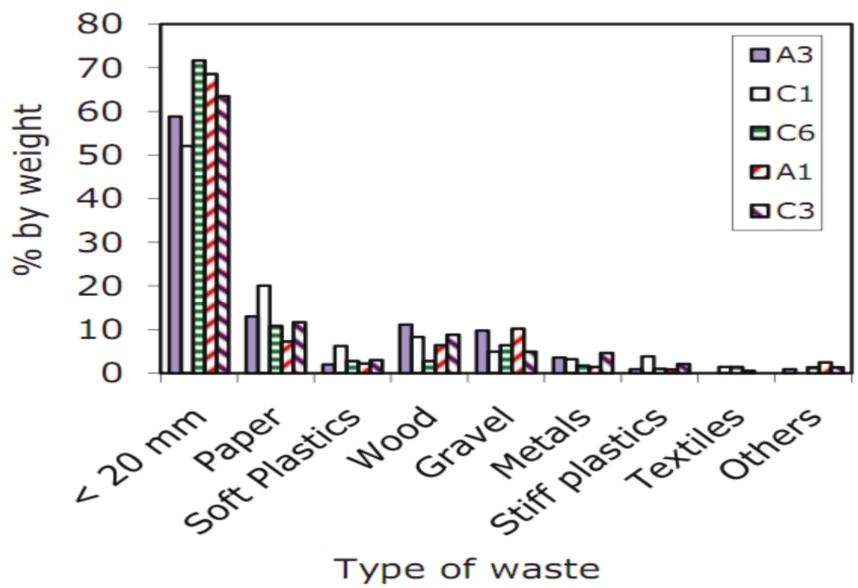

Figure 2-3 Percentage of Weight of the Various Waste Types for Five Different Waste Samples for Tri-cities Waste (Kavazanjian et al., 2010)

Koukouzas et al. performed a case study for Western Macedonia to get knowledge on the existing co-gasification techniques and projects for coal and solid waste. It investigates the economic feasibility, regarding installation and operation of a 30 MW co-gasification power plant. According to the case study the annual amount of municipal solid waste in WMP is 117,000 ton. The composition of MSW produced in that region is shown in Table 2-7.

Table 2-7MSW Composition in Western Macedonia, 2004

Component	% (w/w)
Organics	43
Paper	22
Plastics	15
Aluminum	1
Iron	3.5
Inert	2
Glass	5
Others	8.5

Yu and Maclaren presented a study which compared a traditional engineering approach to collect waste quantity and waste composition data to a social science approach. The two methodologies that they used are direct waste analysis and questionnaire surveys. Direct waste analysis requires direct checking of the waste set out to collect at point-of-generation. Questionnaire survey involves preparing and pre-testing of a questionnaire, sample selection and sending out the questionnaire through telephone surveys, mail-outs, etc.

Otoneil et al. conducted a study to evaluate the composition and generation rate of household hazardous waste caused at residences. According to this survey “approximately 1.6% of the waste stream consists of HHW. Correspondingly, it was estimated that in Morelia, a total amount of 442 ton/ day of domestic waste are produced, including 7.1 ton of HHW per day”. The research performed, required 120 houses in each socio economic stratum, to obtain approximately 360 participating households. For this, bags were collected for seven days and then each bag was weighed individually. A classification system suggested by Wilson (1985) and adapted by CECODES (1987), Restrepo et al. (1991) was used to categorize. Table 2-8 shows HHW found in residential sources by socioeconomic stratum.

Table 2-8 Household hazardous waste found in residential sources by socioeconomic strata (kg, wet basis)

Household hazardous waste (group product)	Socioeconomic stratum			
	Lower	Middle	Upper	Total (HHW)
Home Cleaning	2.29	4.48	19.92	26.71
Automotive	1.00	0.95	0.23	3.16
Batteries & small home appliances	0.54	0.3	0.48	1.33
Medicines	1.59	4.09	2.91	8.59
Biological-infectious	0.11	2.54	0.06	2.72
Insecticides	0.62	0.15	0.11	0.91
Self-care	3.12	5.77	6.87	15.62
Home maintenance	0.46	0.23	2.46	0.91
Others	0.5	1.21	0.39	4.39
Total (HHW)	10.27	19.75	33.45	63.35

Reddy et al. presented the results of a laboratory investigation to deduce the geotechnical properties of fresh Municipal Solid Waste which was collected from the working phase of Orchard Hills Landfill located in Davis Junction, USA. Laboratory testing was performed on shredded MSE in order to determine the hydraulic conductivity, compressibility, and shear strength properties. Depending on the biodegradability MSW components were grouped into different categories. Determination of composition was done according to a protocol developed by the French Environmental Protection Agency (Grellier et al.). Table 2-9 shows the composition of fresh MSW at Orchard Hills Landfill.

Table 2-9 Typical composition of fresh MSW at Orchard Hills Landfill

Category	Waste type	Waste Composition (% by wet mass*)	
Easily biodegradable	Cooking waste	6.6	6.9
	Garden waste	0.3	
Medium	Paper	8.2	24.6
	Cardboard	13.3	
	Food carton	0.0	
	Sanitary waste	3.1	
Hardly biodegradable	Textiles	5.8	19.2
	Nappies	1.7	
	Wood	11.7	
Inert waste	Metal	4.4	29.2
	Plastic bottles	5.7	
	Other plastics	5.3	
	Special waste	0.0	
	Medical waste	0.1	
	Other waste	3.5	
	Inert waste	5.8	
	Glass	4.4	
Residual fines**	Fines (<20mm)	20.1	20.1

Gabr et al. conducted a geotechnical research program to evaluate the engineering properties of aged solid waste samples. The samples used were around 15 – 30 years old which came from the field. A drill rig was used to retrieve samples till a depth of 42 m by drilling holes. Table 2-10 gives the composition of MSW.

Table 2-10 Composition of MSW (Gabr and Valero, 1995)

Category	% of Total Weight	
	Test Samples	Typical Refuse
Food waste	0	5-42
Garden refuse	0	4-20
Paper Products	2	20-55
Plastic & rubber	13	2-15
Textiles	23	0-4
Wood	9	0.4-15
Metal Products	10	6-15
Glass, ceramics	10	2-15
Ash, rock, soil	33	0-15

Xiang-rong et al. (2003) has reported the main ingredients of the MSW in Tianziling landfill as plastic (0-20%), inorganic (50-100%), organic & impurities (0-20%) and minerals.

Hristovski et al. (2007) conducted a short one week study in summer on the residential waste of Veles, Macedonia. The study area is representative of upper end of low income to lower end of middle income community. In this study, the commercial or agricultural wastes were not considered. The average composition of the solid waste was found to be as follows: organic (23.99%), paper (24.47%), glass (7.19%), soft plastic

(4.49%), hard plastic (2.51%), cans (1.32%), other scrap metals (4.78%), garden waste (8.7%), other (23.36%).

Minghua et al. (2009) presented the characteristics of MSW in Pudong city of China. The study area is representative of year round pleasant climate with an average annual temperature of 16.20 C and an annual rainfall of 1183 mm. The area is characterized by both urban and suburban areas. The physical composition of the solid waste of the city is as follows: Food waste (48%), plastic (33%), fruit (7%), paper (4%), textile (3%), glass (3%), and wood (2%).

Sharholy et al. (2007) conducted a study to determine the quantitative and qualitative characteristics of MSW of Allahabad city of India. Of the total MSW stream, 40% comes from households, 27.2% from restaurants and the rest from other sources. The results were obtained based on 20 randomly collected samples. The study determined that MSW contains 45.3% organic matter and 40% miscellaneous materials like brick, fine dust, rubber, wood, leather, waste water, etc. and very low percentage of glass, paper, plastic, metals etc. The composition has been presented as follows: Paper (3.6%), cardboard (1.09%), metals & tin cans (2.54%), glass (0.73%), food waste (45.3%), textile rags (2.22%), plastic bags (2.86%), miscellaneous (41.66%).

Batool & Ch (2009) studied the municipal solid waste of Lahore of Pakistan which is representative of temperature range of 2 to 40oC and 628.8 mm of rainfall per year. For this study, they sampled a total of 360 households covering all three economic classes: low, middle, and high income. Samples were collected randomly and continually from both these sources and disposal sites. Their samples also covered all seasons. Of the total waste generated, 67.02% is organic waste. The composition of waste by weight as reported in this paper is as follows: paper (5.04%), glass (2.19%), ferrous metal (0.02%), non-ferrous metal (0.47%), film plastic (12.94%), rigid plastic (5.55%), organics (67.02%), textiles (1.00%), and others (5.77%).

Elagroudy et al. (2008) worked on waste settlement in bioreactor landfills and presented the composition of municipal solid waste as, food (35%), vegetables (26%), paper (10%), and plastics (6%), textiles (3%), and bio-solids (20%).

According to Han et al. (2006) the composition of MSW on percent wet weight basis are as follows: paper (40%), plastic (11%), yard waste (20%), glass (4%), and food waste (25%).

Sujauddin et al. (2008) studied the characteristics of household solid waste of Chittagong, Bangladesh. For this study, the researchers collected solid waste directly from 75 selected households, 15 from each of 5 socio-economic categories. Waste generation rate was found to with the increase in household income. The compositions of MSW for different socioeconomic groups are presented in this study. The average composition as mentioned by the authors are: paper (3%), pack (9%), can (9%), plastic (2%), glass (5%), and rocks (6%), all categorized as non-compostable; among the compostable components, textile (1%), vegetable (62%), and wood (3%). Composition indicates that the largest component of household solid waste is vegetable or food waste comprising about 62%, and this component increases from high income to low income households.

According to the study by Hudson et al. (2004) plastic film is visually a prominent component of the waste and the putrescible waste content is very low for household waste. The composition reported here is: paper/cardboard (42.3%), plastic film (7.9%), dense plastic (5.3%), textiles (3.5%), miscellaneous combustibles (4.9%), miscellaneous non-combustibles (2%), glass (4.5%), ferrous metal (2.2%), non-ferrous metal (0.8%), putrescible (2%), less than 10 mm sized (24.7%).

According to Sharholy et al. (2008) the quantity of MSW generation depends on a number of factors such as food habits, standard of living, degree of commercial activities, and seasons. The composition for MSW of India at generation sources and collection points has been determined on a wet weight basis and it consists mainly of a large organic fraction (40–60%), ash & fine earth (30-40%), paper (3-6%), and plastic, glass and metals (each less than 1%). According to the authors, characteristics of MSW change with population density and also relative percentage of organic waste in MSW is generally increasing with the decreasing socio-economic status. In the waste, percentage recyclable was very low as rag pickers segregate and collect them at generation sources, collection points and disposal sites.

2.2.2 Moisture Content

Fadel et al. conducted a research to monitor temporal variation of the quality of leachate from waste that was pre-sorted with high organic and moisture content. According to the paper they noticed due to biological activities chemical concentration levels altered which indicate that 1) waste stabilization does not get affected by pre-sorting 2) High moisture content results in leachate generation. It is said that when moisture content exceeds its field capacity it forms leachate which is called maximum moisture retained. Although moisture content is the reason for leachate generation, it is also said to enhance biodegradation processes in landfills.

According to Fadel et al. the difference in waste generated in developing and developed countries leads to different moisture content. Food waste in Lebanon constitutes more than 60% of the waste stream, it is less than one-third the value in the US, and so the moisture content is 2-4 higher. In the conclusions it is mentioned that moisture retention retainability is reduced due to baling.

Han et al. (2006) conducted a study to observe the impact of various leachate recirculation regimes on municipal solid waste degradation. The experiment was divided into seven phases. The solid waste analyzed in the initial phase had approximately 80% moisture content. In the second phase the decomposition regime was continued due to different operating moisture regimes. It was concluded that leachate management of landfill with leachate recirculation is a promising strategy. The moisture content is raised by employing four times per week recirculation frequency to increase microbial population and therefore reduce the time needed for the decomposition process.

Gabr and Valero (1995) reported a range of moisture content of 30% to 130% (at the surface) on a wet basis for a landfilled sample.

A study conducted by Gabr and Valero (1995) between fresh and landfilled sample, the moisture content of fresh sample was found to be 20% on a dry weight basis and the moisture content of landfilled sample ranged from 60% to 150% on a dry weight basis.

Carboo et al.conducted a study on physio-chemical analysis of MSW in Accra metropolis of Ghana. Accra has a city population of 2.7 million people with an average per capita waste generation per day is 0.4 kg. It generates 1000 tons/day and the annual generation rate is 3.7 x 10^4 tons/year. The collection capacity that was existing could only collect 55% of this figure. According to income level and density of population, three distinct zones were identified for sampling. Zone A with high income and low density, Zone B with medium income and medium density and Zone C with low income and low density. Ten household were selected randomly from each zone and samples were collected for two months on every other day. If the moisture content is high the material takes a longer time to be burned. Table 2-11 represents moisture content from different zones.

Table 2-11 Moisture content of MSW in the Accra metropolitan city

Zone	Moisture Content (%) (Gravimetric)
A (high income)	62.2
B (middle income)	46.9
C (low income)	39.8

Hogland et al. (2004) determined moisture content of mixed unsorted waste to be around 30% by weight and found it to be more or less constant at different depths.

Gawande et al. (2003) measured the moisture content of bioreactor landfill as a function of electrical resistance between two electrodes embedded in granular surface and reported that the value is higher than 35% wet weight basis.

Elagroudy et al. (2008) reported the moisture content of bioreactor landfill to be 67%.

As suggested by Hettiarachchi et al. (2009), volumetric moisture content of dry landfills can vary from 5% to 30%. The authors also suggested that the final moisture content at the bottom layer can be approximately 39%.

The moisture content of the waste of Beijing has been suggested as 61.21%, by Zhenshan et al. (2009).

Sha'ato et al. (2007) provides with the moisture content of MSW of Nigeria as determined over a ten days period for waste collected from 100 households, 11 businesses, 5 institutions and 5 industries and according to the authors, the moisture content values for household and nonhousehold solid wastes on wet weight basis are 26.8% and 22.7% respectively.

Maystre & Viret (1995) classified the MSW of Geneva into 52 components and reported their moisture content. The results are presented in Table 2-12

Table 2-12 Moisture content of 52 Waste categories analyzed in MSW from Geneva (Maystre & Viret (1995))

Class or material	Humidity (% by weight)	Class or material	Humidity (% by weight)
Vegetable and food	73.9	iron scraps	3
Meat scraps	45	PVC bottles	5.9
Natural tissues	20.5	polyethylene bottles	6
Synthetic tissues	23.1	solid molded boxes	7.2
Nylon stockings	11.4	rubbish bags	3.8
Unweaved sanitary	36	supermarket bags	23.7
Disposable nappies	53.4	over-packing	6.4
Various textiles	23.1	plastics from foodstuffs	8.7
Glass	0.5	rigid pots (yogurts)	18.8
Newspaper	17	polystyrene	11.3
Packing paper	20.4	plastic scraps	7
Other paper	16.6	cigarette packets	17.7
Other cardboard	28.9	Tetra brik without Al	6.5
Packing cardboard	17.2	Tetra brik with Al	9.6
Household aluminum	30.3	packaging composites	12.1
Aluminum aerosols	-	Al+plastic+plastic	12.8
Aluminum tubes	24.7	packaging composites	13.6
aluminum pastry trays	21.1	paper+paraffin wax	17.3
aluminum covers	27.4	cardboard+paraffin	19.5
aluminum beverage	15.6	batteries	3
aluminum scraps	10	medications packaging	8.7
non-ferrous metals	7	electronic material	3
iron food cans	7.4	toxins	8
iron covers	3.1	wood-leather-rubber	15
iron aerosols	5	inert material	27.5
iron beverage cans	3.2	others	36.9

Hazra and Goel (2009) presented the physical properties of solid waste of Kolkata, India. They reported the average moisture content of this waste as 60%. Sakai (1996) reported the moisture content on percentage wet weight basis for Osaka, Japan to be 46%.

Abduli (1995) studied the solid waste of Tehran. The authors reported the moisture content of MSW as 52.7%.

Bai & Sutanto et al. (2002) conducted a study in Singapore according to which the moisture content on wet weight basis has a range of 30% to 60% with an average of 48.60%, which is considerably higher as compared to 20% for USA.

Abduli (1995) reported moisture content of MSW as 52.7% for a research conducted in Tehran.

Kumar et al. (2009) conducted a research to measure in situ moisture content using resistance based sensors. The moisture content values were derived using both resistivity and gravimetric method. Table 2-13 shows the moisture content values both before and after circulation.

Table 2-13 Moisture content of bioreactor landfill

Moisture content (wet wt. basis)	By Resistivity	By Gravimetric method
Initial: before recirculation	27.40%	23%
Final: after recirculation	44.40%	45%

Han et al. (2006) conducted a study to observe the seasonal variation of moisture in a landfill. Partitioning Gas Tracers Test (PGTT) method was used to determine moisture content and compare the method with few other indirect methods like time domain refractometry, electrical conductivity, and electromagnetic slingram. The study led to the observation that moisture content ranges from 0 to 24.7% when done by PGTT tests and when gravimetric measurements were used in excavated pits the moisture content was 26.5% which are very close.

According to Landva and Clark (1990), when organic content is increased the moisture content increases, which can be up to 120% (wet weight) and 65% (dry weight).

Hossain et al. (2008) observed that moisture content increased from 55% to 64.7% after complete degradation for the simulated ELR landfill reactors built in laboratory.

Gomes et al. (2005) conducted a study to characterize the solid wastes being disposed up at Santo Tirso landfill. The moisture content that was observed ranged from 61% near the surface to 117% at 11m depth.

According to Manassero et al. (1997) most of the domestic landfills of Untied States have moisture content varying from 15 to 40%, which depends on the composition of waste, the season of the year, and natural humidity and rain conditions. In regions where evapotranspiration is more than precipitation, the typical moisture content is 25%. The moisture content values can increase from 30% at surface to 130% at greater depth. For fresh uncompacted waste, moisture content is about 22.5% which can increase to around 55% for 1-5 year old compressed waste.

Guermoud et al. (2009) reported moisture content of different components o MSW of Mostaganem city of western Algeria, which is representative of an industrialized developing country. The reported values are 58.9%, 9.5%, and 3.7% for organic matter, cardboard, and plastic respectively.

Hudson et al. (2004) reported the moisture content of solid waste to be 32.5% on wet weight basis.

Zekkos et al. (2006) determined the moisture content of four different landfills and determined that moisture content usually ranges from 10 to 50% on dry basis.

2.2.3 Unit Weight

"Unit weight of solid waste is an important parameter for both static and seismic stability analysis of landfills" according to Landva and Clark. The type of waste, degree of composition compaction degree, volume of daily cover, depth from which sample is taken, quantity if leachate produced all directly influence the Unit Weight.

Oweis and Khera (1986) investigated combined effect of depth and age of the waste in which 12 inch diameter bucket auger were used. It was observed that the unit weight increased with depth. There was an increase in unit weight from 5 KN/m^3 at a depth of 5m to 13.8 kN/m^3 at a depth of 26 m. It was also observed that wet unit weight of older waste was slightly lower than that of new waste; but the dry unite weight of both were approximately equal. Table 2-14 reports unit weights of different types of landfills.

Table 2-14 Unit weight of different types of Landfill (Oweis & Khera, 1986)

Type and State of Municipal Waste	Total Unit Weight	
	lb/ft^3	kN/m^3
Poor compaction	18-30	2.8-4.7
Moderate to good compaction	30-45	4.7-7.1
Good to excellent compaction	45-60	7.1-9.4
Baled waste	37-67	5.5-10.5
Shredded and compacted	41-67	6.4-10.5
In situ density	35-44	5.5-6.9
Municipal waste from Canada	43-89	6.8-14
Active landfill with leachate mound	42	6.6
Northeast US active landfill	30-40	4.6-6.3

Zornberg at al. conducted a research at San Gabriel Valley Landfill in Los Angeles County, California. The unit weight recorded by them ranged from 10 kN/m^3 at 3m to 15 kN/m^3 at 55m below the surface.

Kavazanjian et al. proposed three methods to evaluate unit weight based on data from Zekkos et al. which are 1) Surveys and landfill records : The total weight of the materials placed in the landfill can be estimated by landfill records and volume of in-place materials can be estimated by topographic surveys. The average in-place total unit weight can be estimated with this data. 2) Unit weight of "undisturbed" species: If intact undisturbed samples can be retrieved unit weight can be measured accurately. However, to retrieve undisturbed samples from such large materials is very difficult. 3) In situ large scale methods: The tests that copy sand-cone density test but at a larger scale are In situ large scale methods. The retrieved material from large scale pits are weighed. Then the volume of the cavity is measured. Finally, the unit weight is calculated by dividing measured weight of excavated MSW by the estimated volume. Table 2-15 depicts the unit weight of some Tri-cities landfill.

Table 2-15 Unit weight and Waste Composition of Some Tri-Cities Landfill Laboratory Specimens

Specimen	γ_t	<20mm	Paper	Soft	Wood	Gravel
A3-2L	13	100	0	0	0	0
A3-3L	9.3	100	0	0	0	0
A3-6L	9.7	76	13	4	7	0
A3-7L	10.4	62	14	3	11	10
A3-8L	8.2	62	14	3	11	10
A3-12L	5	14	56	5	13	12
C6-3L	8.1	62	18	5	5	12
C6-4L	10.2	62	18	5	5	12

According to Vesilind et al. (2002) depending on the pressure exerted on the MSW, it has a highly variable bulk density. When MSW is pushed into the can it can be up to 300 lb/yd^3, but if it is placed loosely it can be between 150 and 250 lb/yd^3 and in the density increases up to 600 to 700 lb/yd$^{3.}$ Once compacted with machinery it can reach up to 1200 lb/yd^3. Also, the value can range from 700 to 1700 lb/yd^3 when cover soil is included.

Abduli (1995) studied the values of waste properties for several years at the solid waste of Tehran. It was mentioned that the densities of waste for years 1983, 1991 were 297 and 320 respectively.

Manassero et al. noticed that the unit weight varies throughout the landfill and is difficult to determine because of the differences in induced ageing, method of placement, variability of composition, depth and local moisture content. It is suggested that the possible range of unit weight is 3 to 14 kN/m^3. Table 2-16 shows different values of unit weight.

Table 2-16 Unit weight of Domestic waste (Manassero et al. 1997)

Source	Unit Weight (kN/m^3)
Fungaroli et al. (1979)	1.1-4
Koriates et al. (1983)	8.6
Oweis & Khera (1986)	6.45
Oweis et al. (1990)	6.45
	9.4-14
	6.3-9.4
Landva & Clark (1990)	10.1-14.4
Gabr & Valero (1995)	
Blengino et al. (1996)	9-11
Manssero (1990)	8-10
Beaven & Powrie (1995)	5-13
Brandl (1990)	11-14
	13-16
Brandl (1994)	9-12
	9-12
	13-17

Zekkos et al. showed that every landfill has a unique characterization of unit weight and that is a function of waste composition, compaction, liquids management and confining stress. A hyperbolic unit weight profile was developed which was applicable for landfills with moisture content at or below field capacity. This model is depicted in Fig 2-4. Table 2-17 shows unite weight varies proportionately with moisture content.

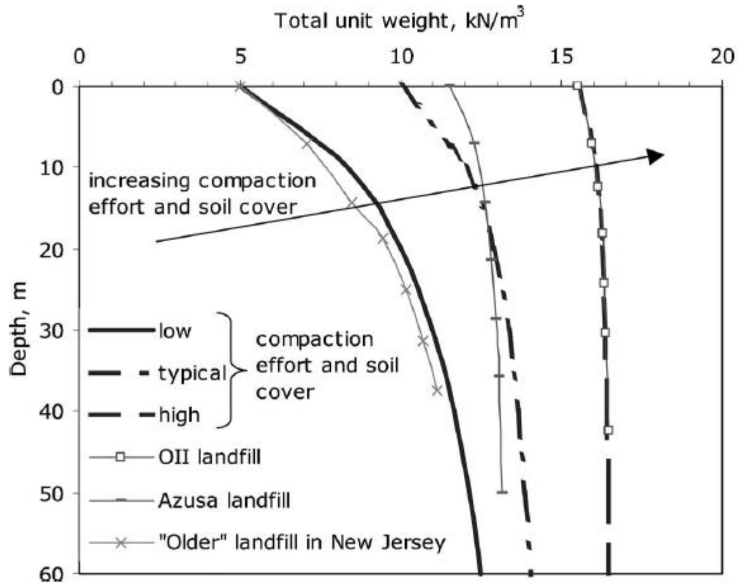

Figure 2-4 Unit weight Profile (Zekkos et al., 2006)

Table 2-17 Unit Weight of MSW (Zekkos et al., 2006)

Source	Unit Weight (kN/m^3)	
Fassett (1993)	Poor compaction	3
	Good compaction	17
Zekkos et al. (2005b)		3-20
Landva & Clark (1986)		8-17
Kavazanjian (1995)	at surface	6
	at 45 m depth	13
Kavazanjian (1996)	at surface	10-13
	at 30 m depth	13-16
Bioreactor		20
Submerged condition		14.5-16

Gabr and Valero (1995) evaluated engineering properties of 15 to 30 years old municipal solid waste. The mean specific gravity of MSW is 2.0. The dry unit weight varies from 7.4 to 8.2 kN/m^3 while maximum dry unit weight of solid waste can be 9.3 kN/m^3.

Chen at al. (2009) conducted research at the Qizhishan landfill, China and showed that the unit weight varies from 5 kN/m^3 to 15 kN/m^3, increasing bi-linearly with depth. The unit weight increases till depth of 22 m and the rate of increase decreases at greater depths.

Guermoud et al. (2009) conducted a study which showed that the density of water is higher in developing countries (0.35 to 0.5 ton/m^3) than in industrial countries.

Study done by Han at al. (2006) gave the information that the compacted bulk density near top during landfills is 647.9 kg/ m^3), but for the Sandtown Landfill of Delaware the average waste density of landfill is 999.6 kg/m^3.

Hudson et al. performed studies to focus on quantifying the changes in density of saturated solid waste resulting from increases in vertical stress. Table 2-18 depicts the densities with stress level.

Table 2-18 Variation in Particle Density with Applied Stress (Hudson et al., 2004)

Raw Domestic waste		Aged Domestic waste	
Average Stress at end of stage	Average apparent particle density	Average Stress at end of stage	Average apparent particle density
kPa	t/m^3	kPa	t/m^3
34.00	0.88	35.00	1.64
65.00	0.97	67.00	1.62
120.00	1.02	123.00	1.64
241.00	1.17	239.00	1.69
463.00	1.30	458.00	1.86

Yousuf and Rahman (2007) conducted a study in Dhaka City, Bangladesh and it was reported that the average bulk density for municipal solid waste for wet season was 0.23 ton/m^3 and dry season was 0.24 ton/ m^3.

Landva and Clark (1990) performed in-situ weight measurement across Canada and found that the MSW unit weight ranges from 6.8 to 16.2 kN/ m^3. The unit weight of the cover soil needs to be measured separately. The unit weight of different components of typical MSW is given in Table 2-19.

Table 2-19 Typical Unit Weight of Refuse (Landva and Clark, 1990)

Category	Unit weight (kN/m^3)	
	Dry	Saturated
Food waste	1.0	1.0
Garden refuse	0.3	0.6
Paper products	0.4	1.2
Plastic, rubber	1.1	1.1
Textiles	0.3	0.6
Wood	0.45	1.0
Metal products	6.0	6.0
Glass & ceramics	2.9	2.9
Ash, rock & dirt	1.8	2.0

Bleiker et al. (1995) coined that as the landfill development progresses vertically the refuse at the bottom of the landfill gets compacted both immediately and over time. According to the authors, if the effective stress increases from 21 kPa to 441 kPa, refuse density increases from 685 to 1345 kg/ m^3. Table 2-20 depicts landfill densities by different researchers.

Table 2-20 Typical Landfill Densities (Bleiker et al 1995)

Source	Density (kg/m^3)	
Landva & Clark (1990)		694-1653
Oweis & Khera (1986)	old refuse	1122-1286
	during active landfilling	673
Sowers (1973)		600
Ham & Bookter (1982)	1.2 m of refuse	458
	1.4 m of refuse	491
Lukas (1992)	poor compaction	321
	good compaction	642
	best compaction	963

Xiang-rong et al. (2003) conducted study of MSW in Tianziling Landfill. It is noted that as the depth increases the unit weight of MSW increases from 8 kN/m^3 to 16.8 kN/m^3. Presence of plastic and branches decreases unit weight while gravel in daily cover does the opposite.

Elagroudy et al. (2008) studied MSE in bioreactor landfills and reported the initial density of solid waste as 532 kg/m^3.

Hettiarachchi et al. (2009) studied bioreactor landfill. The compaction dry density of MSW was reported to be 500 kg/m^3. The wet density of waste was reported to be approximately at a range of 825 to 1125 kg/m^3 and maximum density at the bottom of landfill after 25 years could be 1125 kg/m^3.

Maystre and viret (1995) stated that the specific weight of solid waste in collection bag lies between 0.08 to 0.12 kg/liter for Geneva, Switzerland.

Yu & Maclaren (1995) characterized the industrial, commercial and institutional wastes of Toronto, Canada. The unit weights of different components of MSW are listed in Table 2.-1.

Table 2-21 Composition and density estimate of IDI MSW (Yu & Maclaren, 1995)

Components	Density (kg/m^3)	
	Trash can	Compactor
Paper	77	350
Paperboard	26	337
Ferrous metal	120	270
Non-ferrous metal	32	178
Plastics	38	198
Glass	390	1293
Rubber	102	175
Leather	29	191
Textile	29	191
Wood	360	444
Vegetation	300	720
Fine	60	480
Special	32	178
Construction materials	360	444
Food	360	930

Gharabaghi et al. studies two landfills in Brazil. One is the Muribeca landfill, which is a partially engineered landfill where the density of waste is 850 kg/m^3 and the unit weight is 14.7 kN/ m^3. The other is Cruz das Almas landfill, which is an open dump where the density is 450-600 kg/m^3 and unit weight is 8.8 kN/ m^3.

Dixon and Jones (2005) performed tests on engineering properties of solid waste. According to the paper, factors that affect unit weight are compaction effort, layer thickness, the depth of burial and the amount of liquid present. As the large waste constituents vary the unit weight vary significantly. Table 2-22 lists bulk unit weights for different countries.

Table 2-22 Bulk Unit Weight of MSW for Different Countries (Dixon & Jones, 2005)

Country	Bulk unit weight (kN/m^3)	
United Kingdom		6-8
Belgium		5-10
France	Fresh MSW	7
USA	Fresh MSW	6-7
	Degraded MSW	14-20

Hogland et al. (2004) determined that no reliable trend of variation exists in density of different layers of buried waste.

From the short one week study conducted by Hristovski et al. (2007) in summer on the residential waste of Veles, Macedonia, the uncompacted and compacted specific weights were found to be 140.5 kg/m^3 and 223 kg/m^3 respectively.

The density of municipal solid waste of Mexico has been reported as 400 kg/m^3 by Hernández-Berriel et al. (2008).

2.2.4 Volatile Solids of Municipal Solid Waste

Volatile solids tests are relatively easy to perform but still a good indication of the remaining gas generation potential of the waste.

Kelly et al. (2006) conducted a study to determine which parameters are most indicative of stability of the landfill waste. For this particular study, samples were collected from 12 different landfills aged from fresh to 11 years old. Tests were conducted to determine cellulose, lignin, and biochemical methane potential and volatile solids along with the plastics of the collected samples. The main objective of the study was to determine which methods accurately predict the biodegradable or organic fraction of waste and the point where the degradation of waste becomes stable. The degradation phenomenon was different for individual landfills because of the heterogeneity of waste and the unique landfill conditions. The researchers plotted the VS, Cellulose, BMP and Lignin of the samples with the age of the waste. It was observed that most samples had less than 5% Cellulose after 5 years in the landfill. From the data it was observed the bioreactor landfills were more degraded and the values of VS, Cellulose, Lignin and BMP were lower for ELR landfills. According to the researchers, the BMP values are supposed to be good indicators of degradation but are subjected to the variability of inoculums type. The BMP with age plot showed a similar trend as Cellulose with age. Kelly et al developed correlations between Cellulose and VS, Lignin and VS, BMP and VS; and Cellulose + Lignin and VS. The Cellulose versus VS showed a stronger correlation with VS than Lignin and BMP, as illustrated in Figure 2-5 The authors commented that Cellulose could be reasonably predicted from VS.

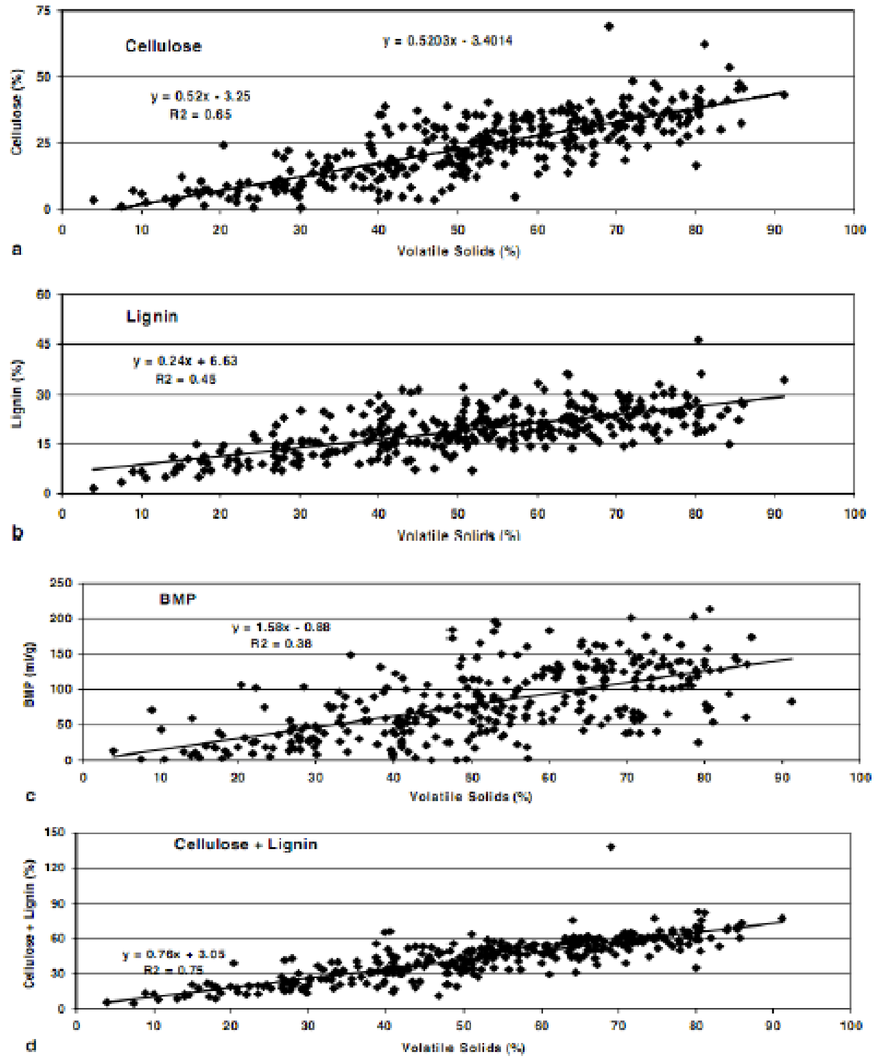

Figure 2-5 Relationship between Volatile Solids and (a) Cellulose, (b) Lignin, (c) BMP and (d) Cellulose + Lignin using Data from 12 Landfills

Gabr and Valero (1995) conducted a research program to estimate the geotechnical properties of 15 to 30 years old municipal solid waste. A drill rig was used to recover samples up to 42 m depth. According to the authors, based on the age of the tested waste samples food waste, garden waste, and paper products made up a much smaller portion than in fresh samples. The textiles, rock, and soil made up the larger portion of the aged samples. The organic content was 33% and pH was measured to be 8.8.

Kavazanjian et al. (2010) collected landfilled sample from tri-cities landfill. The organic content was estimated to be for the sample groups A3, C6 and C3 respectively 13%-23%, 11%-13%, and 17%-27%. A3 waste was retrieved from depth of 25.6- 26.2 m and 15 years old, C3 retrieved from depth of 3.5-4.5m and 2 years old, C6 group samples retrieved from depth of 7.6-9.6 m and less than 1 year old at the time of drilling.

Gomes et al. (2005) conducted a study to characterize the solid waste being disposed at San Tirso landfill. For different ages of waste three different profiles were selected. Organic content at surface ranged from 43%-63% for recent wastes and for 56% for 3 year old waste.

Townsend et al. (1996) studied the conversion of an existing conventional landfill to leachate recirculated landfill. The samples of leachate, landfill gas and landfilled solid waste samples were collected and analyzed before and after leachate recycle for four years to observe the effect of leachate addition to the waste. The researchers reported an increase in moisture content of the MSW due to recirculation. The leachate was recycled by means of an infiltration pond leachate recycle system. Four infiltration ponds were constructed for recycle for the whole landfill except the controlled section where no recirculation was conducted. There was not a significant change reported for the leachate quality. The total sample volatile solids, Biodegradable Organic Fraction (BDOF) volatile solids and BDOF ultimate methane yield were plotted with estimated sample age as presented in Figure 2-6

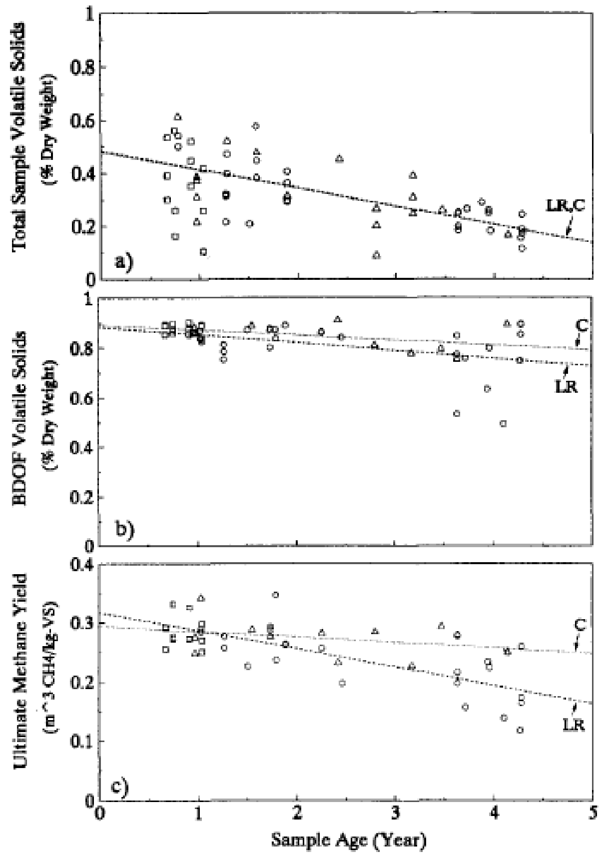

Figure 2-6 MSW Sample Characteristics with Age (a) Total Volatile Solids, (b) BDOF Volatile Solids and (c) Ultimate Methane Yield BDOF: Leachate Recycled Area, Δ Controlled Area (C), and □ New Waste Area

The total volatile solids content decreased with sample age for both the leachate recycle area and control area. The BDOF volatile solids did not show any significant correlation with age in both areas. For the ultimate methane yield the samples from controlled area no significant correlation with age was found. However, the leachate recycled area displayed a significant correlation of volatile solids with sample age. The landfill subsidence results and ultimate methane yield indicated that the degree of stabilization was greater in the wet area.

2.3 Effects on Physical Properties

2.3.1 Effect of age of waste

According to Chan et. al the content of compressible components such as plastics, paper, wood and textile decreases with an increase in the fill age of MSW. It was found that the magnitude of compression index decreased linearly with an increase in the fill age. Even within a particular landfill with same MSW input, the composition of MSW varies with its fill age.

CHAPTER 3

Methodology

3.1 Introduction

The main objective of this study is to collect fresh waste and landfilled solid waste from the City of Denton Landfill of Texas, determine the physical and hydraulic properties such as physical composition, unit weight, moisture content and volatile solid content.

This chapter presents the methodology for collection of sample and storage and also the test procedures followed for determining the physical and hydraulic properties of municipal solid waste.

3.2 Selected study area

The city of Denton Landfill is located on the south east side of Denton. The aerial view of the landfill is shown in Figure 3-1.

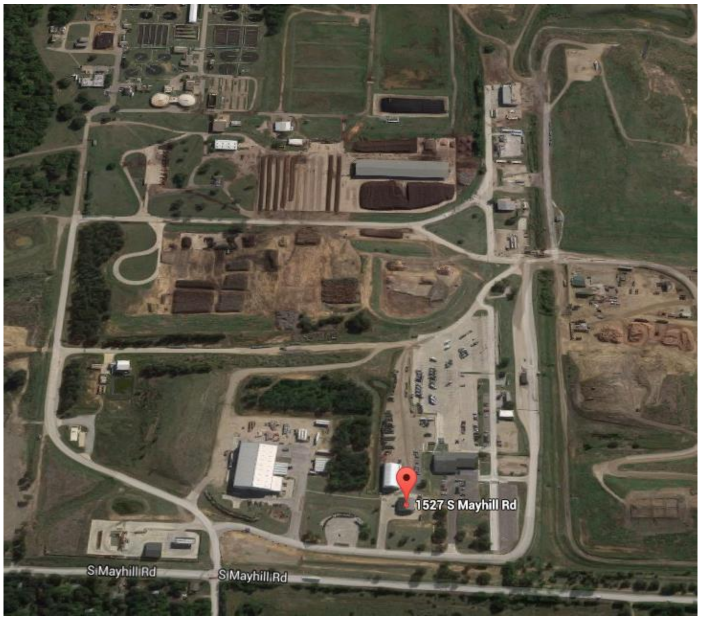

Figure 3-1 City of Denton Landfill

The landfill is owned and operated by the city of Denton. It opened in 1984 under permit 1590 which was pre subtitle D. The landfill started with 32 acres and in 1998 and then expanded the landfill 252 acres, which covers 152 acres for waste and 100 acres for office, compost area, buffer zone and extra rented land. Currently, there are six cells in the landfill and the former cell is considered as cell zero or cell 1590. It follows operational rules given in the 30 TAC 330 subchapters D, which is provided by the Texas Administration Code.

The city of Denton Landfill is a type 1 landfill that means it receives Municipal Solid Waste (MSW). There are 20 groundwater monitoring wells and 20 gas monitoring wells. Cell 0 is pre-subtitle D landfill and the rest of the landfill is sub-title D landfill with a liner system which protects the groundwater from pollution. The waste in the landfills decomposes very slowly due to lack of oxygen. Adding oxygen to the waste increases the rate of decomposition and the waste decomposes faster.

In 2008, the city of Denton landfill installed a landfill gas collection system to collect and use landfill gas energy as a green energy source. The electric power generator on site takes the collected gas. The capacity of the electric generator is 1.6 megawatts, which is equivalent to powering 1,200 homes per year. The electric power station was designed to expand as methane gas production increases.

For the present study, sample waste was collected from seven boreholes (BH-D to BH-G and BH-05 to BH-07) at different depths of Cell 0 for the conventional cells and six boreholes (BH-A to BH-C and BH- 3A, 3B, 3C) from Cell 2 and Cell 3 for the ELR cells. The fresh waste was collected from the active Cell in five bags (F1 to F5). Figure 3-2 gives a demonstration of the positions of the boreholes.

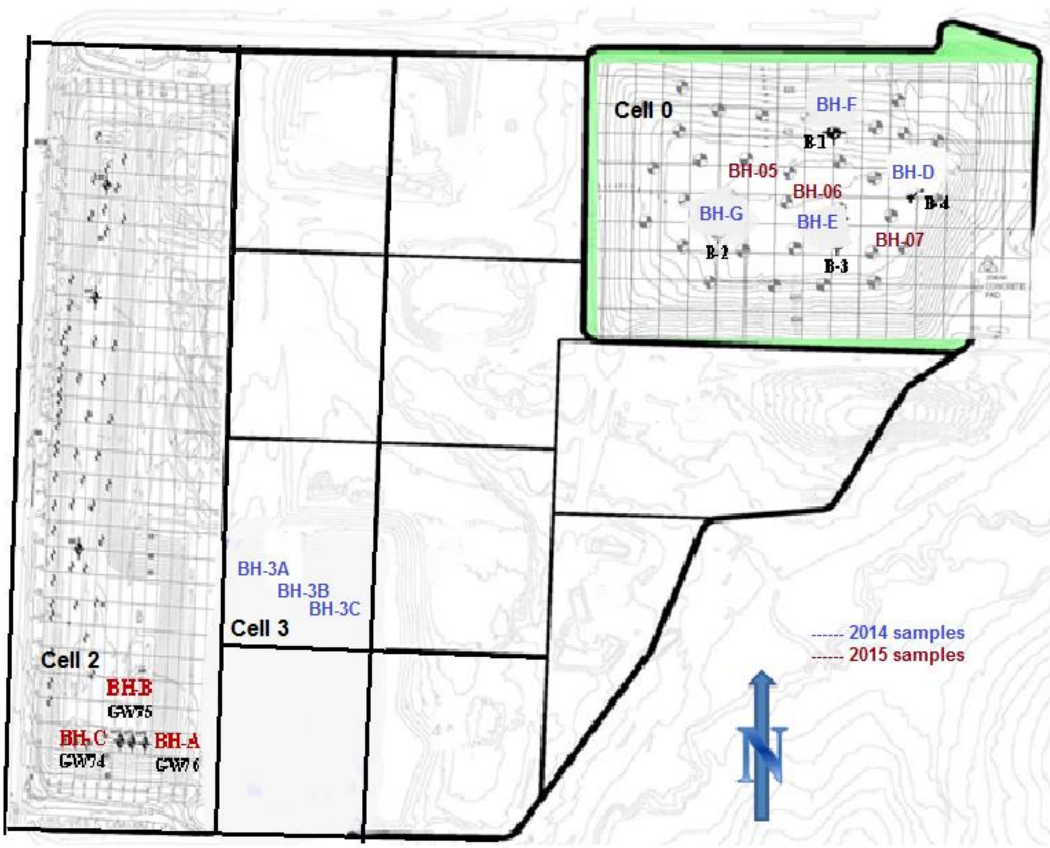

Figure 3-2 Location of Boreholes in the Layout of City of Denton Landfill

3.3 Sample collection and storage

3.3.1 Landfilled Sample Waste

Solid waste samples were collected from the Denton Landfill in June 2014 and 2015. A 3 ft. diameter bucket augur attached to an AF130 Hydraulic Drill Rig was used for drilling, as shown in Figure 3-3. Solid waste samples were collected from 7 boreholes for conventional cells and six boreholes for ELR cells.

Figure 3-3 Landfilled MSW collection with AF 130 Hydraulic Drill Rig

The collected samples were brought to the laboratory in sealed plastic bags. All the samples were stored and preserved at approximately 38℉ (below 4℃) in an environmental growth chamber. The environmental growth chamber and sample storage is shown respectively in Figure 3-4 and Figure 3-5.

Figure 3-4 Environmental Growth Chamber

Figure 3-5 Samples Stored in Environmental Growth Chamber

Samples were collected at different depths for each borehole. From previous study work conducted by Taufiq (2010), it was observed that the required MSW waste for characterization is 25 to 30 lbs. Therefore, 25 to 30 lbs was collected from each sample.

3.3.2 Fresh Sample Waste

The fresh sample wastes have been collected from the working face of the City of Denton Landfill. For the fresh MSW, samples waste were collected in five bags (F1 to F5) and the average weight of each bag was about 30 lbs each.

The procedure used to collect the samples is as follows. First, three random locations were chosen on the landfill. From the first location the solid waste was taken out by backhoe and places on a neat surface. Then the samples were thoroughly mixed with the backhoe and approximately 30 lbs of waste was collected in each bag. Two bags were filled with MSW chosen by grab sampling which was done without any bias. The next two bags were collected from the second chosen location following the same procedure. The last bag was collected from the third location following the same procedure.

3.4 Sample Storage

The collected samples were brought to the lab in plastic bags. All the bags were preserved and stored at approximately 38℉ (below 4℃) in environmental growth chamber. The environmental growth chamber is depicted in Figure 3-6 and the stored samples are depicted in Figure 3-7.

Figure 3-6 Environmental Growth Chamber

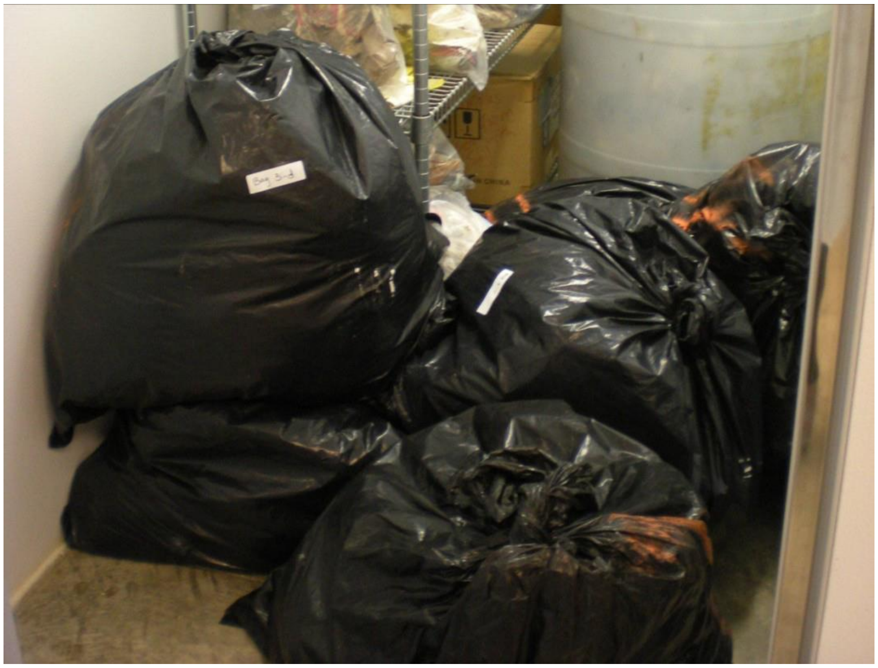

Figure 3-7 Stored Samples

3.5 Test Methodology

The test methodology selected to determine each of the physical and hydraulic characteristics of the samples are described in the following subsections.

3.4.1 Physical Composition

To determine the Physical Composition of MSW each of the plastic bags were emptied onto a large plastic sheet and then were manually separated into the following categories: paper, plastic, food waste, leather and textile, yard waste , metals, glass, styrofoam and sponge, other (soils and fines), and construction debris, as shown in Figure 3-8.

Figure 3-8 Physical Composition of MSW

The category “paper” consists of all sorts of paper including packing cardboard, magazines, newspaper, office paper, etc. Under the “plastic” category, all the plastic container like PET bottles, food wrappers, polythene bags, etc. were placed. Rubber was grouped together with plastic instead of sorting separately. The “wood and yard waste” consisted of not just branches, leaves and grass from the grass trimming but also broken pieces of wood from construction and demolition. All sorts of metals including silverware, soda cans, and dry cells were put under “metal” category. Construction debris consisted of broken brick, dry walls, stone chips, tiles, paints, etc. If any portion of the solid waste could not be sorted under any of the above categories like lumps of mud and objects too small to separate were categorized as “others”.

The components that were sorted were weighed individually and the weights were shown as a percentage of total weight. Also the total weight in food waste, leather and textile, paper and wood and yard waste categories were considered degradable and the rest of the total weight as non-degradable. The degradable and non-degradable percentages were also determined.

3.4.2 Moisture Content

For determination of moisture content, three types of specimen can be used:

1. Grab sampling before sorting.
2. Proportionately taking each component according to the physical composition after sorting.
3. Taking standard proctor compacted sample (proportionate to composition)

For the present study, method 1 was used for moisture content determination. Determination of moisture content of samples was done according to standard method ASTM D 2974 – 00 and APHA 2540 – B (Kelly, 2002). For each of the tests, a minimum of 2 lbs of waste were taken, so that it would be more representative of the original MSW.

The measured samples were dried in the oven at 105℃ in the oven for 24 hours to determine the moisture loss. The percent loss was determined on both wet weight and dry weight basis. The moisture content on wet weight basis and dry weight basis was determined according to equation 3.1 and 3.2, respectively. Figure 3-9 shows samples being dried in the oven for the determination of moisture content. The moisture content on wet weight basis is expressed as follows (Tchobanoglous et al., 1977):

$$Moisture\ content, \%(wet\ weight\ basis) = \frac{a-b}{a}\ X\ 100 \qquad (3.2)$$

Where,

a = initial weight of sample as delivered

b = weight of the sample after drying

Moisture content on dry weight basis can be expressed as follows:

$$Moisture\ content, \%(dry\ weight\ basis) = \frac{a-b}{b}\ X\ 100 \qquad (3.1)$$

Where,

a = initial weight of the sample as delivered

b = weight of the sample after drying

Figure 3-9 Samples placed in oven for Determination of Moisture content

3.4.3 Unit Weight

The Unit weights of the sample were determined at their natural moisture content. The Standard Proctor Compaction ASTM D698 was used to compact the municipal solid waste. A large sized compaction mold with 6 inch diameter, 6.1 inch height, with a volume of 1/10 cubic feet with detachable collar was used. The mold was filled with three layers of solid waste up to the rim. A 5.5 lb hammer with 2 inch face was dropped 75 times for a fall height of 12 inch on each of the 3 MSW layers to attain the required compaction. The use of 75 blows instead of 25 was determined based on the compaction energy per volume.

$$Energy\ transferred\ in\ standard\ proctor\ compaction\ test, E = n \times h \times \frac{P}{V}$$

Where,

n = number of blows

P = weight of hammer

V = volume of the mold

Weight of mold was measured both before and after filling with waste. Equation 3.3 is used to calculate compacted unit weight of solid waste. Figure 3-10 and 3-11 show the sample preparation for unit weight determination.

$$Unit\ Weight\ (lb/ft3) = \frac{weight\ of\ compacted\ waste\ inside\ mold\ (lb)}{Volume\ of\ mold\ (ft3)} \quad (3.3)$$

Figure 3-10 Samples being compacted

Figure 3-11 Fully compacted MSW in compacted mold

3.4.3 Volatile Solids of Municipal Solid Waste

The organic content of the MSW is determined by the Volatile Solid test. The test procedure followed a modified version of Standard Methods APHA Method 2440-E. Approximately 50 gm of dried MSW were placed in pre-weighed porcelain cubicles and inserted into a muffin furnace at 550℃ for 2 hrs. Equation 3.4 shows how volatile solids of solid waste is calculated. Figure 3-12 illustrates the sample preparation of volatile solids determination.

$$Volatile\ Solids = \frac{Weight\ loss\ after\ burnt}{Dry\ weight\ of\ sample\ before\ burnt}\ x\ 100\% \qquad (3.4)$$

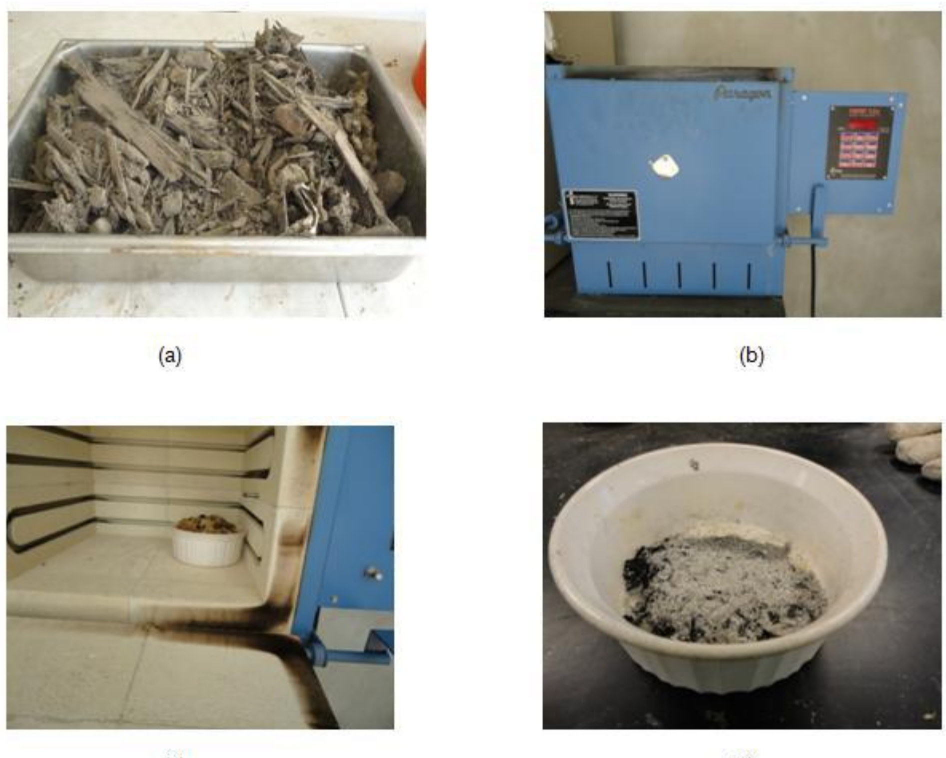

Figure 3-12 (a) Oven dried sample (b) Muffle Furnace set at 550℃ (c) Sample placed in the oven (d) Burnt sample

CHAPTER 4

Results and Discussions

4.1 Introduction

To achieve the objectives of the current study, municipal waste samples have been collected from the city of Denton Landfill and have been tested in the laboratory following the procedures described in chapter 3. MSW is heterogeneous and the physical properties are expected to change when the waste degrades with time. The age of the collected waste is approximately ranged from 9 to 25 years. The need to understand the composition of the waste sample is important. This chapter gives a brief discussion of various physical and engineering characteristics.

4.2 Results and Discussions

The test results for the physical composition, moisture content, unit weight, and volatile solids are presented in the following sub sections.

4.2.1 Physical Composition of the collected Municipal Solid Waste (MSW)

The physical composition of the collected landfilled samples from all the borings were determined by manual sorting.

4.2.1.1 Municipal Solid Waste (MSW) from Cell 0

Cell 0 is a conventional landfill and the waste is collected from 4 boreholes in 2014 (BH-D to BH-G) and from 3 boreholes in 2015 (BH-05 to BH-07). The physical compositions of the waste collected in 2014 is depicted in Table 4-1 and 4-2 and the degradable composition is given in Table 4-3. The physical composition of waste collected in 2015 is shown in Table 4-4 and the biodegradable composition is given in Table 4-5.

Table 4-1 Sample Collection Data from Cell 0 (2014)

Boring	Number of Samples	Description
D	1	Sample collected at 90 ft depth.
E	6	Sample collected at every 10 ft depth, maximum 90 ft. No sample was collected from top 40 ft depth.
F	2	Sample collected at 50 ft depth and 60 ft depth.
G	7	Sample collected at every 10 ft depth, maximum 77 ft depth.

Table 4-2 Physical Composition of Landfilled MSW for Cell 0 (2014)

Boring	Physical Composition (% by weight)									
	Paper	Plastic	Food waste	Textile + leather	Yard waste + wood	Metals	Glass	Styrofoam sponge	C & D debris	Others (soil and fines)
D	3.2	25.0	0	0.96	2.85	3.44	0.72	1.8	3.66	58.3
E	17.9	10.6	0	2.89	13.2	4.44	0.44	1.44	1.83	47.0
F	5.43	10.0	0	3.39	7.01	22.5	0.73	1.95	1.02	47.8
G	22.1	8.17	0	2.12	6.54	2.07	0.42	0.57	2.49	55.4
Average	20.0	9.40	0.00	2.51	9.91	3.26	0.43	1.01	2.16	51.2
Standard	2.93	1.74	0.00	0.54	4.77	1.68	0.01	0.62	0.47	5.96
Maximu	22.1	10.6	0	2.89	13.2	4.44	0.44	1.44	2.49	55.4
Minimum	17.9	8.17	0	2.12	6.54	2.07	0.42	0.57	1.83	47.0

Table 4-3 Degradable and non-degradable composition of Landfilled Municipal Solid Waste for Cell 0 (2014)

Boring	Physical Composition (By degradability)	
	Degradable	Non-Degradable
D	7.00	93.00
E	34.16	65.84
F	15.82	84.18
G	32.78	67.22
Average	22.44	77.56
Standard deviation	13.25	13.25
Maximum	34.16	93.00
Minimum	7.00	65.84

Table 4-4 Physical Composition of Landfilled MSW of Cell 0 (2015)

Boring	Physical Composition (% by weight)									
	Paper	Plastic	Food waste	Textile + leather	Yard waste + wood	Metals	Glass	Styrofoam sponge	C & D debris	Others (soil and fines)
05	23.9	7.50	0.00	2.48	6.52	6.55	1.86	1.02	3.68	46.4
06	21.4	11.2	0.03	2.62	4.61	4.32	1.46	2.14	2.53	49.5
07	8.73	8.69	0.00	1.01	13.0	3.12	0.98	0.85	2.68	60.9
Average	18.0	9.14	0.01	2.04	8.05	4.66	1.43	1.34	2.96	52.3
Standard Deviation	16.3 4	3.80	0.04	1.78	8.83	3.48	0.88	1.40	1.24	15.2 3
Maximu	23.9	11.2	0.03	2.62	13.0	6.55	1.86	2.14	3.68	60.9
Minimum	8.73	7.50	0.00	1.01	4.61	3.12	0.98	0.85	2.53	46.4

Table 4-5 Degradable and non-degradable composition of Landfilled Municipal Solid Waste for Cell 0 (2015)

Boring	Physical Composition (By degradability)	
	Degradable	Non-Degradable
05	32.95	67.05
06	28.75	71.25
07	22.77	77.23
Average	28.16	71.84
Standard deviation	5.11	5.11
Maximum	32.95	77.23
Minimum	22.77	67.05

There was only one sample for boring D at 90 ft. depth. From the Figure 4-1 it was observed that the soil and fine content was 58% at 90 ft. depth for boring D which indicates that most of the waste had been degraded at that depth. The second highest percentage was plastic (25%). Degradable wastes were only 7% left at this depth.

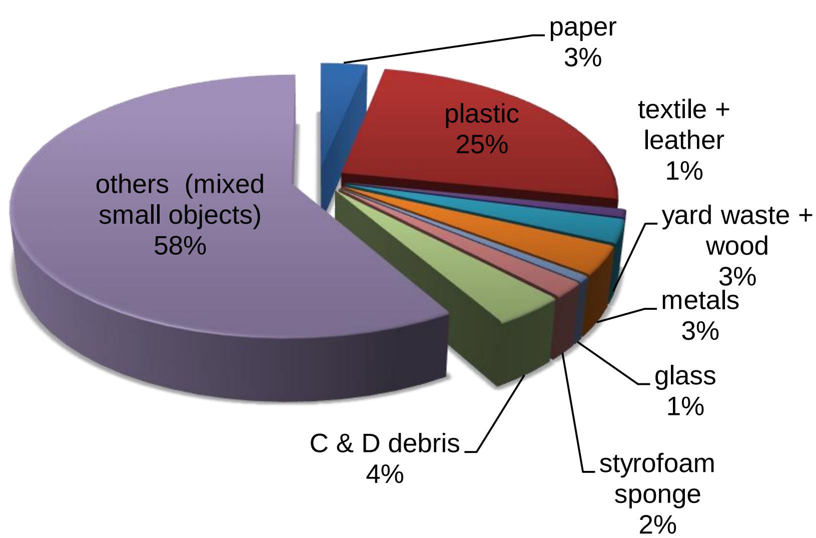

Figure 4-1 Weight Percentages of MSW from Boring D at 90 feet

From the composition illustrated in Figure 4-2 it was observed that the paper content was 29.1% and plastic content was 28.28% at 40 ft. depth for boring E. At 60 ft. most of the portion is fines (78.62%), but at 70 ft. paper and wood waste had suddenly been increased in huge portion. at 80 ft. and 90 ft. most of the wastes were degraded and mostly degraded fines had been found.

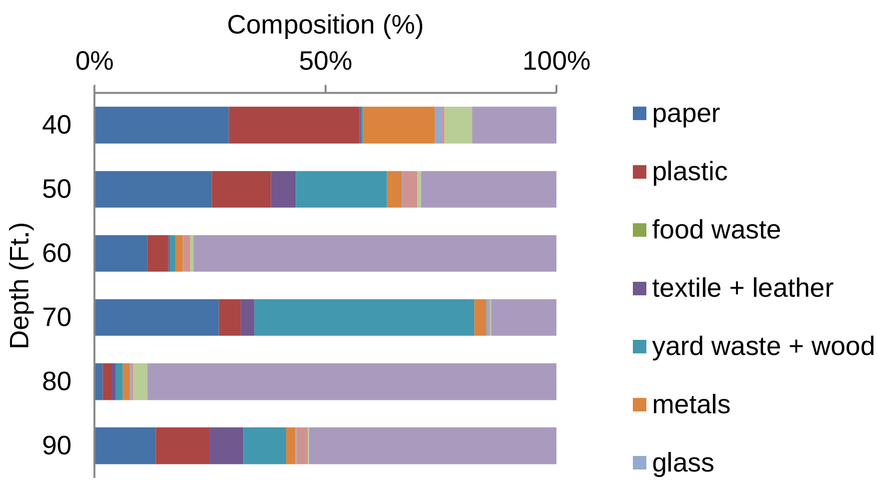

Figure 4-2 Weight Percentages of MSW from Boring E at Different Depths

The average composition of the boring E presented in Figure 4-3 illustrates percentage of non-degradable component was more than degradable components. The non-degradable components and soil & fine percentage were approximately 56% of the composition. The results indicated that major portion of waste was soil and degraded fines (47%). From the combined average for landfilled MSW samples, the main components of waste other than soils and degraded fines were paper (18%) and wood waste (13%).

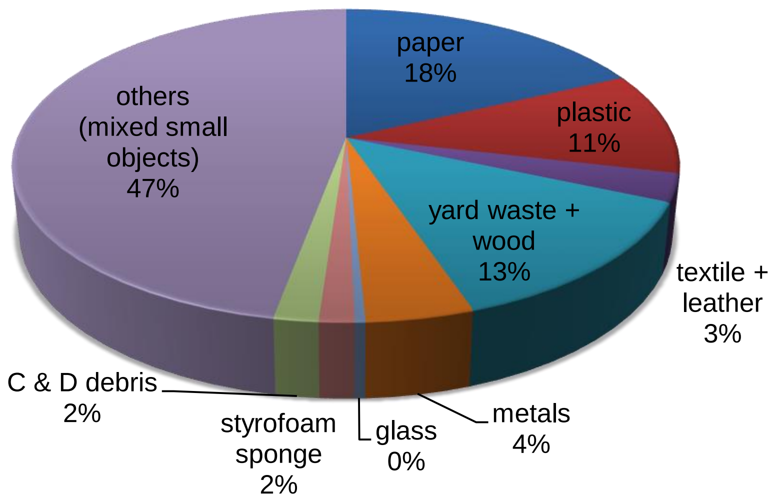

Figure 4-3 Average Weight Percentages of MSW from Boring E

There were only two samples collected from 50 ft. and 60 ft. of boring F. From the composition illustrated in Figure 4-4 it was observed that the metal content was 36.82% at 50 ft. depth for boring F. The second highest percentage was seen as fines. Similar type of composition had been seen at depth 60 ft. with more amounts of fines.

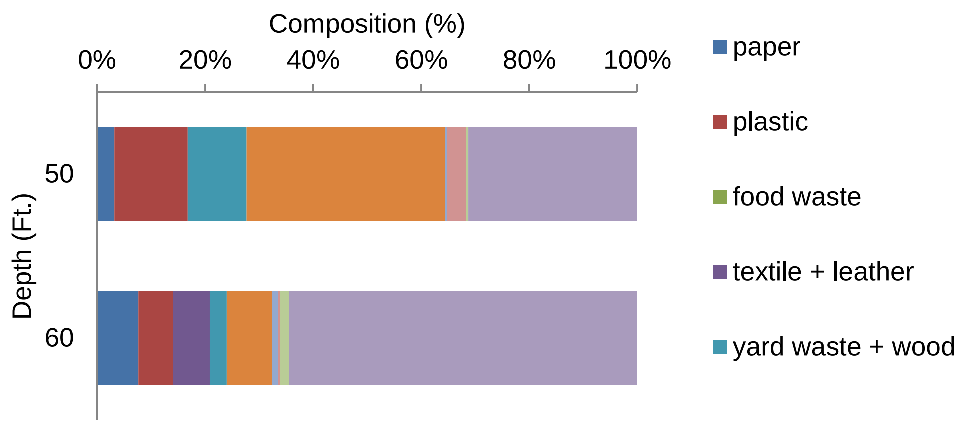

Figure 4-4 Weight Percentages of MSW from Boring F at Different Depths

The average composition of the boring F presented in Figure 4-5 illustrates percentage of non-degradable component was more than degradable components. The non-degradable components and soil & fine percentage were approximately 75% of the composition where soil and degraded fines were (48%). From the combined average for landfilled MSW samples, the main components of waste other than soils and degraded fines were metal (23%) and plastics (10%).

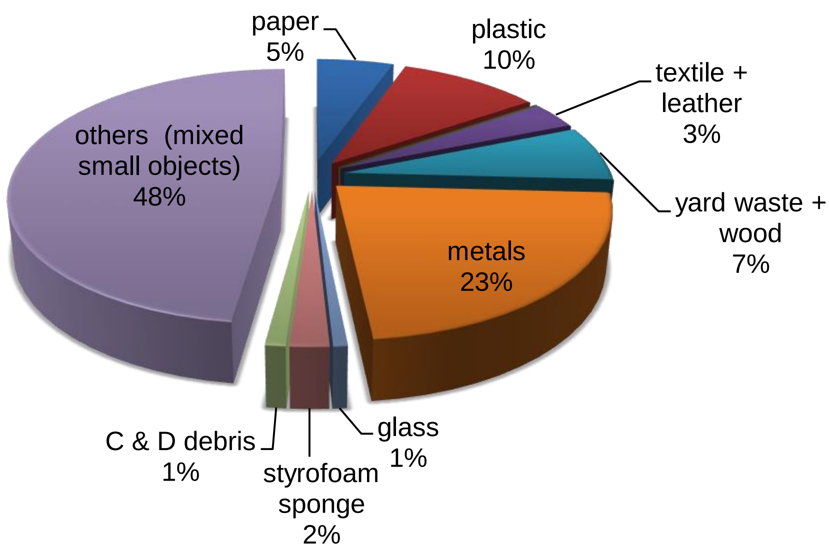

Figure 4-5 Average Weight Percentages of MSW from Boring F

From the composition illustrated in Figure 4-6 it was observed that the soil and fines content was 84.21% at 10 ft. depth for boring G. But at 20 ft. most of the portion is paper and wood (48.37% and 22.4% respectively). Percentage of soil increased from 30 ft. to 60 ft., but decreased in the highest amount at 77 ft. Very high percentage of paper was retrieved from 77 ft. with 70.37%.

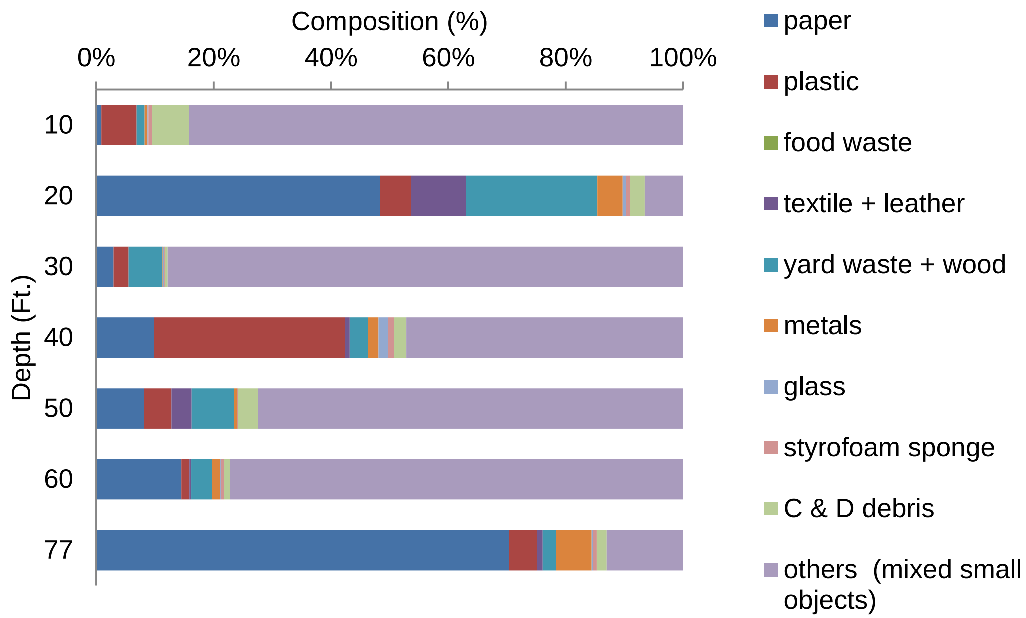

Figure 4-6 Weight Percentages of MSW from Boring G at Different Depths

The average composition of the boring G presented in Figure 4-7 illustrates percentage of non-degradable component was more than degradable components. The non-degradable components and soil & fine percentage were approximately 62% of the composition. The results indicated that major portion of waste was soil and degraded fines (55%). From the combined average for landfilled MSW samples, the main components of waste other than soils and degraded fines were paper (22%) and plastics (8%).

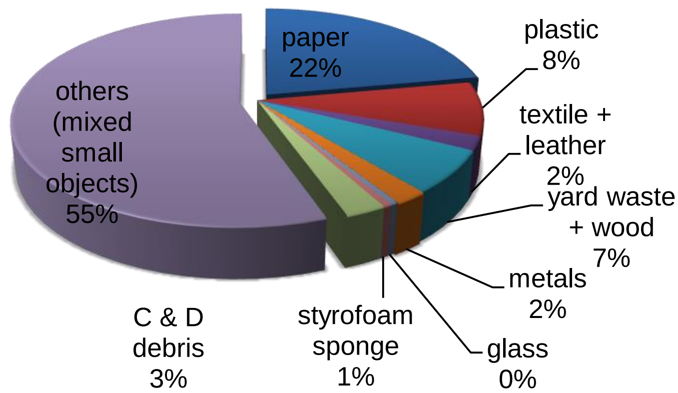

Figure 4-7 Average Weight Percentages of MSW from Boring G

The average composition of the landfilled samples, including all 4 borings, is presented in Figure 4-8. The major component of the landfilled waste was determined to be fines and other mixed objects (47%). Paper content was determined to be 12%. Food waste was 0.04% and plastic was 16% in the total waste mass.

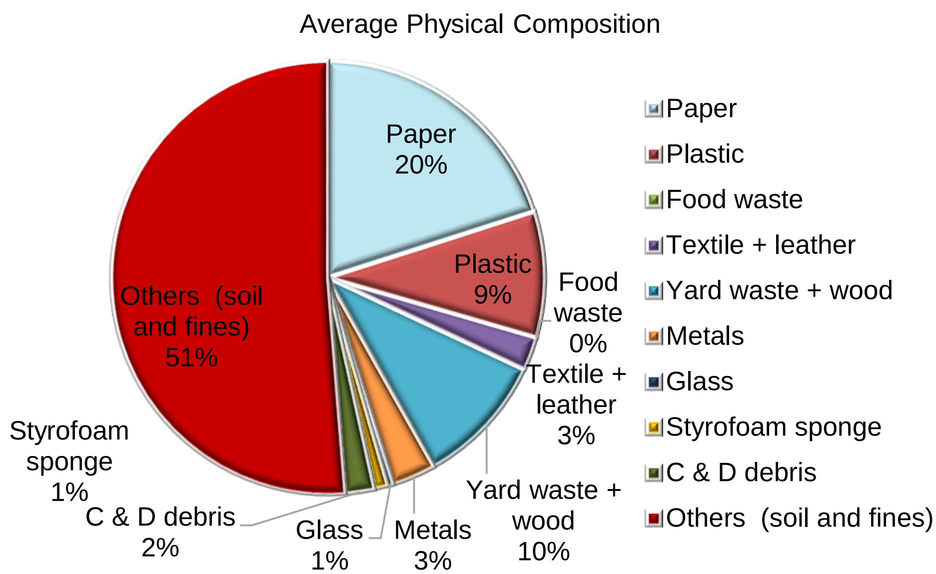

Figure 4-8 Average Composition of Landfilled Waste

Composition of MSW for BH-05, BH-06 and BH-07 are presented as percentage of weight of individual waste components to the weight of total waste in Figure 4-9 through 4-11.

The average composition of BH-05 as presented in 4.11 illustrates paper as 24%, plastic 7%, textile + leather 2%, yard and wood waste 7%, metals 7%, glass 2%, styrofoam and sponge 1%, C & D debris 4% and others (mixed other objects and fines) 46%.

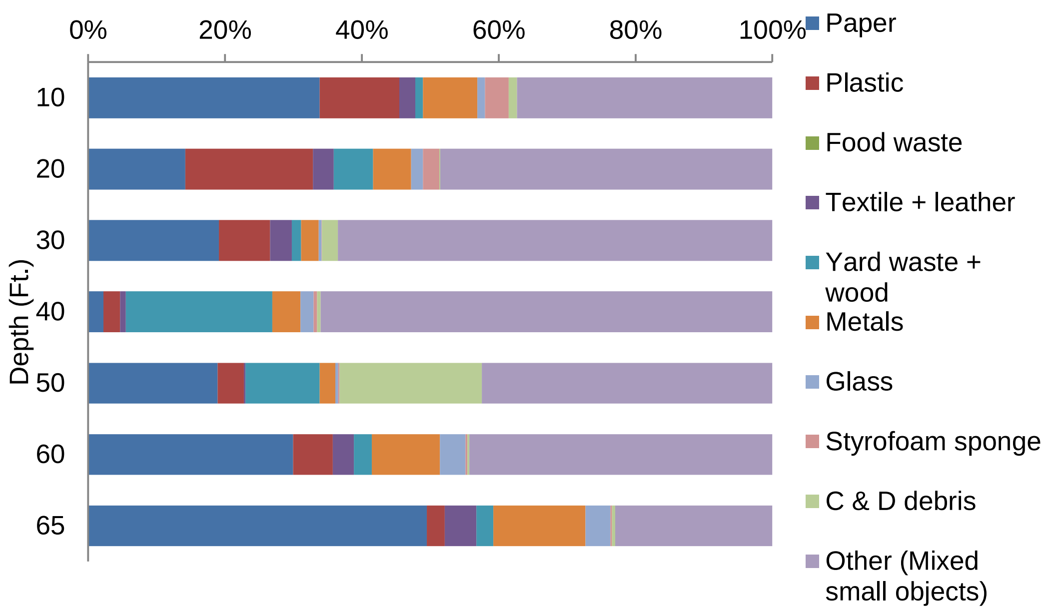

Figure 4-9 Weight Percentages of Municipal Solid Waste from BH-05 at Different Depths

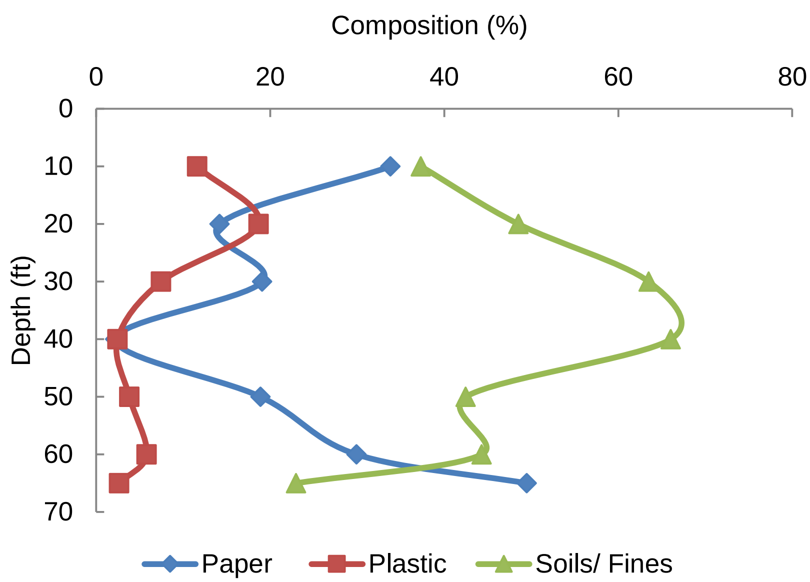

Figure 4-10 Weight Percentages of Paper, Plastic and Soils/ fines of Municipal Solid Waste from BH-05 at Different Depth

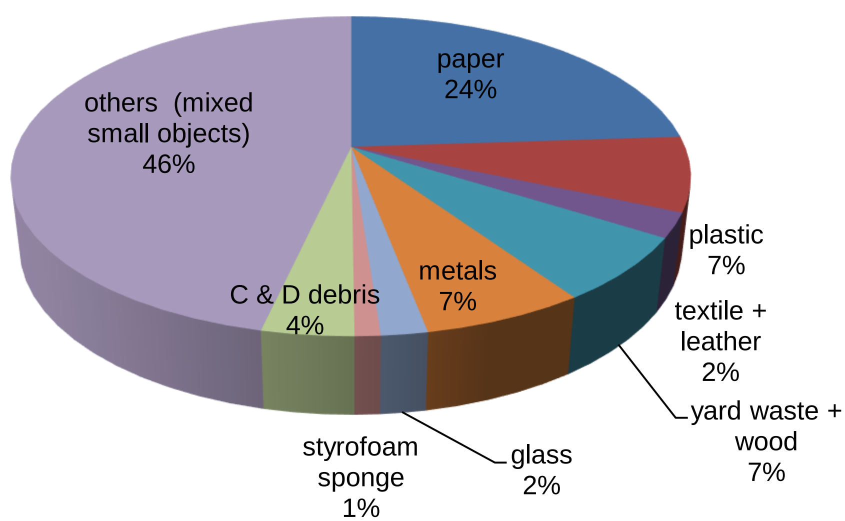

Figure 4-11 Average Weight Percentages from BH-05

From the composition illustrated in Figure 4-12, it was observed that the paper content was 30.8% at 15 ft. depth for BH-06. The percentages of plastic components and other (soils and fines) component were also high. Food waste was present in only 45 ft. depth with very low percent. At 60 ft. soil/fines percentage is high approximately 74.71%. The paper content decreases with the depth of boring except at 45 feet depth. Soil content was high in this sample. It can be explained as uneven distribution of moisture in the landfill and extensively heterogeneous nature of waste. The degradation is a function of moisture availability. The samples were mostly degraded and remaining degradable percentage is very low for the particular boring MSW samples.

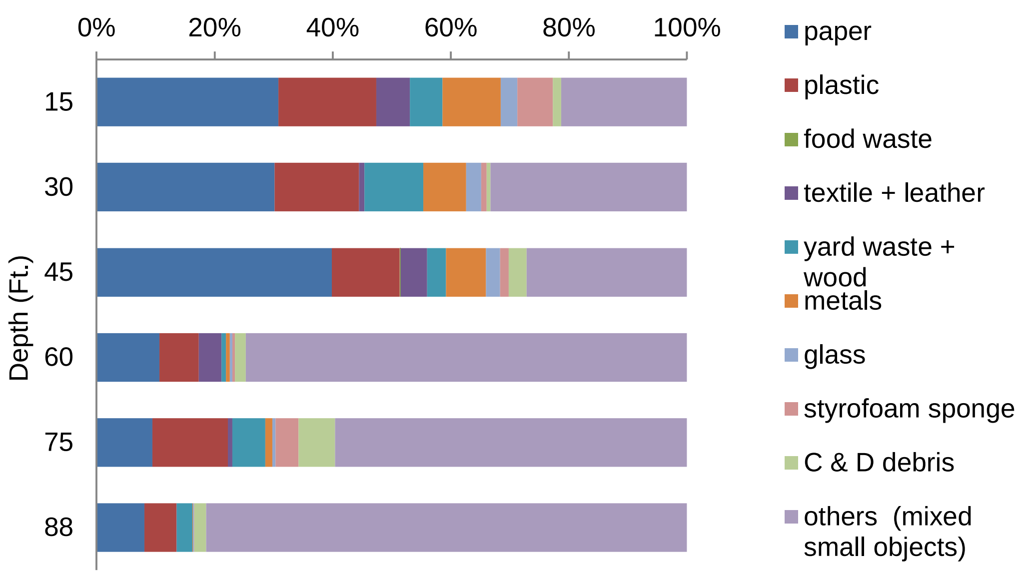

Figure 4-12 Weight Percentages of MSW from BH-06 at Different Depths

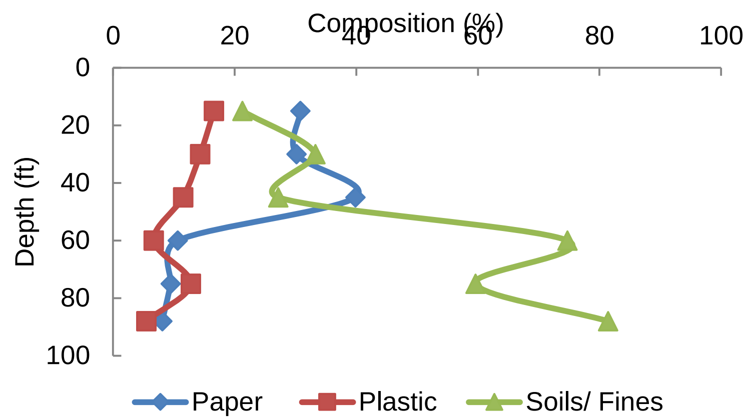

Figure 4-13 Weight Percentages of Paper, Plastic and Soils/ fines of MSW from BH-06 at Different Depth

The average composition of the BH-06 presented in Figure 4-14 illustrates percentage of degraded soils/fines is 50%. The degradable components were approximately 40% of the composition. The results indicated that major portion of waste was soil and degraded fines. From the combined average for landfilled MSW samples, the main components of waste other than soils and degraded fines (50%) were paper (21%), plastics (11%) and metal (4%).

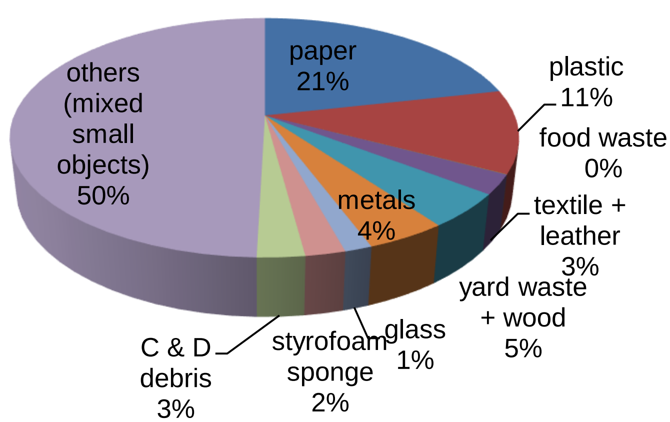

Figure 4-14 Average Weight Percentages of MSW from BH-06

From the composition illustrated in Figure 4-15 it was observed that the soil content was 77.19% at 15 ft. depth for BH-07. But at 45 ft. most of the portion is yard and wood waste (56.19%). Soil content was in this sample also high like BH-06. At 88 feet soil content is almost 83.31%.

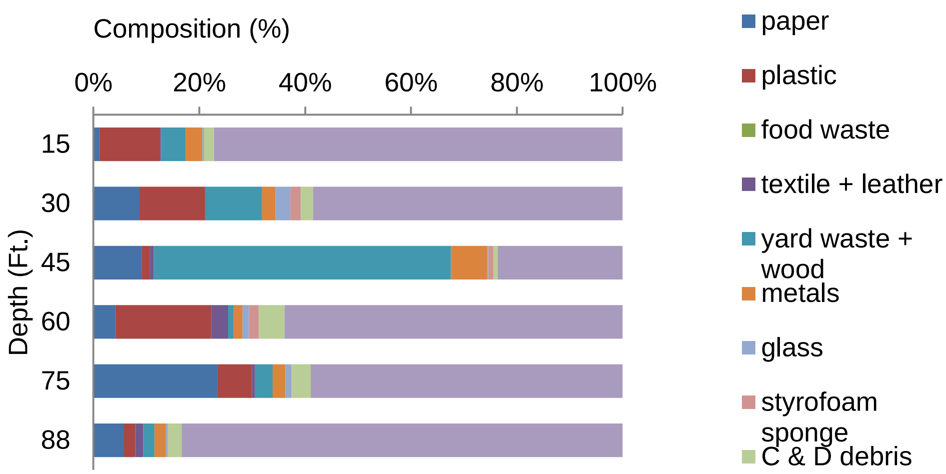

Figure 4-15 Weight Percentages of MSW from BH-07 at Different Depths

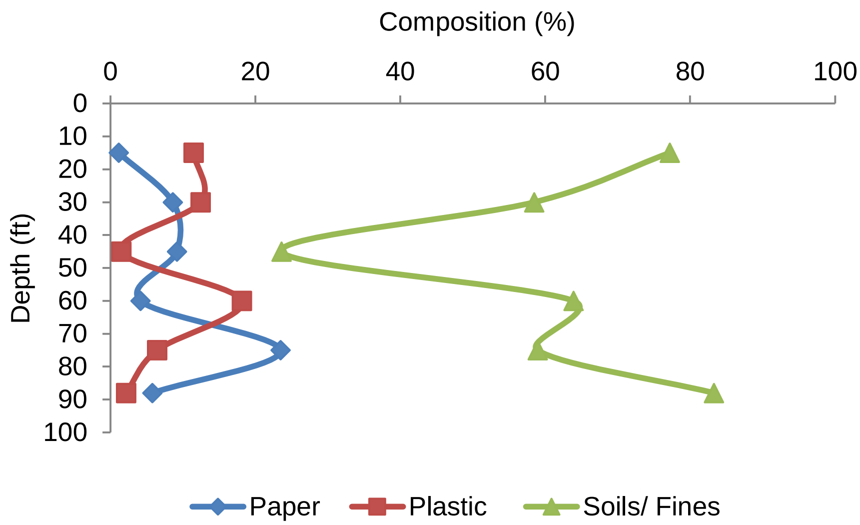

Figure 4-16 Weight Percentages of Paper, Plastic and Soils/ fines of MSW from BH-07 at Different Depth

The average composition of the BH-07 presented in Figure 4-17 illustrates percentage of non-degradable component was much higher than degradable components. The non-degradable components and soil & fine percentage were approximately 68% of the composition. The results indicated that major portion of waste was soil and degraded fines (61%). From the combined average for landfilled MSW samples, the main components of waste other than soils and degraded fines were yard and wood waste (13%), paper (9%), plastics (9%) and metal 3%.

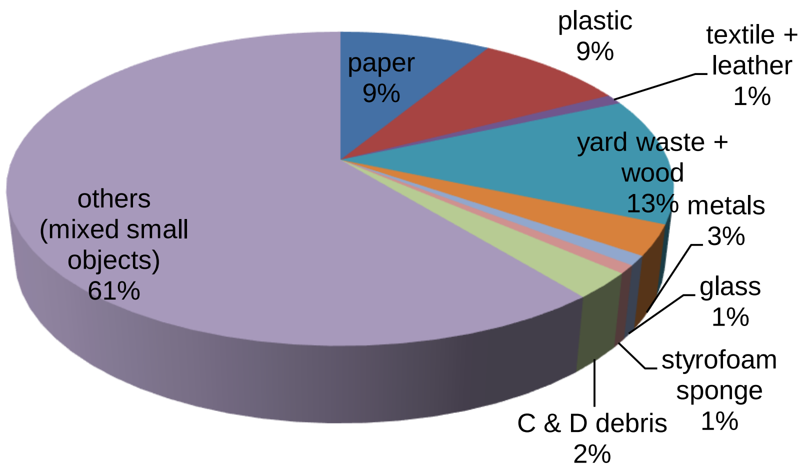

Figure 4-17 Average Weight Percentages of MSW from BH-07

The average composition of three borings presented in Figure 4-18 illustrates percentage of non-degradable component was much higher than degradable components. The non-degradable components and soil & fine percentage were approximately 63% of the composition. The results indicated that major portion of waste was soil and degraded fines (52%). From the combined average for landfilled MSW samples, the main components of waste other than soils and degraded fines were yard and paper (18%), plastics (9%) wood waste (8%), and metal 5%.

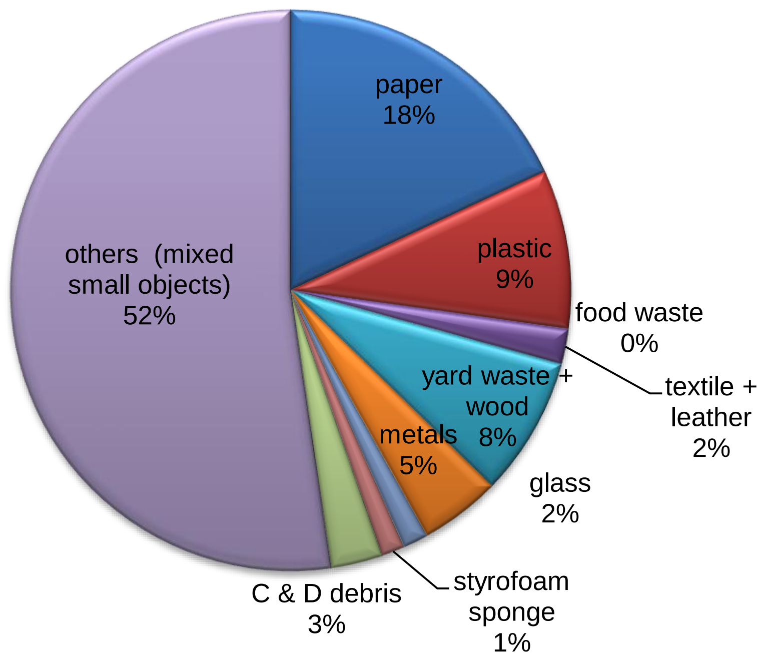

Figure 4-18 Average Composition of Landfilled Waste

4.2.1.2 Municipal Solid Waste (MSW) from Cell 2

Cell 2 is an enhanced leachate recirculation (ELR) landfill and the samples have been collected in 2014. Physical compositions of collected samples from Cell 2 are listed in Table 4-6 and Table 4-7. The samples are also separated into degraded and non-degraded composition which are listed in Table 4-8

Table 4-6 Sample Collection Data for Cell 2

Boring	Number of Samples	Description
A	8	Sample collected at every 10 ft. depth, maximum depth 80 ft.
B	4	Sample was collected from 20 ft., 30 ft., 60 ft. and 70 ft. depth.
C	8	Sample collected at every 10 ft. depth, maximum depth 80 ft.

Table 4-7 Average composition based on all the samples of Landfilled MSW of Cell 2

Boring	Physical Composition (% by weight)									
	Paper	Plastic	Food waste	Textile + leather	Yard waste + wood	Metals	Glass	Styrofoam sponge	C & D debris	Others (soil and fines)
A	11.17	18.48	0	6.13	14.33	2.89	0.35	1.25	3.11	42.29
B	11.29	18.54	0.22	4.11	8.98	6.13	0.39	2.06	5.1	43.16
C	15.24	23.94	0.02	2.77	8.71	5.85	0.24	1.51	3.93	37.8
Average*	12.57	20.32	0.08	4.34	10.67	4.96	0.33	1.61	4.05	41.08
Standard Deviation	5.19	7.00	0.14	4.07	7.14	3.89	0.16	0.60	1.58	6.05
Maximum	15.24	23.94	0.22	6.13	14.33	6.13	0.39	2.06	5.1	43.16
Minimum	11.17	18.48	0	2.77	8.71	2.89	0.24	1.25	3.11	37.8

Table 4-8 Degradable and non-degradable composition of Landfilled MSW for Cell 2

Boring	Physical Composition (By degradability)	
	Degradable	Non-Degradable
A	30.91	69.09
B	24.61	75.39
C	26.74	73.26
Average	27.42	72.58
Standard deviation	3.21	3.21
Maximum	30.91	75.39
Minimum	24.61	69.09

Composition of MSW for borings A, B, and C are presented as percentage of weight of individual waste components to the weight of total waste in Figure 4.-9 through Figure 4.-5.

The average composition of boring A as presented in Figure 4-21 illustrates paper as 11%, plastic 19%, textile + leather 6%, yard and wood waste 14%, metals 3%, glass 1%, styrofoam and sponge 1%, C & D debris 3% and others (mixed other objects and fines) 42 %.

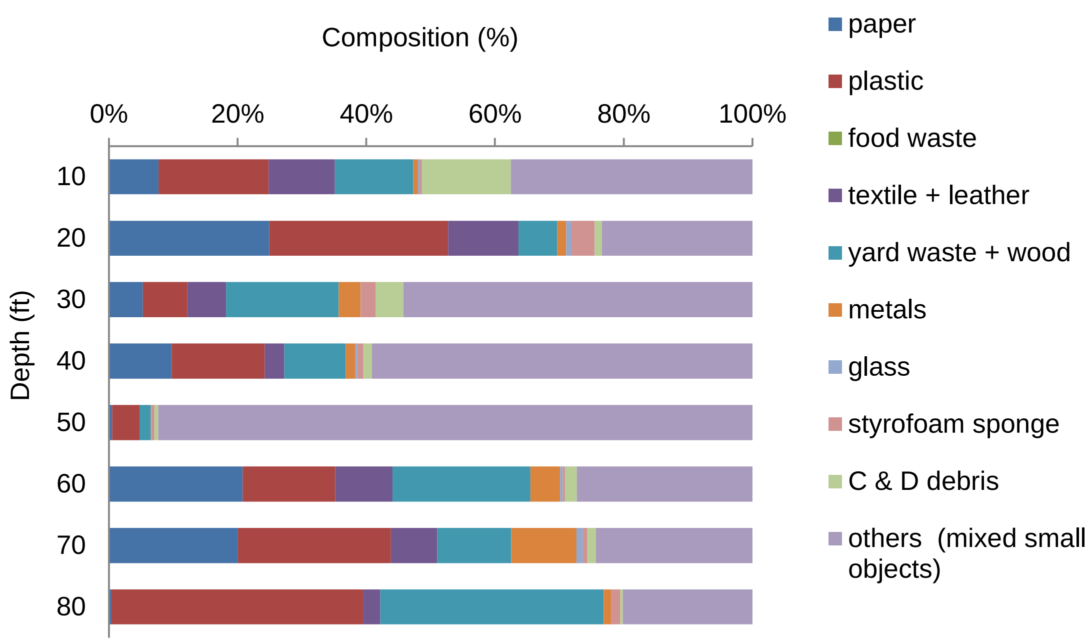

Figure 4-19 Weight Percentages of MSW from Boring A at Different Depths

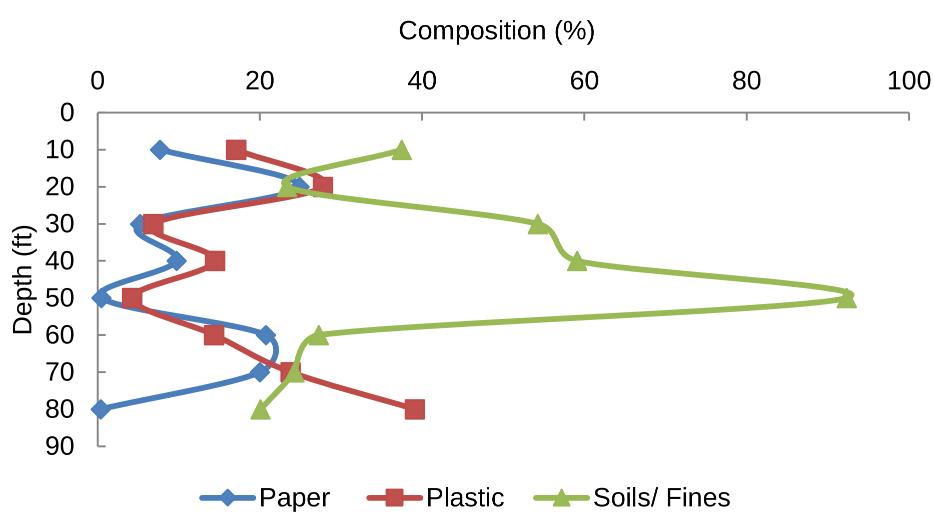

Figure 4-20 Weight Percentages of Paper, Plastic and Soils/ fines of MSW from Boring A

at Different Depth

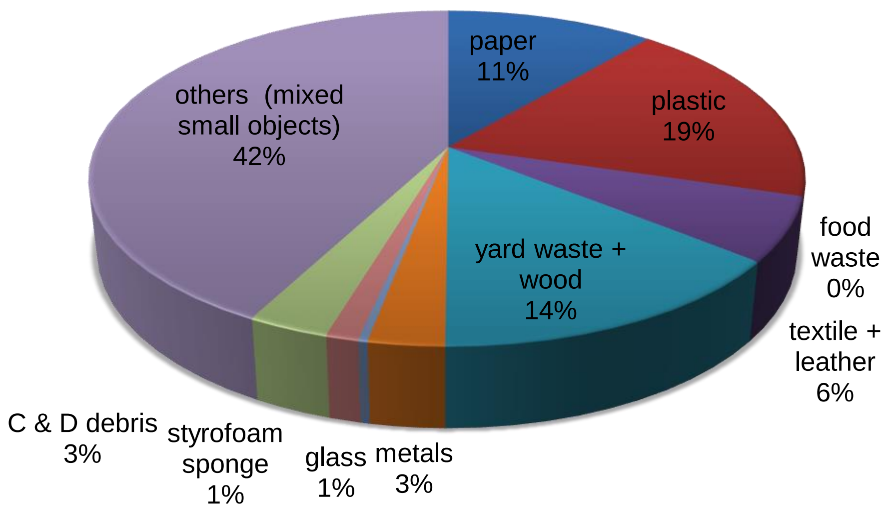

Figure 4-21 Average Weight Percentages from Boring A

From the composition illustrated in Figure 4-22, it was observed that the paper content was 37.7% at 20 ft. depth for boring B. The percentages of plastic components and other (soils and fines) component were also high. Food waste was present in only 20 ft. depth. At 60 ft. plastic percentage is high approximately 36.39%. The paper content decreases with the depth of boring. Soil content was high in this sample. It can be explained as uneven distribution of moisture in the landfill and extensively heterogeneous nature of waste. The degradation is a function of moisture availability. Therefore it can be predicted that the waste present in the vicinity of boring B were in the more saturated zone than boring A. And therefore the samples were mostly degraded and remaining degradable percentage is very low for the particular boring MSW samples.

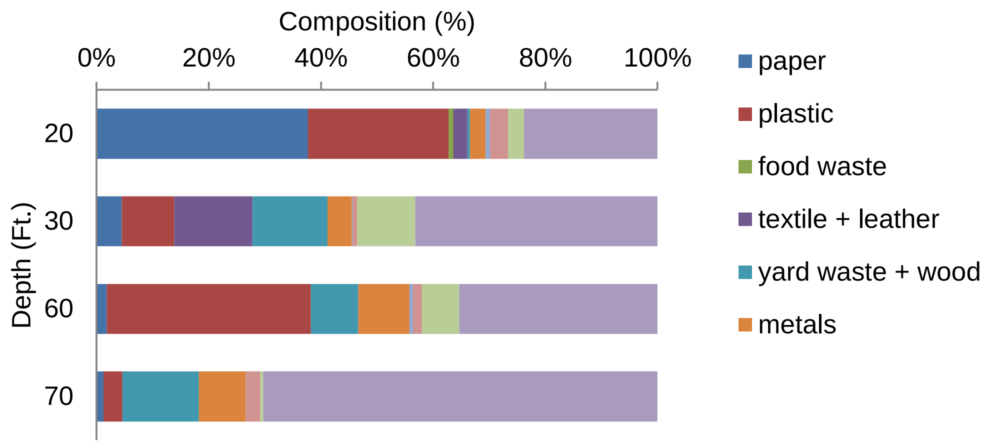

Figure 4-22 Weight Percentages of MSW from Boring B at Different Depths

The average composition of the boring B presented in Figure 4-23 illustrates percentage of degradable component was slightly less than non-degradable components. The non-degradable components and soil & fine percentage were approximately 57% of the composition. The results indicated that major portion of waste was soil and degraded fines. From the combined average for landfilled MSW samples, the main components of waste other than soils and degraded fines (43%) were paper (11%) and plastics (19%).

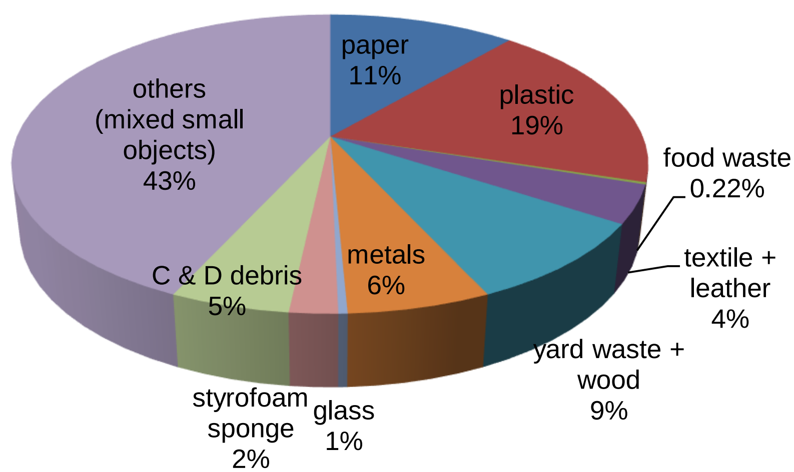

Figure 4-23 Average Weight Percentages of MSW from Boring B

From the composition illustrated in Figure 4-24 it was observed that the paper content was 50.32% at 10 ft. depth for boring C. But at 20 ft. most of the portion is plastic and fines (39.16% and 39.38% respectively). Percentage of plastic decreased from 30 ft. to 70 ft., but increased in the highest amount at 80 ft. There was no paper at 80 ft. Soil content was in this sample.

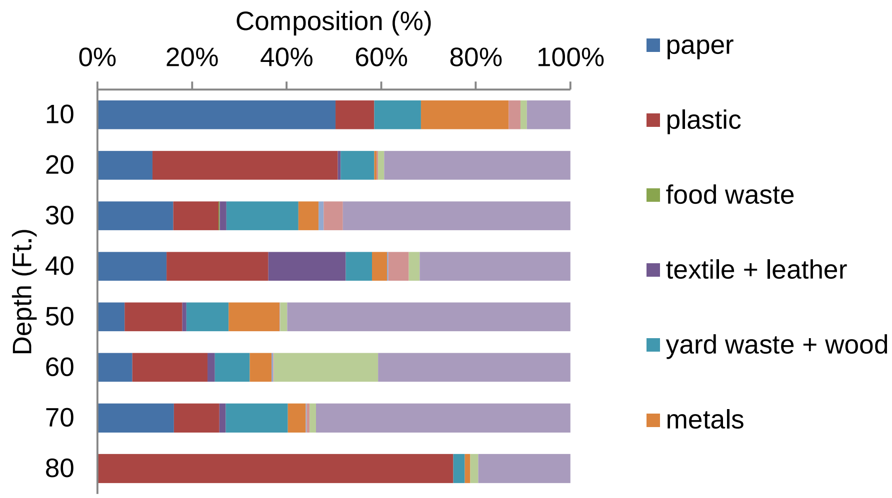

Figure 4. 24 Weight Percentages of MSW from Boring C at Different Depths

The average composition of the boring C presented in Figure 4-25 illustrates percentage of non-degradable component was slightly less than degradable components. The non-degradable components and soil & fine percentage were approximately 49% of the composition. The results indicated that major portion of waste was soil and degraded fines (38%). From the combined average for landfilled MSW samples, the main components of waste other than soils and degraded fines were paper (15%) and plastics (24%).

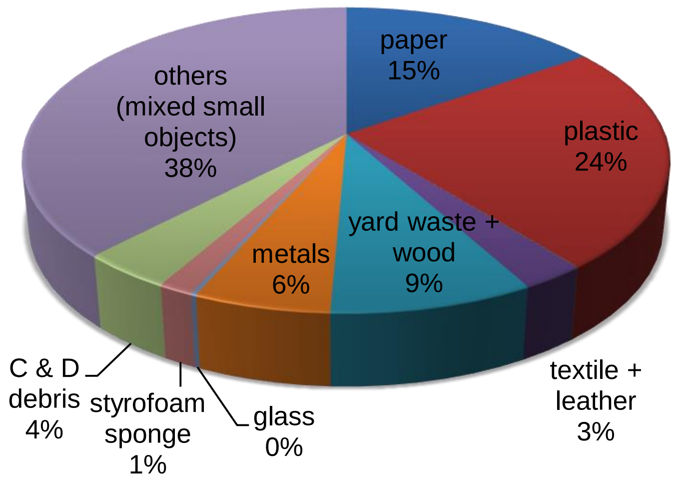

Figure 4-25 Average Weight Percentages of MSW from Boring C

4.2.1.3 Municipal Solid Waste (MSW) from Cell 3

Cell is an ELR landfill and the samples were collected in 2015. Physical compositions of collected samples from Phase 3 (ELR) are listed in Table 4-9. The samples are also separated into degraded and non-degraded composition which are listed in Table 4-10.

Table 4-9 Average composition based on all the samples of Landfilled MSW of Phase 3

Borehole	Physical Composition (% by weight)									
	paper	plastic	food waste	textile + leather	yard waste + wood	metals	glass	styrofoam sponge	C & D debris	others (mixed small objects)
3A	19.66	12.84	0.18	3.44	12.16	6.48	1.27	6.49	4.15	38.09
3B	21.69	18.35	0.14	2.72	8.30	1.72	1.25	2.57	2.53	40.73
3C	18.59	14.63	0.09	1.90	14.42	4.90	1.31	2.77	1.01	40.40
Average	19.98	15.27	0.13	2.69	11.63	4.37	1.28	3.94	2.56	39.74
Standard deviation	1.57	2.81	0.05	0.77	3.09	2.42	0.03	2.21	1.57	1.44
Maximum	21.69	18.35	0.18	3.44	14.42	6.48	1.31	6.49	4.15	40.73
Minimum	18.59	12.84	0.09	1.90	8.30	1.72	1.25	2.57	1.01	38.09

Table 4-10 Degradable and non-degradable composition of Landfilled MSW for Phase 3

Boring	Physical Composition (By degradability)	
	Degradable	Non-Degradable
3A	35.44	64.56
3B	32.84	67.16
3C	34.99	65.01
Average	34.43	65.57
Standard deviation	5.48	94.52
Maximum	39.72	60.28
Minimum	28.88	71.12

Composition of MSW for borings 3A, 3B, and 3C are presented as percentage of weight of individual waste components to the weight of total waste in Figure 4-26 through Figure 4-31.

The average composition of the boring 3A presented in Figure 4-27 illustrates that the soils and fines (37%) compose the main components of the waste. The other main components of the waste are paper (19%), plastic (12%) and yard waste (12%).

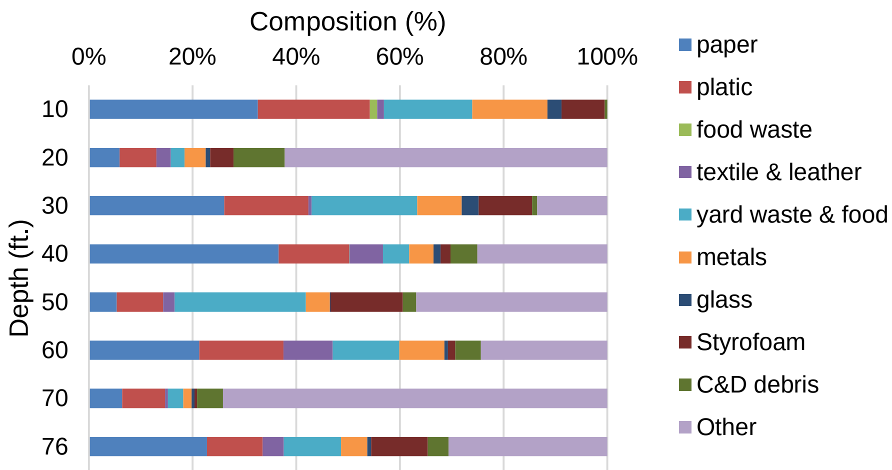

Figure 4-26 Weight Percentages of MSW from Boring 3A at Different Depths

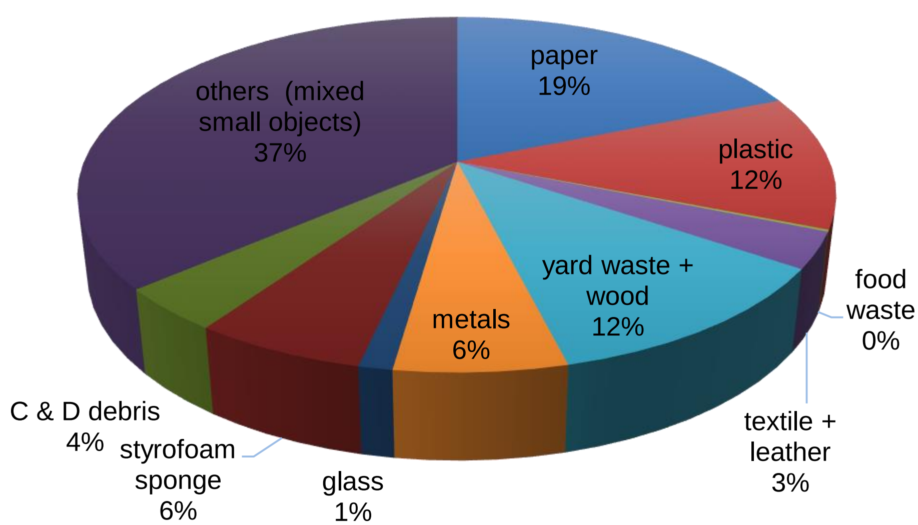

Figure 4-27 Average Weight Percentages of MSW from Boring 3A

The average composition of the boring 3B presented in Figure 4-29 illustrates percentage of degradable component was slightly less than non-degradable components. The non-degradable components and soil & fine percentage were approximately (52%) of the composition. The results indicated that major portion of waste was soil and degraded fines. From the combined average for landfilled MSW samples, the main components of waste other than soils and degraded fines (37%) were paper (19%) and plastics (12%) and wood and yard waste (12%).

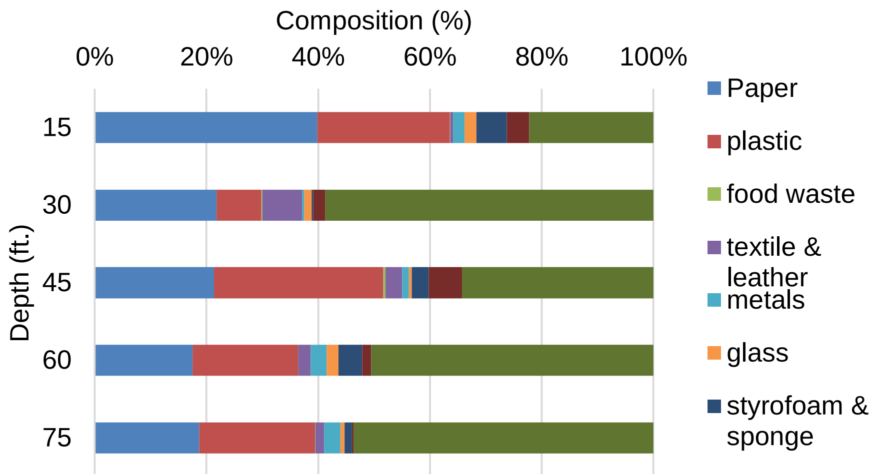

Figure 4-28 Weight Percentages of MSW from Boring 3B at Different Depths

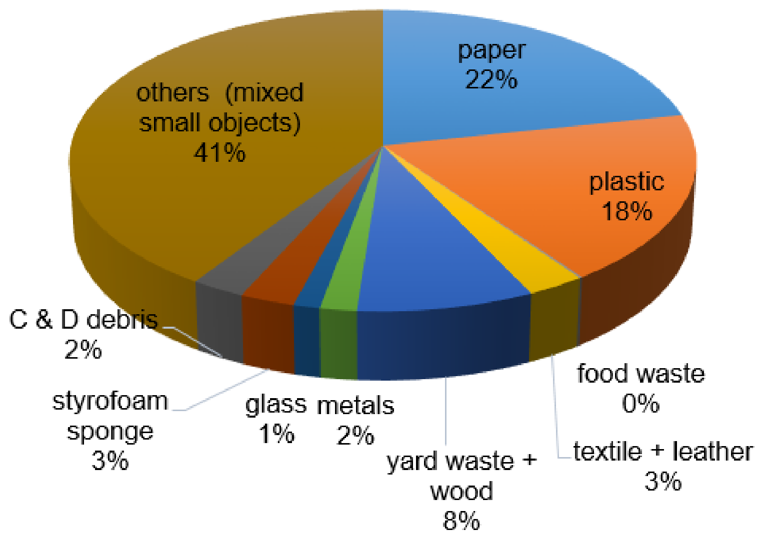

Figure 4-29 Average Weight Percentages of MSW from Boring 3B

From the composition illustrated in Figure 4-30 it was observed that the food waste was found only at 10 ft. depth. The paper content at 66 ft. depth is high approximately 41%. The percentages of plastic components and others (soils and fines) were also high. The uneven ranges of components can be explained due to uneven distribution of moisture in the landfill.

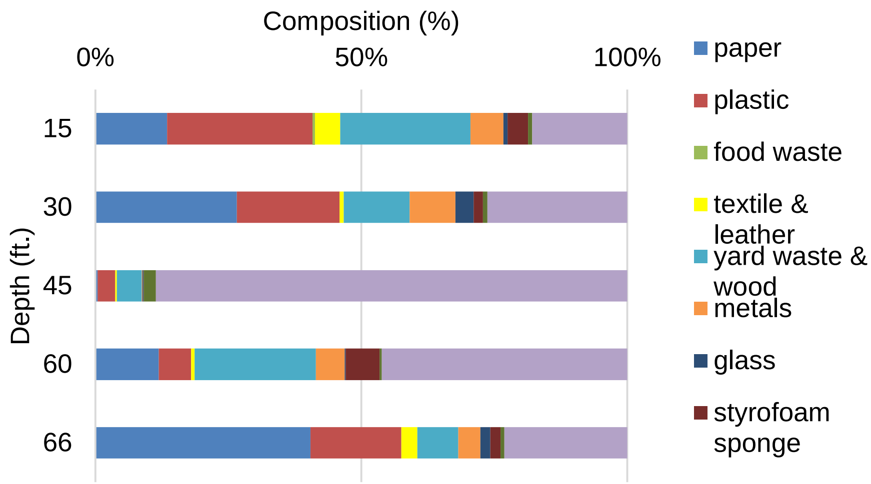

Figure 4-30 Weight Percentages of MSW from Boring 3C at Different Depths

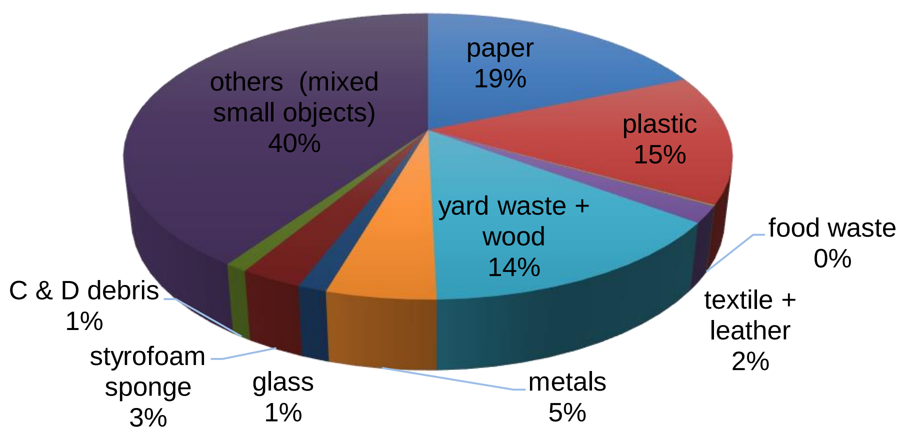

Figure 4-31 Average Weight Percentages of MSW from Boring 3C

4.2.1.4 Fresh Solid Waste

The physical composition of the collected fresh samples from bags F1, F2, F3, F4, F5 were determined by manual sorting. Physical compositions of the collected samples are listed in Table 4-11. The samples are also separated into degraded and non-degraded composition which are listed in Table 4-12.

Table 4-11 Average composition based on all the samples of Fresh MSW

Bag Designation	Physical Composition (% by weight)									
	paper	plastic	food waste	textile + leather	yard waste + wood	metals	glass	styrofoam sponge	C & D debris	others (mixed small objects)
F1	19.74	7.58	0.00	4.65	25.03	2.86	1.09	6.70	12.35	20.01
F2	43.63	20.35	0.00	6.42	4.90	9.22	0.71	7.30	0.44	7.03
F3	48.85	17.57	5.91	3.00	1.24	4.16	0.88	2.79	3.21	12.40
F4	42.67	28.61	2.01	5.99	2.78	3.24	2.50	3.72	0.40	8.08
F5	15.73	23.17	4.10	7.34	3.53	0.80	0.84	14.24	8.58	21.67
Average	34.12	19.46	2.40	5.48	7.50	4.06	1.20	6.95	5.00	13.84
Standard deviation	15.21	7.79	2.59	1.69	9.89	3.14	0.74	4.50	5.29	6.73
Maximum	48.85	28.61	5.91	7.34	25.03	9.22	2.50	14.24	12.35	21.67
Minimum	15.73	7.58	0.00	3.00	1.24	0.80	0.71	2.79	0.40	7.03

Table 4-12 Degradable and non-degradable composition of Fresh MSW

Boring	Physical Composition (By degradability)	
	Degradable	Non-Degradable
F1	49.42	50.58
F2	54.95	45.05
F3	59.00	41
F4	53.45	46.55
F5	49.77	50.23
Average	53.32	46.68
Standard deviation	3.96	3.96
Maximum	59.00	50.58
Minimum	49.42	41

From the results and also from visual inspection, it is evident that paper (approximately 35%) is the main constituent of the MSW. Plastic was as much as paper, or sometimes even more than paper by Volume and this could be due to plastic being lightweight and also due to having less water holding capacity than paper. Food waste is an important part of the solid waste and it was still found to be only 2.5% on an average and this could be because food is a readily degradable material. Another main component of the waste was the “others” group which consisted of 14% approximately. The “others” group consisted mainly of broken down pieces that were too small to be sorted manually. Yard waste which consists of wood and any natural components consists of 8% of the total waste. The average composition of MSW is given in Figure 4-32. The physical composition of each of the bag samples collected is given in Figure 4-33.

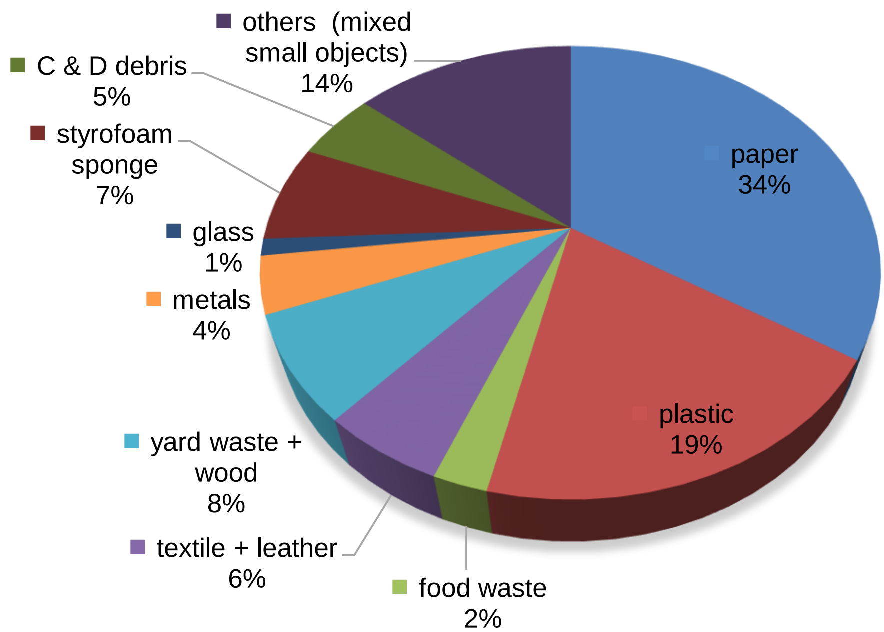

Figure 4-32 Average Physical Composition of Fresh Waste by Weight

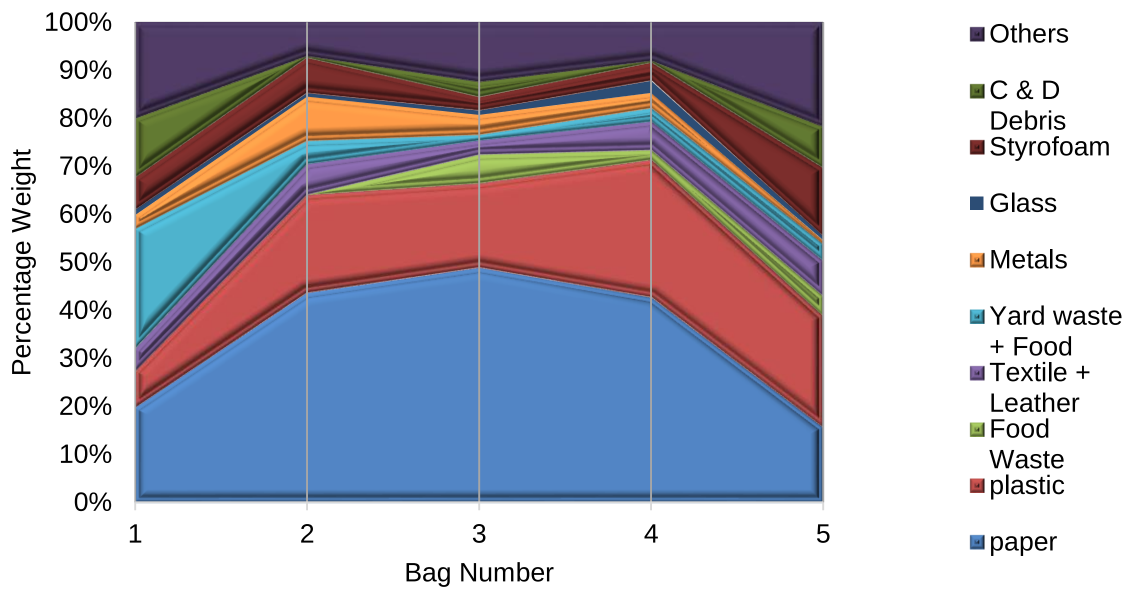

Figure 4-33 Physical Composition of all Bag Samples of Fresh Waste

4.2.1.5 Comparison between collected samples

The average composition of the landfilled waste from all the cells were compared with each other and the results are represented in Table 4-13.

Table 4-13 Comparison between collected samples

Composition Type	Cell 0 (2014) Conventional	Cell 0 (2015) Conventional	Cell 2 (2014) ELR	Cell 3 (2015) ELR	Fresh MSW (2015)
Paper	20.07	18.06	12.57	19.98	34.12
Plastic	9.40	9.14	20.32	15.27	19.46
Food Waste	0.00	0.01	0.08	0.13	2.40
Textile and leather	2.51	2.04	4.34	2.69	5.48
Wood and yard waste	9.91	8.05	10.67	11.63	7.50
Metals	3.26	4.66	4.96	4.37	4.06
Glass	0.43	1.43	0.33	1.28	1.20
Styrofoam and sponge	1.01	1.34	1.61	3.94	6.95
C & D	2.16	2.96	4.05	2.56	5.00
Soils & fines	51.28	52.31	41.08	39.74	13.84
Degraded	22.44	28.16	27.42	34.43	53.32

Figure 4-34 shows the comparison between all the collected samples in form of a figure.

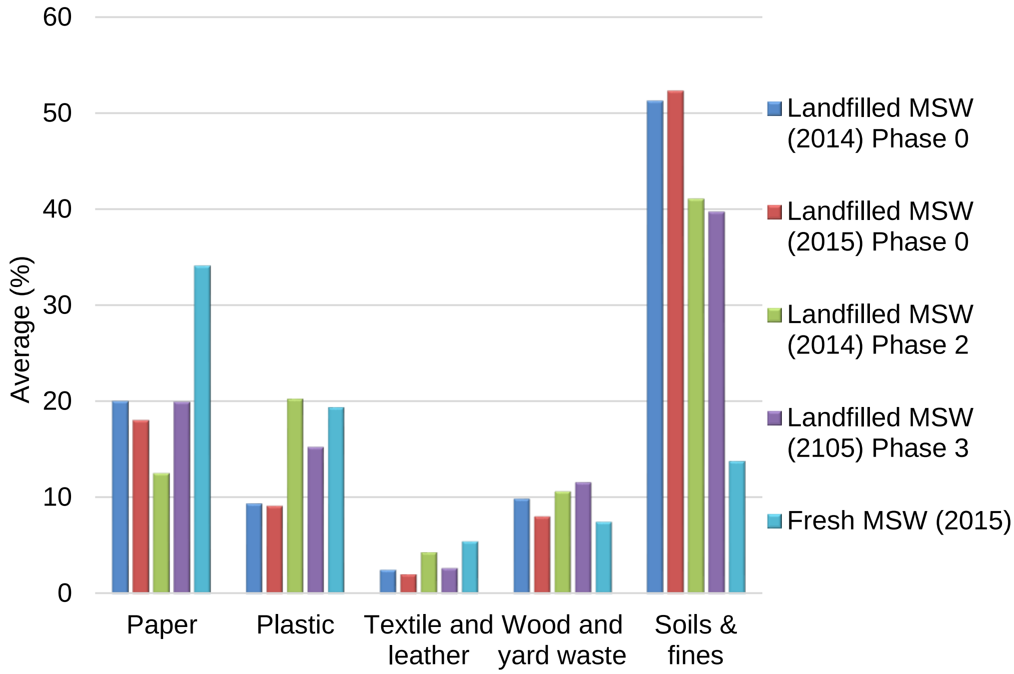

Figure 4-34 Comparison between collected samples

(a) Based on age:

Degradation of MSW is enhanced with age and by presence of moisture. Cell 0 is the oldest landfill and the waste collected from that cell is anticipated to be more degraded, however since this is a conventional landfill, no moisture was provided to the landfill. Therefore we, can summarize that unavailability of moisture can result in less degradation. Compared to cell 2 and cell 3 which are both ELR landfill, the samples from cell 3 were collected in 2015 while the samples of cell 2 were collected in 2014. So, the materials like paper, wood and yard waste are more degraded in cell 2.

When we compare the results of fresh waste which is aged 0 years, the composition of all the components are higher in fresh waste because its age is negligible. While the landfilled samples are aged samples.

The soils and fines content for the fresh waste are very less compared to the landfilled samples because it does not require any top cover unlike the landfilled samples, which get most of their soils and fines content from the top cover material.

(b) Based on Landfill Operation:

The amounts of paper is more in the conventional landfill and the amounts of plastic is more in the ELR landfill. When there is more paper, then the amount of moisture required for the landfill would be higher as paper is an absorbent material. As plastic is non-degradable there is a very little chance of gas production in the ELR landfills. When it comes to food waste and wood and yard waste, the amount is more in the ELR landfills compared to conventional landfills which will help in gas production as these are few of the main contributors to gas production. The amount of glass produced is almost the same for all the cells.

4.2.1.6 Comparison between collected MSW samples and Literature

Table 4-14 compares the collected landfilled and fresh MSW sample data with the literature study of landfilled waste by Gomes et. Al and fresh waste by Taufiq,T.,2010.

Table 4-14 Comparison between physical composition of collected MSW samples and Literature

Composition Type	Cell 0 (2014) Conventional	Cell 0 (2015) Conventional	Cell 2 (2014) ELR	Cell 3 (2015) ELR	Fresh MSW (2015)	Landfill Waste in San Tirso landfill in Brazil (Gomes et al.)	Fresh Waste (Taufiq, T 2010)
Paper	20.07	18.06	12.57	19.98	34.12	0.9	40
Plastic	9.40	9.14	20.32	15.27	19.46	28.3	18
Food Waste	0.00	0.01	0.08	0.13	2.40	33.3	2
Textile and leather	2.51	2.04	4.34	2.69	5.48	2.8	4
Wood and yard waste	9.91	8.05	10.67	11.63	7.50	2.8	9
Metals	3.26	4.66	4.96	4.37	4.06	10.2	5
Glass	0.43	1.43	0.33	1.28	1.20	2.8	1
Styrofoam and sponge	1.01	1.34	1.61	3.94	6.95	---	1
C & D	2.16	2.96	4.05	2.56	5.00	---	2
Soils & fines	51.28	52.31	41.08	39.74	13.84	11.2	18

From the comparison of test studies with previous test results, it can be drawn that for the previous studies aged 6-30 years, the soils and fines content was lower than the current studies. The paper percentage for the current study was much higher than the literature and this could be due to the unavailability of moisture for degradation of wastes. The food waste in the literature study was high. This could be due to high production of food waste in that area and also due to the fact that the age of the waste was 6-7 years old.

Comparing the fresh waste of the current study with the literature study, it is noticed that the paper, food waste are almost the same amount as each other. The study from fresh waste by Taufiq,T has slightly higher content of paper which is better if the landfill is operated as an ELR landfill. Because, in that case paper being readily degradable and also high in organic content, there is a higher chance of gas production. Since, plastic is a non-degradable material, its presence will affect oppositely. Wood and yard trimming for the current accounts for only 7.5% whereas the literature study shows 9%. More wood and yard content will lead to higher gas generation in the landfill. The percentage of degradable waste is higher in the literature study than in the current study.

4.2.2 Moisture Content

To determine the moisture content 2 lbs of sample was randomly selected prior to sorting of the samples.

4.2.2.1 Municipal Solid Waste (MSW) from Cell 0

The moisture content results of the Landfilled solid waste of Cell 0 collected in 2014 are presented in Table 4-15 and those collected in 2015 are given in Table 4-16.

Table 4-15 Moisture content of Cell 0 (2014)

Borehole	Moisture Content (%)	
	Before sorting (uncompacted)	
	Wet Wt. Basis	Dry Wt. Basis
D	20.70	26.10
E	18.60	23.14
F	15.09	17.94
G	16.38	19.84
Average	17.69	21.76
Standard deviation	2.47	3.61
Maximum	20.70	26.10
Minimum	15.09	17.94

Table 4-16 Moisture content of Cell 0 (2015)

Borehole	Moisture Content (%)	
	Before sorting (uncompacted)	
	Wet Wt. Basis	Dry Wt. Basis
05	22.08	30.10
06	19.06	23.77
07	15.81	19.26
Average	18.98	24.38
Standard deviation	3.13	5.45
Maximum	22.08	30.10
Minimum	15.81	19.26

The moisture content of boring D was 20.7% (wet weight basis) and 26.1% (dry weight basis). The moisture content of the boring E averaged 18.6% (wet weight basis) and 23.14% (dry weight basis). The moisture content of the boring F averaged 15.09% (wet weight basis) and 17.94% (dry weight basis). The moisture content of the boring G averaged 16.38% (wet weight basis) and 19.84% (dry weight basis). With higher degradation, the organic components of waste decreases. According to Landva and Clark (1990), presence of high organic content in MSW increases moisture content of the waste. Therefore, with degradation moisture content might be reduced. The moisture contents of all borings with variation of depth are presented in Figure 4-35 to Figure 4-38.

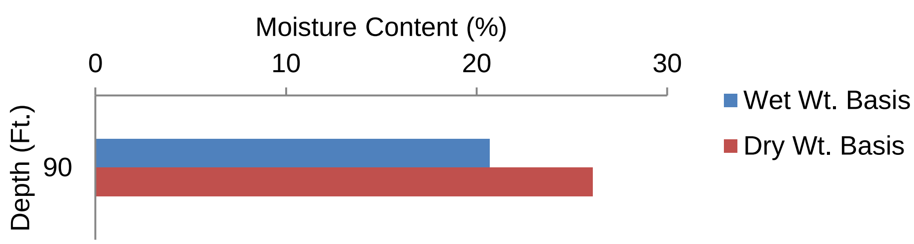

Figure 4-35 Moisture Content of MSW of Boring D

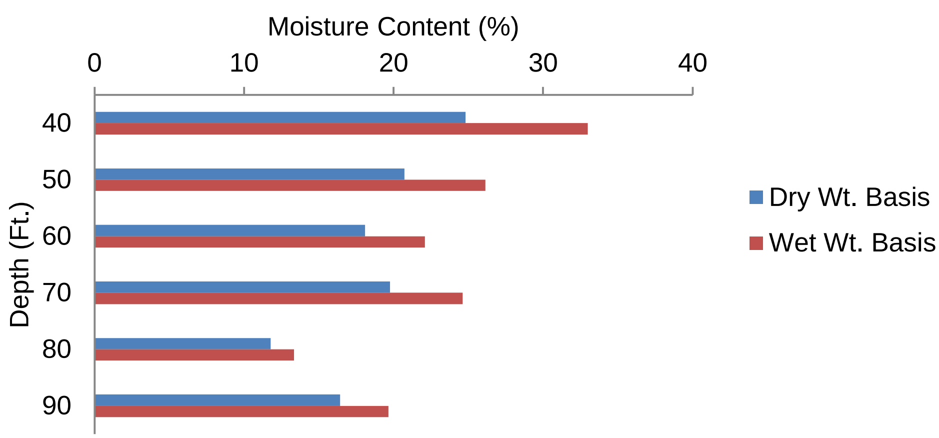

Figure 4-36 Moisture Content of MSW of Boring E

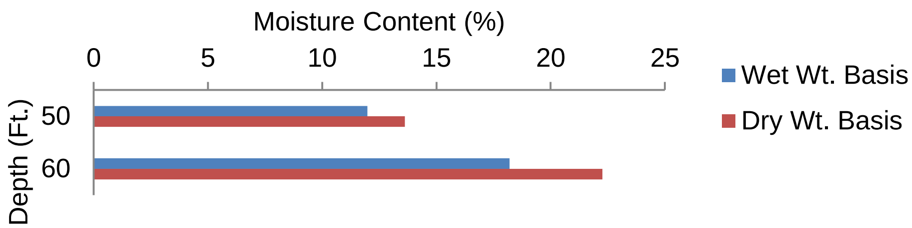

Figure 4-37 Moisture Content of MSW of Boring F

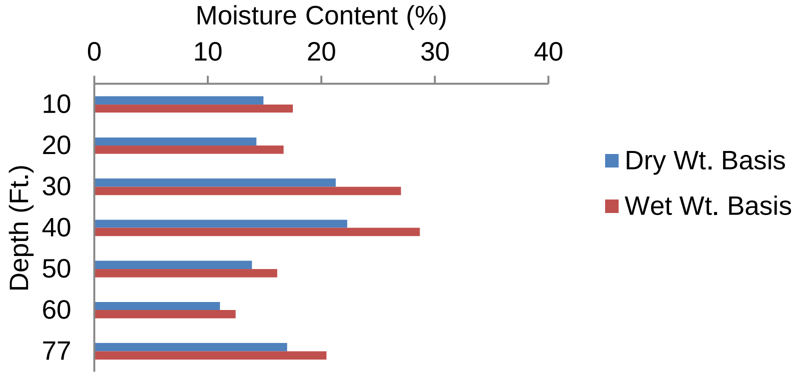

Figure 4-38 Moisture Content of MSW of Boring G

The moisture content of the BH-05 averaged 22.08% (wet weight basis) and 30.10% (dry weight basis). The moisture content of the BH-06 averaged 19.06% (wet weight basis) and 23.77% (dry weight basis). The moisture content of the BH-07 averaged 15.81% (wet weight basis) and 19.26% (dry weight basis). The moisture contents of all borings with variation of depth are presented in Figure 4-39 to Figure 4-41.

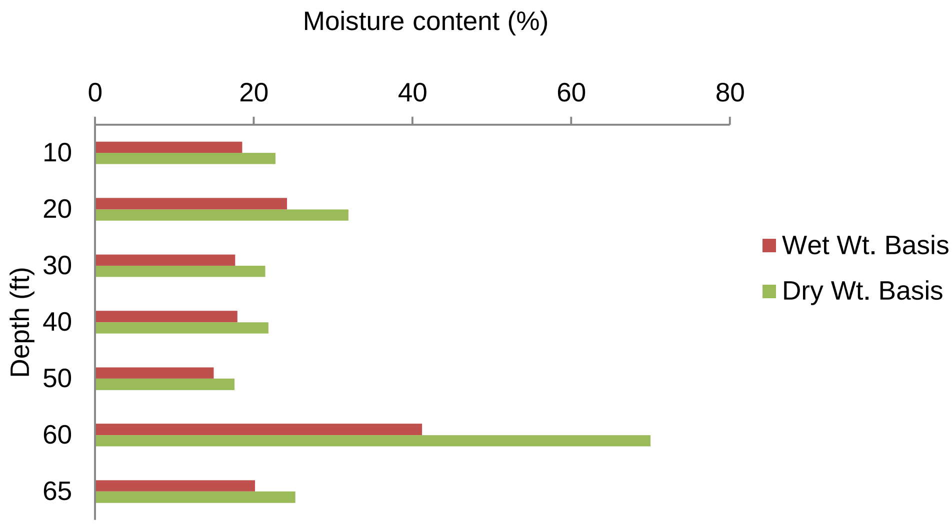

Figure 4-39 Moisture Content of MSW of Boring 05

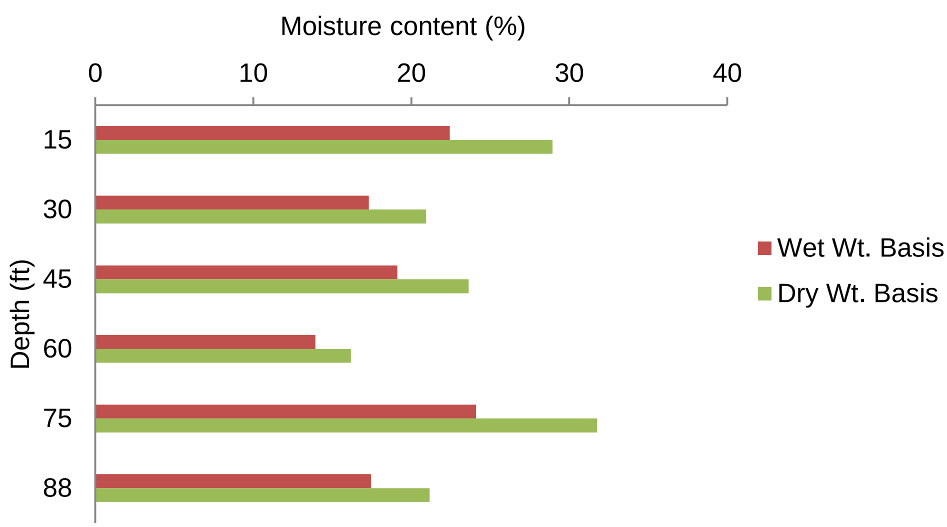

Figure 4-40 Moisture Content of MSW of Boring 06

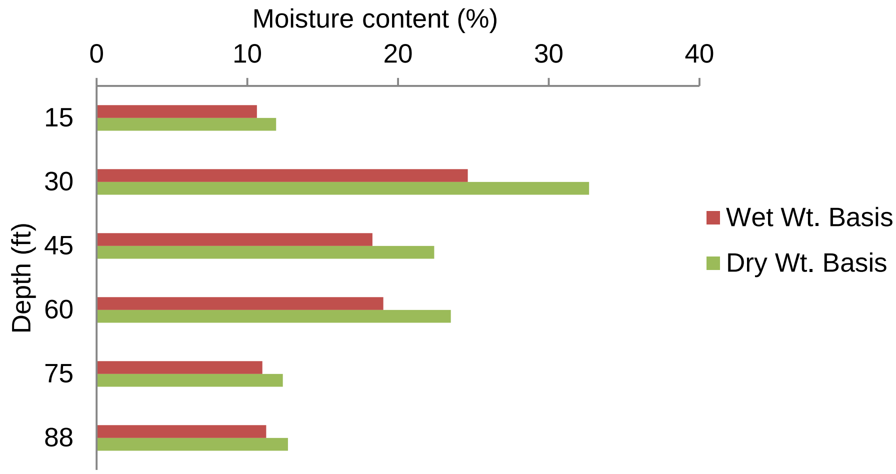

Figure 4-41 Moisture Content of MSW of Boring 07

4.2.2.2 Municipal Solid Waste (MSW) from Cell 2

The moisture content of the landfilled solid waste of Cell 2 are given in Table 4-17.

Table 4-17 Moisture content of Landfilled MSW of Cell 2

Borehole	Moisture Content (%)	
	Before sorting (uncompacted)	
	Wet Wt. Basis	Dry Wt. Basis
A	16.14	21.11
B	16.14	21.11
C	20.39	26.74
Average	17.55	22.99
Standard deviation	2.46	3.25
Maximum	20.39	26.74
Minimum	16.14	21.11

The moisture content of the boring A averaged 24.5% (wet weight basis) and 34.95% (dry weight basis). The moisture content of the boring B averaged 21.38% (wet weight basis) and 28% (dry weight basis). The moisture content of the boring C averaged 20.39% (wet weight basis) and 26.74% (dry weight basis). The moisture contents of all borings with variation of depth are presented in Figure 4-42 to Figure 4-44.

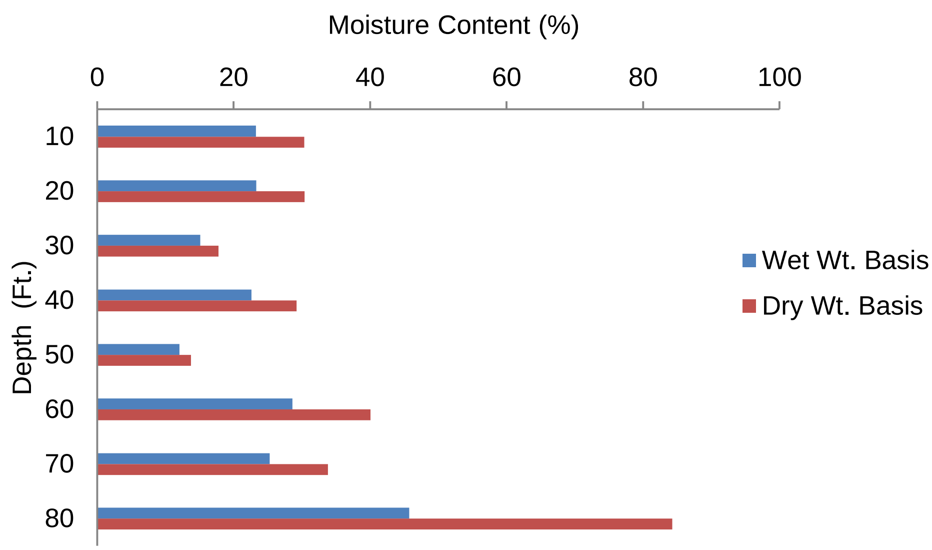

Figure 4-42 Moisture Content of MSW of Boring A

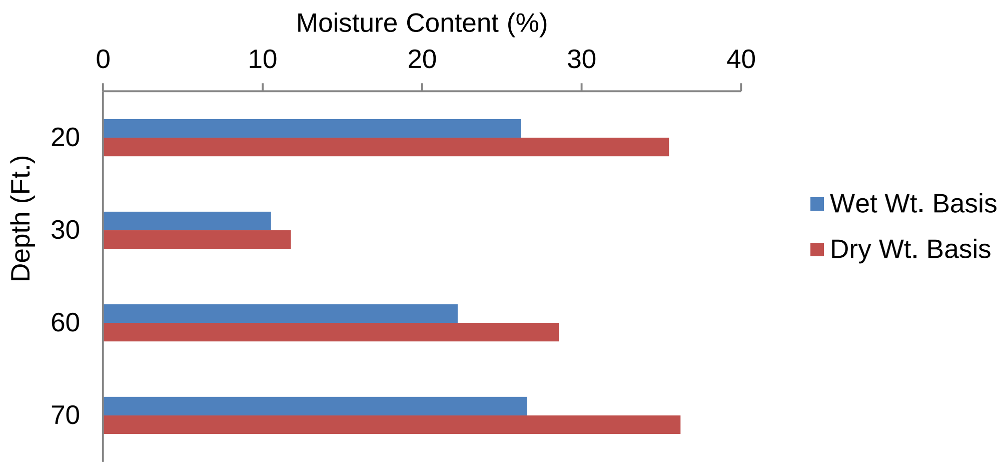

Figure 4-43 Moisture Content of MSW of Boring B

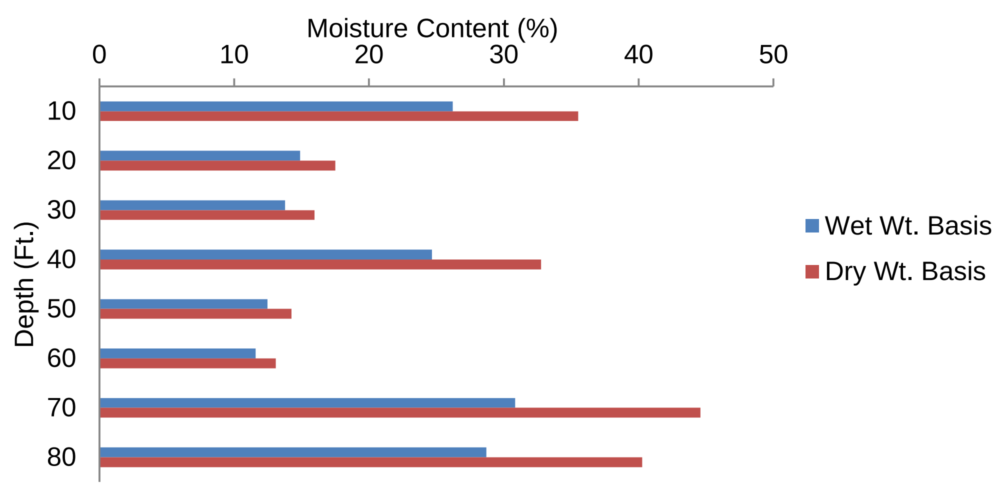

Figure 4-44 Moisture Content of MSW of Boring C

4.2.2.3 Municipal Solid Waste (MSW) from Cell 3

The moisture content of the landfilled solid waste of Cell 3 are given in Table 4-18.

Table 4-18 Moisture content of Landfilled MSW of Cell 3

Borehole	Moisture Content (%)	
	Before sorting (uncompacted)	
	Wet Wt. Basis	Dry Wt. Basis
3A	19.43	25.09
3B	19.53	24.31
3C	23.51	34.026
Average	20.83	27.81
Standard deviation	2.33	5.40
Maximum	23.51	34.03
Minimum	19.43	24.31

The moisture content of the boring 3A averaged 19.43% (wet weight basis) and 25.09% (dry weight basis). The moisture content of the boring 3B averaged 19.53% (wet weight basis) and 24.31% (dry weight basis). The moisture content of the boring 3C averaged 23.51% (wet weight basis) and 34.03% (dry weight basis). The moisture contents of all borings with variation of depth are presented in Figure 4-45 to Figure 4-47.

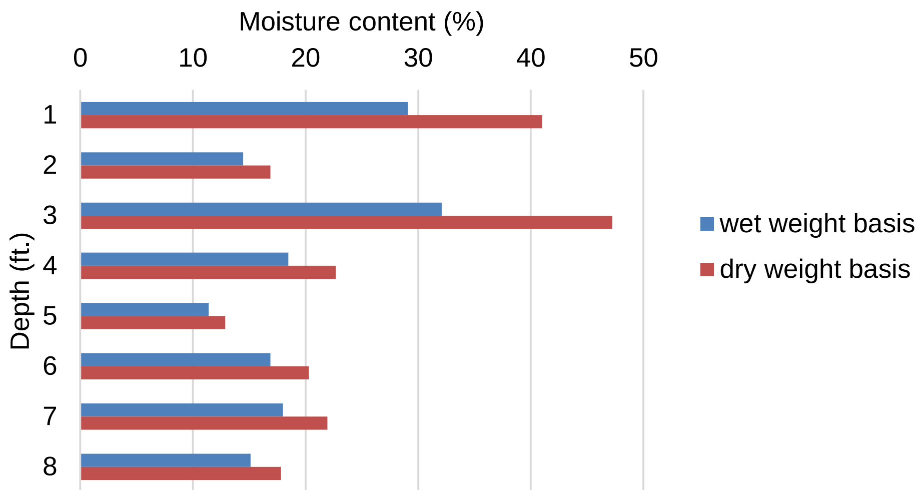

Figure 4-45 Moisture Content of MSW of Boring 3A

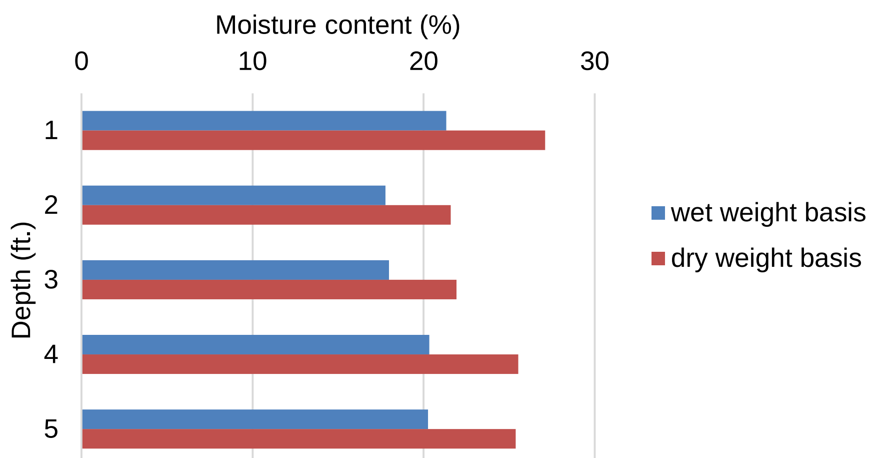

Figure 4-46 Moisture Content of MSW of Boring 3B

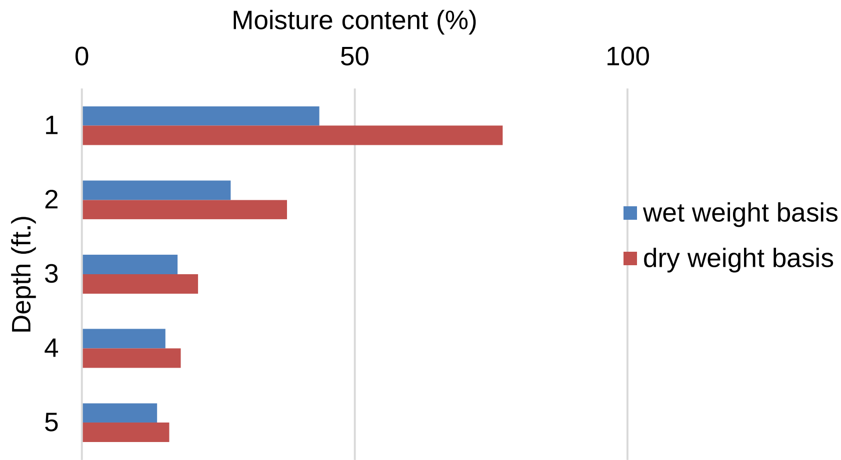

Figure 4-47 Moisture Content of MSW of Boring 3C

4.2.2.4 Comparison between collected samples

The moisture content of all the cells are compared and the results are given in Table 4-20. Figure 4-48 shows the moisture content graph of all collected samples.

Table 4-19 Comparison between collected samples

Cell 0 (2014)	Moisture Content (%) Before sorting (uncompacted)		Cell 0 (2015)	Moisture Content (%) Before sorting (uncompacted)		Cell 2 (2014)	Moisture Content (%) Before sorting (uncompacted)	
	Wet Wt. Basis	Dry Wt. Basis		Wet Wt. Basis	Dry Wt. Basis		Wet Wt. Basis	Dry Wt. Basis
D	20.70	26.10	05	22.08	30.10	A	16.71	21.7
E	18.60	23.14	06	19.06	23.77	B	16.71	21.7
F	15.09	17.94	07	15.81	19.26	C	20.39	26.7
G	16.38	19.84						
Average	17.69	21.76	Average	18.98	24.38	Average	17.93	23.4
Standard	2.47	3.61	Standar	3.13	5.45	Standar	2.13	2.88
Maximu	20.70	26.10	Maximu	22.08	30.10	Maximu	20.39	26.7
Minimum	15.09	17.94	Minimu	15.81	19.26	Minimu	16.71	21.7

Cell 3 (2015)	Moisture Content (%) Before sorting (uncompacted)		Fresh waste	Moisture Content (%) Before sorting (uncompacted)	
	Wet Wt. Basis	Dry Wt. Basis		Wet Wt. Basis	Dry Wt. Basis
3A	19.43	25.09	F1	23.82	31.27
3B	19.53	24.31	F2	26.07	35.25
3C	23.51	34.03	F3	37.2	59.22
			F4	54.85	121.49
			F5	28.38	39.62
Average	20.83	27.81	Average	34.06	57.37
Standard deviation	2.33	5.40	Standard deviation	12.68	37.42
Maximum	23.51	34.03	Maximum	54.85	121.49
Minimum	19.43	24.31	Minimum	23.82	31.27

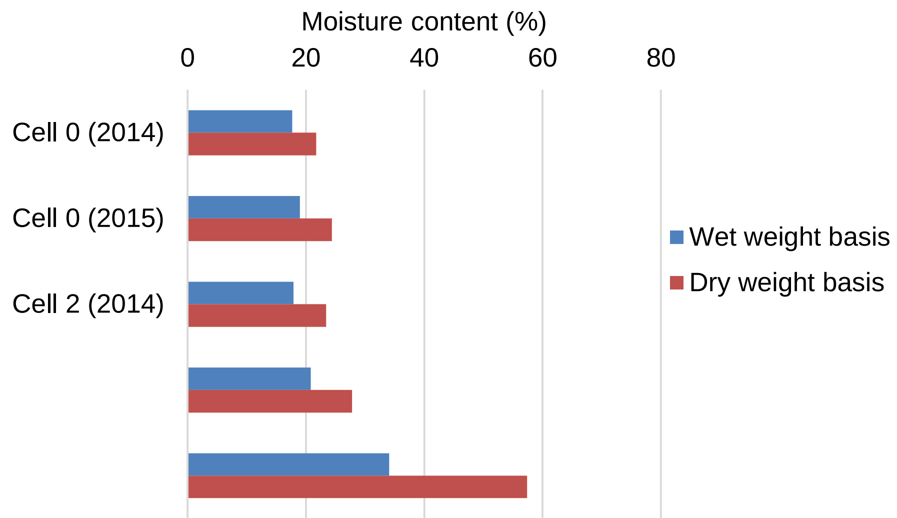

Figure 4-48 Moisture content of Collected MSW

(a) Based on age :

The moisture content of the collected samples were compared based on their age. The moisture content data is presented in Table 4-20. The moisture content of the fresh waste was 34% (w/w) and the moisture content of the landfilled waste ranged from 18 to 21 % (w/w). So the moisture content of the fresh waste is definitely more than that of the landfilled samples because of higher organic components in the waste and since the fresh waste is aged 0 years, it is less degraded than the landfilled samples and hence the moisture content of fresh waste is higher than that of landfilled samples.

The moisture content of cell 0 should have been the least according to the age of the landfill. But it is almost equal to that landfilled samples. Cell 2 and Cell 3 which are both ELR landfill are compared and Cell 3 had more moisture content (21% (w/w)). Cell 2 has 18% moisture content (w/w) which is because cell 2 samples are more aged than the cell 3 samples.

(b) Based on landfill operation

The landfilled samples are compared with each other based on the landfill operation (ELR/conventional). Cell 3 has the highest amount of moisture content of 21% (w/w) compared to cell 2 which has a moisture content of 18% (w/w). The moisture content of conventional landfills is almost equal to the ELR landfills because ELR landfills have more moisture content. This prove that the ELR landfills are more degraded than the conventional landfills.

4.2.2.5 Comparison of Collected MSW Samples and Literature

The collected MSW samples are compared with the literature study. Table 4.20 shows the comparison between of moisture content between collected samples and literature studies.

Table 4-20 Comparison between moisture content of MSW samples and Literature

Source	Moisture Content (%)	Condition	Remarks
Zekkos et. Al	10-50	d/w	Portugal
Landva & Clark (1990)	120	Maximum	Canada
Mannassero et al. (1997)	22.5	Fresh uncompacted	USA
Hoglan et. Al (2004)	30		
Bai & Sutano (2002)	46.8	w/w	Singapore
Han et. Al (2006)	26.5	Household	Sandtown, Delaware
Pichtel (2005)	15-40	w/w	USA
Hudson et. Al (2004)	32.5	w/w	
Cell 0 (2014)	22	d/w	City of Denton Landfill
Cell 0 (2015)	24	d/w	City of Denton Landfill
Cell 2 (2014)	23	d/w	City of Denton Landfill
Cell 3 (2014)	28	d/w	City of Denton Landfill
Fresh Waste	57	d/w	City of Denton Landfill

The values of moisture content given by different researches vary as given. Pichtel (2005), Mannasero et. Al (1997), Han et. Al (2006) reported moisture content for fresh waste in USA.The fresh waste from the current study is higher than the published values. The higher moisture content can help when the landfill is operated as an ELR landfill. It can help to reduce the amount of leachate recirculation to attain the required moisture content. In the present case, most of the moisture is trapped within papers.

The moisture content of landfilled samples when compared to the literature studies, was almost similar to the current study. According to the current study the moisture content range from 22 to 28 % (w/w) and from the literature review ranged from 26% to 32%.

4.2.3 Unit Weight

The unit weights determined in this study are for samples compacted by standard proctor compaction effort. Unit weight of solid waste is an important factor in estimating the stability of landfills. It might get influenced by the type of waste, degree of compaction, volume of daily cover, degree of composition, depth from which sample is taken.

4.2.3.1 Municipal Solid Waste from Cell 1

The Unit Weight results of the Landfilled MSW from Cell 0 in 2014 are given in Table 4-21 and those collected in 2015 are given in 4-22.

Table 4-21 Unit Weight of Landfilled Sample from Cell 0 (2014)

Boring	Compacted Density	
	pcf	KN/m^3
D	25.20	3.96
E	76.97	12.09
F	82.63	12.98
G	79.69	12.52
Average	66.12	10.39
Standard deviation	27.38	4.30
Maximum	82.63	12.98
Minimum	25.20	3.96

Table 4-22 Unit Weight of Landfilled Sample from Cell 0 (2015)

Boring	Compacted Density	
	pcf	KN/m^3
05	87.60	13.76
06	85.51	13.44
07	85.85	13.49
Average	86.32	13.56
Standard deviation	1.12	0.17
Maximum	87.60	13.76
Minimum	85.51	13.44

The average unit weight of Cell 0 (2014) was 66 pcf and cell 0 (2015) was 86 pcf. Unit weight of Cell 0 (2015) was higher than the other due to presence of more degraded components. As the particle size decreases, voids between waste mass decreases, which increases the unit weight. Percentage of soils and fines in cell 0 (2014) was 53% and in cell 0 (2015) was 51%. So it can be concluded that unit weight increases with increase in quantity of soils and fines.

4.2.3.2 Municipal Solid Waste from Cell 2

The Unit Weight results of the Landfilled MSW from Cell 2 is given in Table 4-23.

Table 4-23 Unit Weight of Landfilled Sample from Cell 2

Boring	Compacted Density	
	pcf	KN/m^3
A	68.73	10.80
B	32.16	5.05
C	50.51	7.93
Average	50.47	7.93
Standard	18.28	2.88
Maximum	68.73	10.80
Minimum	32.16	5.05

The unit weight of boring A average to be 69 pcf and boring B and boring C average unit weight was 32 pcf and 50 pcf respectively.

4.2.3.3 Municipal Solid Waste from Cell 3

The Unit Weight results of the Landfilled MSW from Cell 3 is given in Table 4-24.

Table 4-24 Unit Weight of Landfilled Sample from Cell 3

Boring	Compacted Density	
	pcf	KN/m^3
3A	73.88	11.61
3B	85.91	13.50
3C	82.07	12.89
Average	80.62	12.67
Standard	92.05	14.46
Maximum	85.91	13.50
Minimum	73.88	11.61

4.2.3.4 Comparison between Collected Samples

The Unit weight of the collected samples are shown in Table 4-25 and the average unit weights are depicted in Figure 4-49.

Table 4-25 Unit Weight of collected samples

Boring	Compacted Density		Boring	Compacted Density		Boring	Compacted Density	
	pcf	KN/m³		pcf	KN/m³		pcf	KN/m³
D	25.20	3.96	05	87.60	13.76	A	68.73	10.80
E	76.97	12.09	06	85.51	13.44	B	32.16	5.05
F	82.63	12.98	07	85.85	13.49	C	50.51	7.93
G	79.69	12.52						
Average	66.12	10.39	Average	86.32	13.56	Average	50.47	7.93
Standard deviation	27.38	4.30	Standard deviation	1.12	0.17	Standard deviation	18.28	2.88
Maximum	82.63	12.98	Maximum	87.60	13.76	Maximum	68.73	10.80
Minimum	25.20	3.96	Minimum	85.51	13.44	Minimum	32.16	5.05

Boring	Compacted Density		Boring	Compacted Density	
	pcf	KN/m³		pcf	KN/m³
3A	73.88	11.61	F1	60.25	9.47
3B	85.91	13.50	F2	47.65	7.49
3C	82.07	12.89	F3	60.65	9.53
			F4	60.05	9.43
			F5	70.18	11.03
Average	80.62	12.67	Average	59.76	9.39
Standard deviation	92.05	14.46	Standard deviation	8.01	1.26
Maximum	85.91	13.50	Maximum	70.18	11.03
Minimum	73.88	11.61	Minimum	47.65	7.49

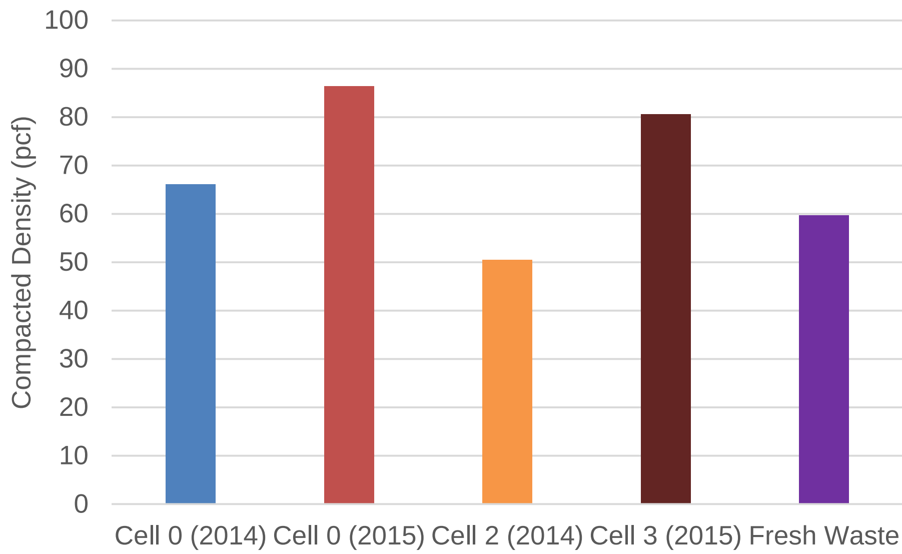

Figure 4. 49 Comparison of unit weight of collected samples

(a) Based on age:

The unit weight of Cell 0 and cell 2 in 2014 were less than the unit weight of cell 0 and cell 3 in 2015. Figure 4.49 shows the variance in unit weight. Unit weight varies due to the percentage of 'others and fines'. The percentage of 'others and fines' were more in the samples collected in 2015. The unit weight of cell 0 (2014) and cell 2 (2014) are 66 pcf and 51 pcf respectively. The unit weight of cell 0 (2015) and cell 3 (2015) are 87 pcf and 81 pcf respectively. We can summarize that with age the decomposition increases and when the decomposition increases, unit weight increases.

The unit weight of fresh waste is less than the average of landfilled waste unit weight. Fresh waste has an age of 0 years and has negligible decomposition. Landfilled waste have a certain age that is higher than the landfilled waste. So the unit weight of landfilled waste is higher than the unit weight of fresh waste.

(b) Based on landfill operation:

The unit weight of conventional landfill varies from 66 to 86 pcf and the unit weight of landfilled samples varies from 51 to 81 pcf. Since the cell 0 which is the conventional landfill is a closed cell, the soils and fines from these samples were higher than those of the landfilled samples. Hence, the high percentage of soils and fines result in increase of unit weight.

4.2.3.5 Comparison between collected samples and Literature

The unit weight of the collected MSW samples were compared with the literature and the results are presented in Table 4-26.

Table 4-26 Comparison of unit weight of MSW samples with the literature

Reference	Unit Weight (pcf)	Conditions	Remarks
Gabr & Valero (1995)	47.08 to 52.18	14 to 30 years old waste	
Reddy et. al (2009)	37.46 to 38.41	Working face	Orchard Hills Landfill
Vesilind et. al (2002)	23.3	Collection Truck	
	25.93 to 62.96	Landfilled (with cover soil)	
Yousuf & Rahman (2207)	14.36	Wet season	Dhaka City, Bangladesh
Landva & Clark	43.27 to 103		Canada
Chen et. al (2009)	31.82 to 95.46	Increases with depth	China
Han et. al (2006)	62.4	Average	Sandtown Landfill, Delaware
Cell 0 (2014)	66.12	Average	City of Denton Landfill
Cell 0 (2015)	86.32	Average	City of Denton Landfill
Cell 2 (2014)	50.47	Average	City of Denton Landfill
Cell 3 (2015)	80.62	Average	City of Denton Landfill
Fresh Waste	59.76	Average	City of Denton Landfill

The unit weight data that was obtained from the studies had a wide range of variation in the values. This might have been because of the heterogeneity of the waste composition with age, depth and location.

4.2.4 Volatile Test Results

Volatile Test results provide a good indication of the degradation level of the waste mass.

4.2.4.1 Municipal Solid Waste (MSW) from Cell 0

The waste samples collected from Cell 0 in 2014 and 2015 were tested in the lab to determine the volatile solid in the samples. The data is given in Table 4-27 and Table 4-28 respectively.

Table 4-27 Organic Content of Landfilled MSW of Cell 0 (2014)

Borehole	Depth	Volatile Solid (%)
G	10	4.00
	20	38.00
	30	12.00
	40	10.00
	50	18.00
	60	8.00
	77	34
	Average	17.71
	Standard Deviation	13.24
	Maximum	38.00
	Minimum	4.00

Table 4-28 Organic Content of Landfilled MSW of Cell 0 (2015)

Borehole	Depth	Volatile Solid (%)	Borehole	Depth	Volatile Solid (%)	Borehole	Depth	Volatile Solid (%)
05	10	16.27	06	15	40.71	07	15	10.50
	20	36.05		30	44.75		30	22.20
	30	22.83		45	53.69		45	43.97
	40	24.10		60	10.26		60	18.56
	50	23.32		75	12.87		75	13.58
	60	21.03		88	14.37		88	27.47
	65	32.60						
	Average	25.17		Average	29.44		Average	22.71
	Standard Deviation	6.83		Standard Deviation	19.07		Standard Deviation	12.04
	Maximum	36.05		Maximum	53.69		Maximum	43.97
	Minimum	16.27		Minimum	10.26		Minimum	10.50

From the test results an increasing trend of volatile solid with depth was observed. At boring G, the average percentage of volatile solids was 34.86%. Volatile solid contents vary with depth but do not follow any trend.

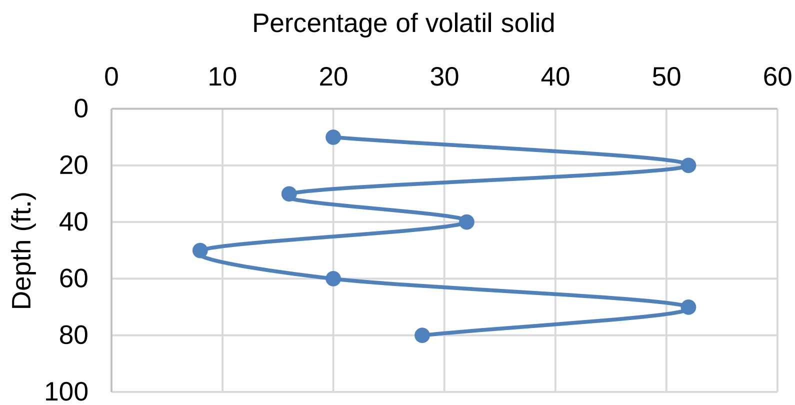

Figure 4-50 Volatile Solids of Boring G with Depth

From the test results, an increasing trend of volatile solid with depth was observed. The waste samples collected from BH-05, BH-06 and BH-07 were tested in the lab to determine the content of volatile solid in the samples. At BH-05, average percentage of volatile solid is 25.17% where at BH-06 and BH-07 have average of 29.44% and 22.71% respectively. For all three borings, average volatile solid content is 25.78%.

Volatile solid contents vary with depth but do not follow any trend. As for example, the highest amounts of organic content have been found at 45 ft. of both BH-06 and BH-07. For BH-05, maximum organic content has been found at 20 ft.

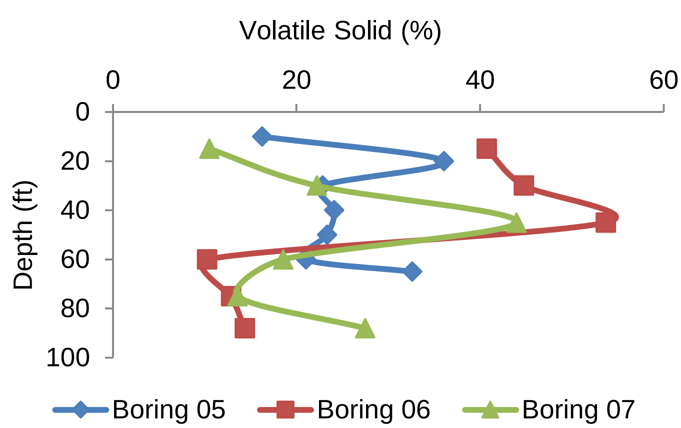

Figure 4-51 Volatile Solids of Cell 3 with Depth

4.2.4.2 Municipal Solid Waste (MSW) from Cell 2

The volatile test results of Landfilled MSW from Cell 2 are given in Table 4-29.

Table 4-29 Organic Content of Landfilled MSW of Cell 2

Boring A @ depth, ft	Volatile Solid (%)	Boring C @ depth, ft	Volatile Solid (%)
10	20.00	10	44.00
20	52.00	20	8.00
30	16.00	30	28.00
40	32.00	40	48.00
50	8.00	50	20.00
60	20.00	60	12.00
70	52.00	70	16
80	28.00		
Average	28.50	Average	25.14
Standard Deviation	16.20	Standard Deviation	15.61
Maximum	52.00	Maximum	48.00
Minimum	8.00	Minimum	8.00

From the test results an increasing trend of volatile solid with depth was observed. At boring A, average percentage of volatile solid is 28.5% where as boring C have average of 25.14%. Volatile solid contents vary with depth but do not follow any trend. As for example, the highest amounts of organic content (52%) have been found at both 20 ft. and 70 ft. of boring A. For boring C, maximum organic content has been found at 40 ft.

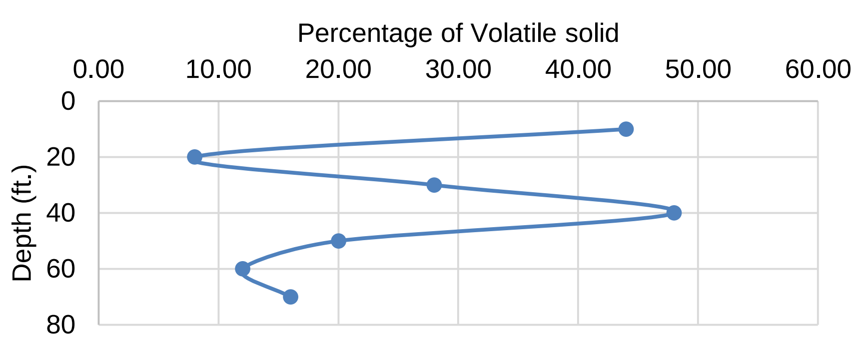

Figure 4-52 Volatile Solid of A and G with Depth

4.2.4.3 Municipal Solid Waste from Cell 3

The volatile test results of Landfilled MSW from Cell 3 are given in Table 4-30.

Table 4-30 Organic Content of Landfilled MSW of Cell 3

Borehole	Depth	Volatile Solid (%)	Borehole	Depth	Volatile Solid (%)	Borehole	Depth	Volatile Solid (%)
3A	10	57.26	3B	15	45.71	3C	15	42.18
	20	15.42		30	17.06		30	51.38
	30	49.09		45	27.72		45	14.00
	40	27.67		60	22.97		60	18.29
	50	18.22		75	14.37		66	29.28
	60	31.16						
	70	16.93						
	76	28.21						
	Average	30.49		Average	25.57		Average	31.03
	Standard	15.30		Standard	12.40		Standard	15.76
	Maximum	57.26		Maximum	45.71		Maximum	51.38
	Minimum	15.42		Minimum	14.37		Minimum	14.00

From the test results an increasing trend of volatile solid with depth was observed. At boring 3A, the average percentage of volatiles solids is 30.49 % and the average of 3B and 3C are 25.57 % and 31.02 % respectively. The maximum organic content has been found at 10 ft. depth of boring 3A.

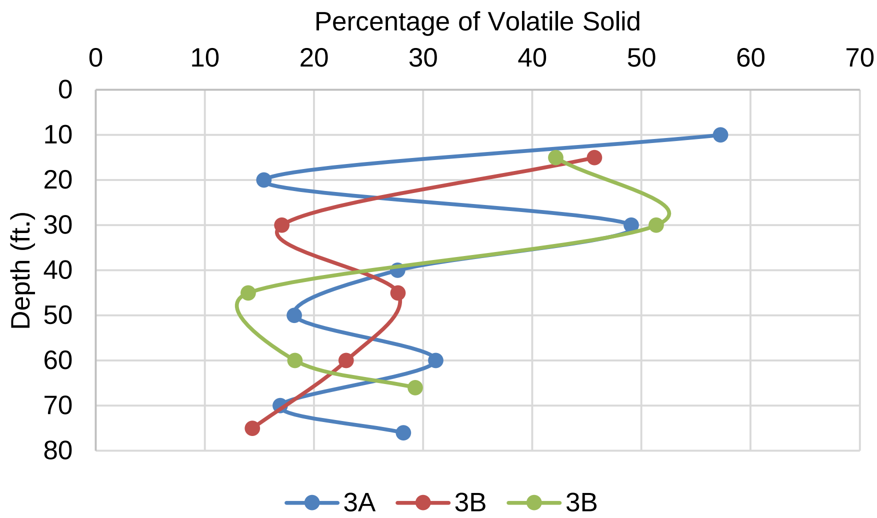

Figure 4-53 Volatile Solid of boring with Depth

4.2.4.4 Comparison between collected samples

The volatile solid content of the collected samples are compared in this section.

Table 4-31 Volatile solid content of collected samples

Cell 0 (2014)	Volatile Solid (%)	Cell 0 (2015)	Volatile Solid (%)	Cell 2 (2014)	Volatile Solid (%)	Cell 3 (2015)	Volatile Solid (%)	Fresh Waste	Volatile Solid (%)
G	17.71	05	25.17	A	28.50	3A	30.49	F1	32.00
		06	29.44	C	25.14	3B	25.57	F2	28.00
		07	22.71			3C	31.02	F3	64.00
								F4	56.00
								F5	24.00
Average	17.71	Average	25.78	Average	26.82	Average	29.03	Average	40.80
Standard deviation	17.71	Standard deviation	3.40	Standard deviation	2.37	Standard deviation	3.01	Standard Deviation	17.98
Maximum	17.71	Maximum	29.44	Maximum	28.50	Maximum	31.02	Maximum	64.00
Minimum	17.71	Minimum	22.71	Minimum	25.14	Minimum	25.57	Minimum	24.00

(a) Based on age:

Volatile Solid content is an indication of the degradation level of the waste mass. Cell 0 has the least value of the volatile solid content showing that it is the most degraded. Comparing cell 2 and cell 3, cell 2 has a lower value of volatile solid content implying that it is more degraded than cell 3. This is because the age of cell 2 is more than that of cell 3.

Fresh waste which is aged 0 years has the highest value of volatile solid content which shows that it is the least degraded. So, it can be summarized that the samples have been degrading with time, hence, there was a probability of future gas generation for these samples.

(b) Based on landfill operation:

When we compare the conventional volatile solid content with the landfilled solid content, the conventional solid content is almost equal to the landfilled solid content. The conventional should have lower volatile solid content indicating it is more degraded, but since the volatile solid content is not low, the waste is not as degraded as it should be in 25 years. Although the landfilled waste is aged only 3 to 6 years, it is equally degraded with the conventional landfill.

CHAPTER 5

Conclusions and Recommendations

The main objective of this study was to characterize the physical and hydraulic properties of MSW and compare the landfilled and fresh MSW. The landfilled waste was collected from Cell 0 which is a conventional landfill in 2014 (BH-D to BH-G) and 2015 (BH-05 to BH-07), from Cell 2 which is an ELR landfill in 2014 and from Cell 3 which is also an ELR landfill in 2015. The concept of a conventional landfill is to prevent the intrusion of moisture in the waste and that of an ELR (enhanced leachate recirculation) landfill is to add moisture/leachate to the landfill and accelerating the process of waste decomposition. The physical and hydraulic that the waste was characterized to were physical composition, moisture content, unit weight and volatile solids. MSW is known to be heterogeneous, so the properties are expected to be different for different landfills. The properties determined from the present study will help to get a better understanding of the solid waste that comes to Denton landfill which will further help in future planning of operational practices.

5.1 Summary and Conclusions

The work done for the present study can be summarized as follows:

1. The landfilled and fresh samples have been collected from the City of Denton Landfill from 3 Cells of the landfill and at different depths varying mostly at 10 feet depth intervals.

2. The composition for each bag was done by manual sorting. The average composition for landfilled waste was determined as follows:

Cell 0 (2014) – Paper (20%), Plastic (9%), Food waste (0%), Textile and leather (3%), Yard and wood waste (10%), Metals (3%), Glass (1%), Styrofoam (1%), C&D debris (2%), soils and fines (51%).

Cell 0 (2015) – Paper (18%), Plastic (9%), Food waste (0%), Textile & leather (2%), Yard and wood waste (8%), Metals (5%), Glass (2%), C&D debris (3%), soils and fines (52%).

Cell 2 (2014) – Paper (13%), Plastic (20%), Food waste (0%), Textile and leather (4.5%), Yard and wood waste (11%), Metals (5%), Glass (0.5%), Styrofoam (2%), C&D debris (4%), Soils and fines (41%).

Cell 3 (2015) – Paper (20%), Plastic (15.5%), Food waste (0%), Textile and leather (3%), Yard and wood waste (12%), Metals (4.5%), Glass (2%), Styrofoam (4%), C&D debris (3%), Soils and fines (40%).

Soils and fines are the major component in all the Cells and then is paper.

3. The average composition of Fresh waste determined as Paper (21%), Plastics (7%), Food waste (0%), Textile and leather (5%), Yard waste and food (25%), Metals (3%), Glass (1%), Styrofoam (7%), C&D debris (12%), Soils and fines (20%).

4. When the composition of the landfilled waste and fresh waste are compared, the paper percentage was less for the landfilled waste because of degradation. Plastic percentage was determined less in fresh. The percentage of soils and fines is higher in landfilled waste than the fresh waste.

5. The degradable percentage of landfilled waste was determined as follows:

Cell 0 – Degradable component was 22.5% and non-degradable component was 77.5% in 2014 and degradable component was 28% and non-degradable component was 72% in 2015

Cell 2 – Degradable component was 27.5% and non-degradable component was 72.5%. (2014)

Cell 3 – Degradable component was 34.5% and non-degradable component was 65.5%. (2015)

The ELR landfill has higher degradation rate than conventional landfill.

6. The moisture content of the landfilled sample was determined as follows:

Cell 0 (2014) – wet weight basis was 18% and dry weight basis was 22%

Cell 0 (2015) – wet weight basis was 19% and dry weight basis was 24%

Cell 2 (2014) – wet weight basis was 18% and dry weight basis was 23%

Cell 3 (2015) - wet weight basis was 21% and dry weight basis was 28%.

The moisture content of Cell 3 is higher than Cell 0, might be due to some water intrusion caused here.

7. The moisture content of fresh waste data was determined to be 34% on wet weight basis and 57% on dry weight basis. The moisture content of fresh waste is much higher than the landfilled waste.

8. The average compacted unit weight of the samples was determined using both standard proctor method. The unit weight of the landfilled samples were found out to be as follows:

Cell 0 (2014) - The average unit weight of Cell 0 (2014) samples were determined to be 66 pcf

Cell 0 (2015) – The average unit weight of Cell 0 (2015) samples were determined to be 86 pcf.

Cell 2 (2014) – The average unit weight of Cell 2 (2014) samples were determined to be 50 pcf.

Cell 3 (2015) – The average unit weight of Cell 3 (2015) samples were determined to be 80 pcf.

When the particles are completely degraded, the average unit weight is higher which the case with Cell 3 (2015) is. When the particles are partially degraded, the unit weight is lower. Degradation increases fine particles in waste mass.

9. The volatile test results were conducted with bio degradable organic portions. The average of volatile solids for landfilled waste collected from City of Denton Landfill are represented as follows:

Cell 0 (2014) – Only BH-G has volatile solids data and the average volatile solids content is 18%. Cell 0 (2015) – Only BH-A and BH-C had volatile solids data and the average volatile solids content is 27%.

Cell 2 (2014) – The average volatile solid content is 26%.

Cell 3 (2015) – The average volatile solid content is 29%.

10. The volatile solid tests were conducted for fresh waste and the average volatile solids was 40%.

Volatile organic content are a direct function of the presence of degradable contents. So the presence of less degradable contents have resulted in lower volatile organic contents. The volatile solid of fresh waste is higher than the landfilled volatile solid.

5.2 Recommendations for further studies

To enhance the reliability of the results of the study and make it more effective, it is recommended that the work be continued further as mentioned in the below section:

1. The samples can be collected from different ELR landfills for future studies and the results can be compared for better reliability.

2. The methane gas generation from the ELR landfills can be monitored to estimate the gas generation rate.

3. Other properties such as grain size distribution, permeability and compression indices, could not be determined in this study due to time constraint. These tests can be included to make the study more complete.

4. A different sorting technique can be used to sort the MSW to see if it would result in different summary.

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