Solid waste Generation and Disposal

Module - II

- Waste is a by-product of human activity which has lack of value or use.
- The term 'Solid waste' usually refers to waste that is solid, including semi-liquid or wet wastes with insufficient moisture or fluid content to be free flowing.

Waste Classification

On the basis of:

(a) physical state (solid, liquid, gaseous)
(b) Original use (mining waste, food waste etc.)
(c) Material (paper, glass, construction debris etc.)
(d) physical properties (Combustible, Compostable, recyclable etc.)
(e) Sources (domestic, Commercial, industrial etc.)
(f) Safety Level (hazadous, non-hazadous, inert etc.)

Termindogy

- Agricultural Waste: Wastes arising from agricultural particles, including livestock production.
- Mining Waste: Mainly waste material from Coal mining, metal mining and other mineral extraction industries.
- Energy Production waste: Solid waste from energy production units, including Ash from Coal burning in thermal power plants.
- Industrial waste: Solid wastes generated by Various industries.

Characteristics of Solid Waste

Waste Type	Chemically active	Biologically active	Physically active
Municipal	✓	✓	✓
Industrial	✓	Sometimes	✓
Energy Production (Ash)	?	—	✓
Mining	✓	—	✓

Changes occurring in a Municipal Solid waste Dump

Biological changes:

- Aerobic decomposition
- Anaerobic decomposition

Chemical changes:

- Dissolution and Suspension
- Evaporation and Vaporization
- Sorption
- precipitation
- Oxidation – reduction reactions

Physical changes:

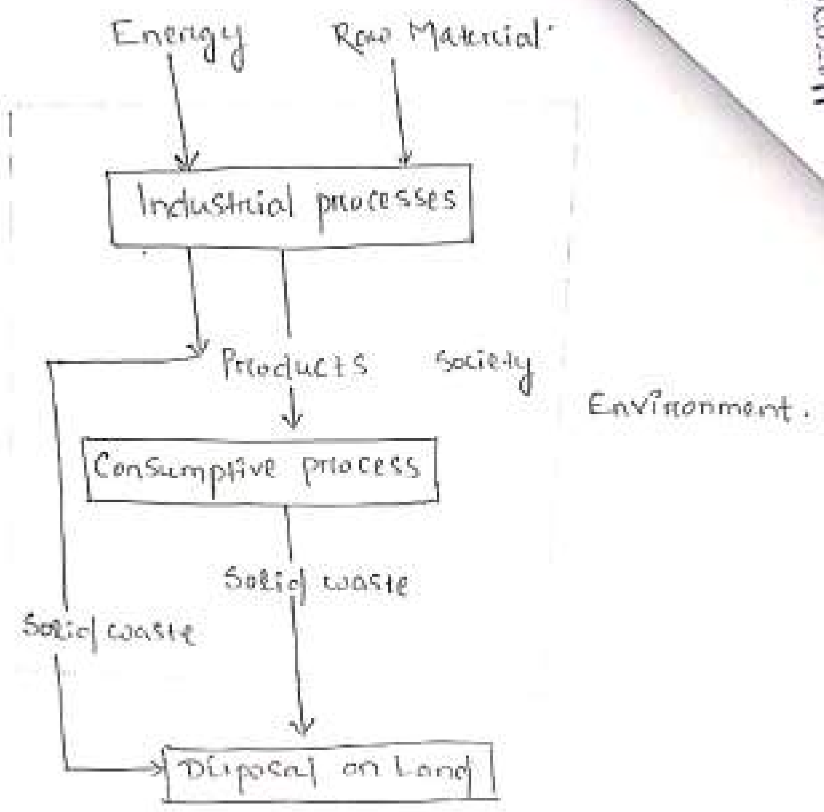
- Lateral movement of gases in the waste and emission of gases.
- Movement of Leachate within the waste and into underlying soils.
- Settlement caused by consolidation and decomposition of the waste.
- Movement of fine Solid particles by wind and water.

Terminology

Dredging waste: Organic and mineral wastes from dredging operations.

- Construction and Demolition waste: Bricks, brickbats, concrete, asphaltic material, pipes, construction debris.
- Treatment plant waste: Solids from grid chambers and sedimentation tanks, sludge digsiers of industrial and domestic waste water treatment plants.
- Household or Residential waste: Garbage including food wastes, paper, packaging, sweepings, yards waste etc.
- Commercial waste: Similar to household wastes, produced from offices, shopes, restaurants etc.
- Institutional waste: Similar to household wastes plus hazadous, explosive, pathological and other wastes which are institution specific (e.g. hospitals, research, educational institutes etc.)
- Biomedical waste: waste produced during diagnosis and treatment, in hospitals, microbiological wastes, animal.

Municipal Solid Waste: This term refers to all waste collected by a local authority or municipality and comprises of waste from different sources, each of which is heterogeneous. It includes households waste (kitchen and yard), commercial waste, institutional waste, construction and demolition waste, park trimmings and street sweepings. It usually excludes agricultural waste, mining waste, industrial waste, energy production waste and dredging waste.



Solid waste generation in An Industrialised Society

Relative Quantities of Solid waste
(Using Indian Mining as 1000 Million Tonnes/year)

Source	U.K.	U.S.A.	India
Mining	290	1400	>1000
Agriculture	260	–	> 3000
Municipal	110	133	26
Thermal plants	13	63	80
Industrial	62	430	?
Construction & Demolition	35	31.5	~10

Waste - Soil Interaction

Hazardous Waste, Non-hazardous Waste, Inert Waste

- Hazardous waste is specifically so listed by regulatory authority
- Mixture containing hazardous waste
- Waste derived from hazardous waste
- Waste exhibiting: ignitability, corrosivity (pH < 2 or > 12) reactivity, toxicity (standard tests)
- Waste which is not listed as hazardous is referred to as non-hazardous waste e.g. MSW.
- C&D Waste is often referred to as 'inert waste'; this is a misnomer.

Non-Hazardous Waste, Inert Waste and Ground Contamination

- Hazardous wastes cause contamination
- Do non-hazardous wastes cause contamination?
- Three Examples:
- Common Salt : Non-Hazardous(?)
- Mining Overburden - Inert (?)
- Clean water in pond above ground level
- Do they cause ground contamination

Saturation in Soil

- Saturated soil : all voids filled with water
- Unsaturated Soil : Voids filled partly with water ; pressure head is -ve (tension or suction)
- Capillary zone : Voids mostly (or all) filled with water ; pressure head is -ve.
- Vadose zone : Unsaturated zone + Capillary zone
- Pheriatic zone : Zone below water table level (Pressure +ve)
- Ground water flows in saturated zone under total hydraulic head from higher level to lower level (adective flow) ; other mechanisms are diffusion and dispersion

PROCESS

- Rain water falls on waste : some runoff , some infiltrates
- Some infiltrating water held by waste ; some goes back by evapotraspiration ; excess moves down.
- Infiltrating water interacts with active contaminants and carries them down as leachate.
- Leachate infiltrates soil
- Some leachate held by soil ; excess moves down
- Some contaminants attenuated by soil
- Leachate with attenuated contaminants reaches ground water.

Physical, Chemical and Biological Properties of MSW

Physical Propeties of MSW

- Specific Weight (Density)
- Moisture Content
- Particle Size and Distribution
- Field Capacity
- Permeability of Compacted Waste

Specific Weight (Density)

- Specific weight is defined as the weight of a material per unit volume (e.g. kg/m^3, lb/ft^3)
- Usually it refers to uncompacted waste.
- It varies with geographic location, season of the year, and length of time in storage.

Typical Specific Weight Values

Component	Specific Weight (density), kg/m^3	
	Range	Typical
Food wastes	130-480	290
Paper	40-130	89
Plastics	40-130	64
Yard waste	65-225	100
Glass	160-480	194
Tin cans	50-160	89
Aluminum	65-240	160

Typical Specific Weight Values

Condition	Density (kg/m³)
Loose MSW, no processing or compaction	90-150
In compaction truck	355-530
Baled MSW	710-825
MSW in a compacted landfill (without cover)	440-740

Moisture Content

$$M = \frac{w-d}{w} x 100$$

The moisture in a sample is expressed as percentage of the wet weight of the MSW material

Analysis Procedure:

- Weigh the aluminum dish
- Fill the dish with SW sample and re-weigh
- Dry SW + dish in an oven for at least 24 hrs at 105°C.
- Remove the dish from the oven, allow to cool in a desiccator, and weigh.
- Record the weight of the dry SW + dish.
- Calculate the moisture content (*M*) of the SW sample using the equation given above.

Typical Moisture Contents of Wastes

Textbook, p. 70, Table 4-1

	Type of Waste	Moisture Content, %	
		Range	Typical
Resindential	Food wastes (mixed)	50 - 80	70
	Paper	4 - 10	6
	Plastics	1 - 4	2
	Yard Wastes	30 - 80	60
	Glass	1 - 4	2
Commercial	Food wastes	50 - 80	70
	Rubbish (mixed)	10 - 25	15
Construction & Demolition	Mixed demolition combustibles	4 - 15	8
	Mixed construction combustibles	4 - 15	8
Industrial	Chemical sludge (wet)	75 - 99	80
	Sawdust	10 - 40	20
	Wood (mixed)	30 - 60	35
Agricultural	Mixed Agricultural waste	40 - 80	50
	Manure (wet)	75 - 96	94

Particle Size and Distribution

- The size and distribution of the components of wastes are important for the recovery of materials, especially when mechanical means are used, such as trommel screens and magnetic separators.

Trommel Screens

- For example, ferrous items which are of a large size may be too heavy to be separated by a magnetic belt or drum system.

Particle Size and Distribution

- The size of waste components can be determined using the following equations:

$$S_c = L$$

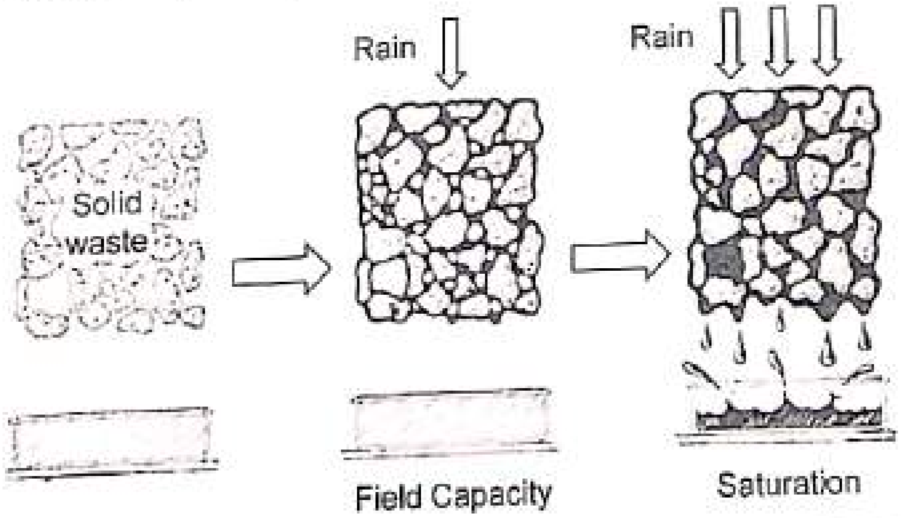
$$S_c = (L+w)/2$$

$$S_c = (L+w+h)/3$$

S_c : *size of component, mm*
L : *length, mm*
W : *width, mm*
h : *height, mm*

Field Capacity

- The total amount of moisture that can be retained in a waste sample subject to the downward pull of gravity



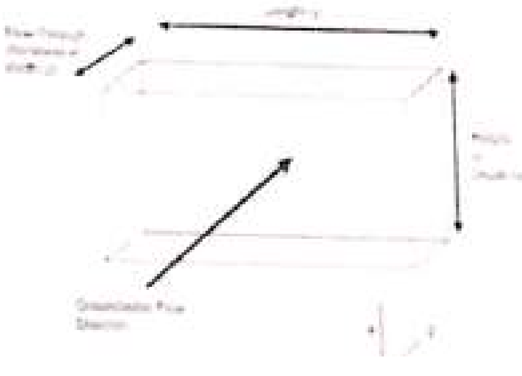
Field Capacity

- Field capacity is critically important in determining the formation of leachate in landfills

- It varies with the degree of applied pressure and the state of decomposition of wastes, but typical values for uncompacted commingled wastes from residential and commercial sources are in the range of 50 - 60%.

Permeability of Compacted Waste

- The permeability (hydraulic conductivity) of compacted solid waste is an important physical property because it governs the movement of liquids & gases in a landfill.
- Permeability depends on;
  - Pore size distribution
  - Surface area
  - Porosity



Chemical Properties of MSW

- Chemical properties of MSW are very important in evaluating the alternative processing and recovery options:
  - Proximate analysis
  - Fusing point of ash
  - Ultimate analysis (major elements)
  - Energy content

Proximate Analysis

- Proximate analysis for the combustible components of MSW includes the following tests:
  - Moisture (drying at 105 °C for 1 h)
  - Volatile combustible matter (ignition at 950 °C in the absence of oxygen)
  - Fixed carbon (combustible residue left after Step 2)
  - Ash (weight of residue after combustion in an open crucible)

Typical Proximate Analysis Values

(% by weight)

Textbook, p.78, Table 4-2

Type of Waste	Moisture	Volatiles	Carbon	Ash
Mixed food	70.0	21.4	3.6	5.0
Mixed paper	10.2	75.9	8.4	5.4
Mixed plastics	0.2	95.8	2.0	2.0
Yard wastes	60.0	42.3	7.3	0.4
Glass	2.0	-	-	96-99
Residential MSW	21.0	52.0	7.0	20.0

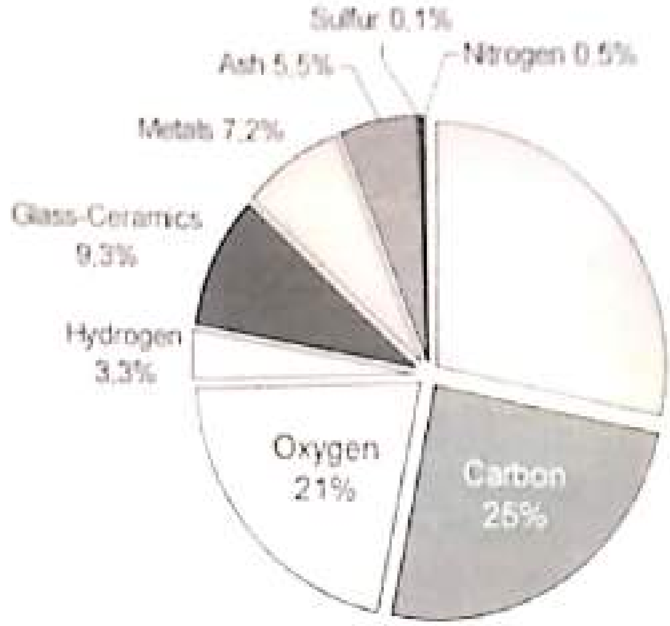
Fusing Point of Ash

- Fusing point of ash is the temperature at which the ash resulting from the burning of waste will form a solid (clinker) by fusion and agglomeration.
- Typical fusing temperatures: 1100 - 1200 °C

Ultimate Analysis

- Involves the determination of the percent C (carbon), H (hydrogen), O (oxygen), N (nitrogen), S (sulfur) and ash.
- The determination of halogens are often included in an ultimate analysis.
- The results are used to characterize the chemical composition of the organic matter in MSW. They are also used to define the proper mix of waste materials to achieve suitable C/N ratios for biological conversion processes.

Chemical composition of typical MSW



Typical data in elemental analysis

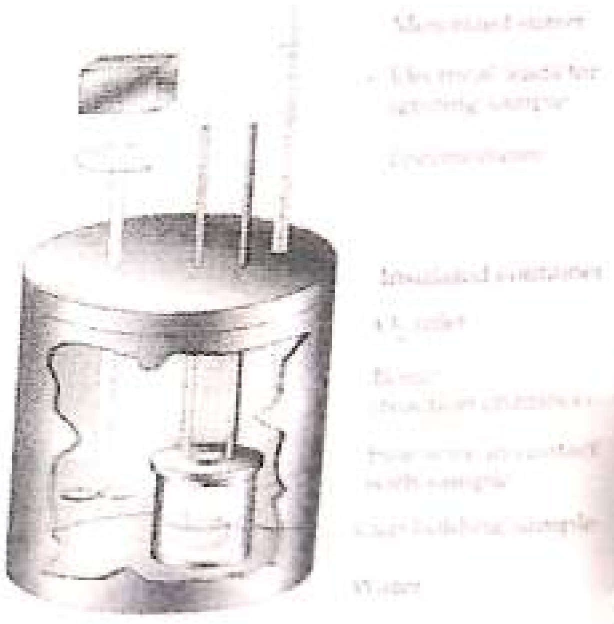
(% by weight)

Type	C	H	O	N	S	Ash
Mixed food	73.0	11.5	14.8	0.4	0.1	0.2
Mixed paper	43.3	5.8	44.3	0.3	0.2	6.0
Mixed plastic	60.0	7.2	22.8	-	-	10.0
Yard waste	46.0	6.0	38.0	3.4	0.3	6.3
Refuse Derived Fuel (RDF)	44.7	6.2	38.4	0.7	<0.1	9.9

Energy Content of Solid Waste

- *Energy content can be determined by:*
  1. By using a full scale boiler as a calorimeter
  2. By using a laboratory bomb calorimeter
  3. By calculation
- Most of the data on the energy content of the organic components of MSW are based on the results of bomb calorimeter tests.

Bomb Calorimeter



Average composition and heating values for MSW

The average energy content of typical MSW is ~10,000 kJ/kg

Waste Component	Weight %	Heating Value (MJ/kg)
Paper and paper products	37.8	17.7
Plastic	4.60	33.5
Rubber and leather	2.20	23.5
Textiles	3.30	32.5
Wood	3.00	20.0
Food wastes	14.2	15.1
Yard wastes	14.6	17.0
Glass and ceramics	9.00	0
Metals	8.20	0
Miscellaneous inorganic	3.10	0

Biological Properties of MSW

The organic fraction of MSW (excluding plastics,rubber and leather) can be classified as:

- Water-soluble constituents - sugars, starches, amino acids and various organic acids
- Hemicellulose - a product of 5 and 6-carbon sugars
- Cellulose - a product of 6-carbon sugar glucose
- Fats, oils and waxes - esters of alcohols and long-chain fatty acids
- Lignin - present in some paper products
- Lignocellulose - combination of lignin and cellulose
- Proteins - amino acid chains

Biodegradability of MSW

- The most important biological characteristic of the organic fraction of MSW is that almost all the organic components can be converted biologically to gases and relatively inert organic and inorganic solids.
- The production of odours and the generation of flies are also related to the putrescible nature of the organic materials. These will be discussed when talking about landfill processes.

Biodegradability of MSW

- Volatile solids (VS), determined by ignition at 550 °C, is often used as a measure of the biodegradability of the organic fraction of MSW.
- Some of the organic constituents of MSW are highly volatile but low in biodegradability (e.g. Newsprint) due to lignin content.
- The rate at which the various components can be degraded varies markedly. For practical purposes, the principal organic waste components in MSW are often classified as rapidly and slowly decomposable.

Production of odors

- Odors are developed when solid wastes are stored for long periods of time on-site between collections, in transfer stations, and in landfills.
- It is more significant in warm climates.
- The formation of odors results from the anaerobic decomposition of the readily decomposable organic components found in MSW.

Physical Transformations

- The principal physical transformations that may occur in the operation of solid waste management systems include:
  - component separation
  - mechanical volume reduction
  - mechanical size reduction
- Physical transformations do not involve change in phase (e.g., solid to gas), unlike chemical and biological transformation.

Chemical Transformations

- Chemical transformations of solid waste typically involve a change of phase (e.g., solid to liquid, solid to gas, etc.)
- To reduce the volume and/or to recover conversion products, the principal chemical processes used to transform MSW include:
  - Combustion (chemical oxidation)
  - Pyrolysis
  - Gasification

  } Thermal processes

Biological Transformations

The biological transformations of the organic fraction of MSW may be used;

1) to reduce the volume and weight of the material
2) to produce compost
3) to produce methane

and include:

1) aerobic composting
2) low-solids anaerobic digestion
3) high-solids anaerobic digestion (anaerobic composting)

Importance of Transformation

- Typically waste transformations are used
  - to improve the efficiency of solid waste management systems
  - to recover reusable and recyclable materials
  - to recover conversion products and energy

Importance of Transformation

- The organic fraction of MSW can be converted to usable products and ultimately to energy in a number of ways including
  - combustion to produce steam and electricity
  - pyrolysis to produce a synthetic gas, liquid or solid fuel, and solids
  - gasification to produce a synthetic fuel
  - biological conversion to produce compost
  - biodigestion to generate methane and to produce a stabilized organic humus

Transformation Processes in MSW Management (Textbook, p.91, Table 4-8)

	Process	Method	Principal Conversion Products
Physical Transformation	separation	manual and/or mechanical	individual components found in comingled MSW
	volume reduction	Force or pressure	original waste reduced in volume
	size reduction	Shredding, grinding, or milling	altered in form and reduced in size
Chemical Transformation	combustion	thermal oxidation	CO_2, SO_2, oxidation products, ash
	pyrolysis	destructive distillation	a variety of gases, tar and/or oil
	gasification	starved air combustion	gases and inerts
Biological Transformation	aerobic compost	aerobic biological conversion	compost
	anaerobic digestion	anaerobic biological conversion	methane, CO_2, trace gases, humus
	anaerobic composting (in landfills)	anaerobic biological conversion	methane, CO_2, digested waste

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Physical Characterization and Geotechnical Properties of Municipal Solid Waste

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Abstract: *Municipal Solid Waste (MSW) is complex refuse consisting of various materials with different properties. Some of the components are stable while others degrade as a result of biological and chemical processes. Leachate resulting from this is hazardous pollutant to the soil and ground water underlying. Leaching of this leachate and heavy metals into the soil leads to the contamination of both soil and groundwater. Municipal solid waste disposal on land has become one of the challenges in landfill engineering design. The stability of landfill is governed by the strength parameters and physical properties of MSW. For the analysis of MSW, geotechnical properties of the MSW play an important role in designing of the landfill and slope stability issues. In this paper results of laboratory investigation of the geotechnical properties of MSW are presented. Waste samples collected were subjected to specific gravity, moisture content, particle size analysis, compaction, permeability, consolidation and direct shear tests. The influence of these properties on the stability of the landfill and other issues of MSW in the designing of landfill are discussed.*

Keywords: *Geotechnical properties, Leachate, Municipal Solid waste (MSW), Physical characterization, Stability.*

I. Introduction

Municipal Solid Waste (MSW) is complex refuse consisting of various materials with different properties. Some of the components are stable while others degrade as a result of biological and chemical processes. Leachate resulting from this is hazardous pollutant to the soil and ground water underlying. Leaching of this leachate and heavy metals into the soil leads to the contamination of both soil and groundwater.

Municipal solid waste mainly consists of kitchen waste, plastics, paper product, textile, garden waste, construction demolition waste, metals, and wood waste etc. However the composition of MSW varies from region to region and it depends upon lifestyle, demographic features and legislation. Open dumping has been the most accepted practice of solid waste disposal. On an average, 5–6% of the wastes are disposed of by using various composting methods [1]. The scope of waste reduction programs and other eco-friendly methods of waste disposal decreases because of lack of technical infrastructure, political willpower, and awareness among people [2].

Proper management of growing quantities of municipal solid wastes (MSW) has been a major concern of environmental professionals. Despite recycling and reuse efforts as well as incineration, huge quantities of MSW are still required to be disposed of in engineered landfills. The collection of reliable data regarding generation and characterization of the waste is the key to a successful MSW management. Presently, lack of reliable information and data regarding generation rate, amount, and nature of solid waste creates a hurdle in developing an appropriate waste management plan.

The geotechnical properties of municipal solid waste (MSW) are of paramount importance in designing and assessing the performance of landfill and in ensuring safe long-term containment of MSW so that human health and the environment are not exposed to undue risk. Geotechnical properties of MSW are difficult to determine because the heterogeneity, wide variation in particle size distribution and time dependent degradation. Geotechnical properties of MSW are determined through in-situ and laboratory tests and /or back analysis of field performance data [3]. In landfill design and stability analysis the characterization of the mechanical behavior of the MSW is necessary as well as other specific physical properties such as composition, unit weight, water and organic contents and permeability. The water and organic content have a direct effect on the long-term mechanical response of the MSW as they affect the processes of biodegradation [4].

Several landfill failures worldwide emphasized the dire need for the proper determination of waste properties to ensure safety and stability of landfills. Dixon and Zones (2005) indicate that measuring and interpreting MSW characteristics is extremely difficult task. However, knowledge of unit weight, vertical compressibility, shear strength, lateral stiffness, in situ stresses and hydraulic conductivity is fundamental to the assessment of landfill stability and integrity of both geosynthetic and mineral lining components. The safety and stability of the landfills need to be assessed based on data from landfills. In this context characterization of MSW is important [5].

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II. Physical Characterization Of MSW

The physical characterization of municipal solid waste is done in order to measure the quantity of the recoverable and to study the effect of the physical composition on the strength and stability characteristics of the MSW. A number of existing classification systems are simply based on material groups (e.g. paper, plastic, metal, etc.) or on the distinction between soil-like (3-D structure) and non-soil-like (2-Dstructure), or fibrous, appearance (Dixon and Langer, 2006). [6]

Some of the classification systems are MSW component-based systems that are primarily used to facilitate physical (reuse and recycle), biological (compost) and chemical (chemical additives) processing of majority of waste material (US EPA, 2003; European Commission, 2003). Component based systems identify MSW as: (1) material type; (2) product type (US EPA, 2001). Material type classification may include paper and paperboard, glass, metals, plastics, rubber and leather, textiles, wood, and others. Product type classification may include durable goods (e.g. appliances, furniture, tires), non-durable goods (e.g. newspaper, office papers, trash bags, clothing), containers, and packaging (e.g. bottles, cans, corrugated boxes), and other wastes (e.g. yard trimmings, food scraps and miscellaneous inorganic wastes). The rest of available classification systems are used to facilitate land filling process with minimal damage to protective landfill base-liner [7].

Table - 1 Overview of existing classification systems of municipal solid waste

Author	Basis for differentiation	Parameters used for differentiation
Turczynski, 1988	Waste type	Density, shear parameters, liquid/ plastic limit, permeability
Siegel et al., 1990	Material groups	Part of composition
Landva and Clark, 1990	Organic, inorganic Materials	Degradability (easily, slowly, non) shape (hollow, platy, elongated, bulky)
ADEME(1993)	Particle size distribution and composition	Size, material groups, moisture content and degradability
Grisolia et al., 1995	Degradable, inert, deformable material groups	Strength, deformability, degradability
Kolsch, 1996	Material groups	Size, dimension
Manassero et al., 1997	Soil-like, Other	Index properties
Thomas et al., 1999	Soil-like, non-soil-like	Material groups
Dixon and Langer, 2006	Shape- related subdivisions	Material groups, size, shape, organic, inorganic, soil-like, non-soil-like

Source: Dixon and Langer, 2006.

2.1. Waste composition

Municipal solid waste is a mixture of wastes that are primarily of residential and commercial origin. Many categories of MSW are found such as food waste, rubbish, commercial waste, institutional waste, street sweeping waste, industrial waste, construction and demolition waste, and sanitation waste. MSW contains compostable organic matter (fruit and vegetable peels, food waste), recyclables (paper, plastic, glass, metals, etc.), toxic substances (paints, pesticides, used batteries, medicines), and soiled waste (blood stained cotton, sanitary napkins, disposable syringes). MSW composition at generation sources and collection points ,determined on a wet weight basis, consists mainly of a large organic fraction (40–60%), ash and fine earth (30–40%), paper (3–6%) and plastic, glass and metals (each less than 1%).

The waste is segregated by hand sorting into paper, plastics, inerts (rubber, leather), glass, stones and the organic fraction of the waste. The physical characterization of the waste passing through 100 mm sieve was done by hand sorting and on the weight basis. The age of the sample was 4- 5 weeks. The quantity of waste taken for composition analysis was 100 kg regarding the composition of MSW generated by the Satna City over the entire study period. The MSW samples used for all the experiments were those passing through the 20 mm sieve and retained by the 4.75 mm sieve. Therefore the composition analysis of the 4.75 mm sieve retained waste was done and found to be: pastel - 39.25%, paper and cardboard - 20.50%, plastic - 17.25%, cloths- 7.50%, glass-2.75%, stones – 1.75%, rubber, wood, metals (each less than 1%) and etc.

Fig. 2 shows waste composition of the municipal solid waste. According to this figure the percentage of the main MSW components are paste (food scrap), plastic and paper/cardboard.

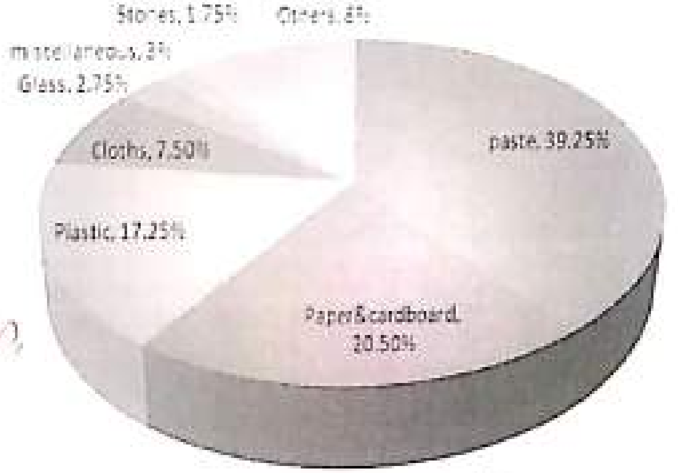

Fig. 2 composition of municipal solid waste

2.2. Water content

The water content of a typical MSW may include both water held in macro or freely draining pores and water absorbed into micro pores within individual waste component such as paper, cardboard, textiles, food etc. In general water content of MSW within a landfill vary between its initial water content on collection and a water content representing fully saturated conditions [8].

The moisture content and organic content of the waste material smaller than 10 mm were measured. Moisture content of the waste smaller than 10 mm material was calculated as the ratio of the weight loss to the weight that remained after heating at a temperature of 70°C until the specimen has dried to a constant mass. Moisture contents measured were ranged from 90% to 145% on dry weight basis, equivalent to 47% to 51% on wet weight basis.

2.3 Specific Gravity

Pycnometer method was employed to determine specific gravity for MSW in laboratory for finding the specific gravity of MSW. Specific gravity of MSW in the present study was found to be 2.22. The lower value of specific gravity can be attributed to the presence of decomposed organic matter.

3.4. Particle size distribution

In the laboratory the MSW used for the experiments were the waste passings through 10mm sieve. Most of the traditional laboratory geotechnical testing equipment cannot accommodate field MSW samples with large particle sizes. Therefore sieve analysis of the waste retained by the 4.75 mm sieve was done on weight basis and in accordance with the ASTM D422 standards. The maximum quantity of MSW retained was 34% on the 2.36 mm sieve. The maximum percent passing was 85% through the 4.75 mm sieve. The results are shown in the Fig. 3. The Cu and Cc values for the samples were calculated as and 15 and 1.66. The values indicate that the samples are well graded and the absence of coarse sand and clay like particles. The MSW constituted of fine sand and silt like particles.

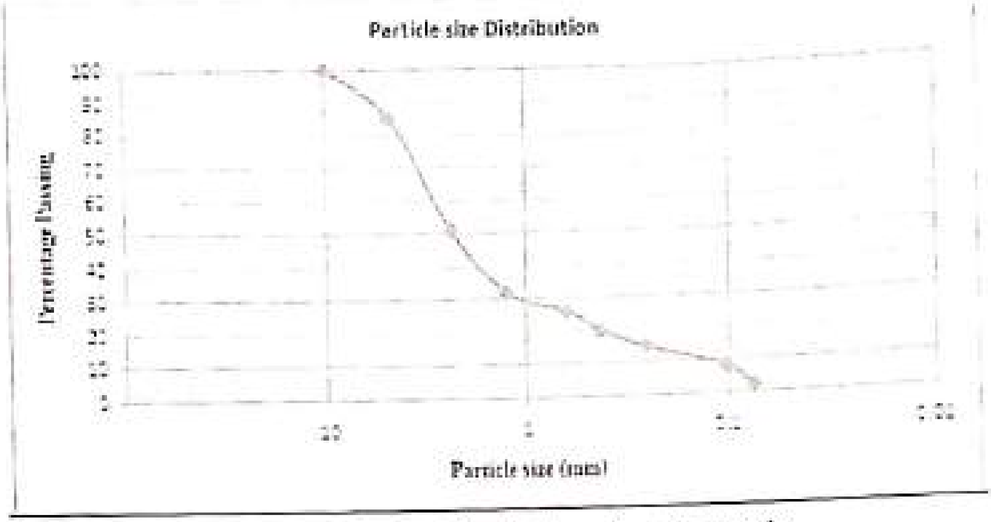

Fig -3 Particle Size Distribution of waste sample

III. Geotechnical Testing Of MSW

In this study, the MSW samples collected from the field and geotechnical testing was conducted using these samples. Compaction, hydraulic conductivity, compressibility, and shear strength tests were conducted.

3.1 Compaction Test

Compaction is the process of densification of soil mass by reducing air voids. The degree of compaction is measured in terms of its dry density. The degree of compaction mainly depends upon its moisture content, compaction energy and type of soil. The compaction test is carried out based on ASTM D698 Standard Proctor Test on MSW using a 100 mm diameter mould. The waste is compacted with 25 blows for 3 layers using standard Proctor hammer. The test is repeated for another five determinations. A dry density is plotted against moisture content, to determine the maximum dry density and optimum moisture content.

3.2 Compressibility Test

Compressibility testing was carried out in an oedometer in order to determine the compressibility characteristics of MSW. The test was performed for a water content of 45% and a bulk density 1100 kg/m^3. The size of the sample was 60mm diameter and 15 mm height. The maximum load applied was 800 kPa. The waste was compacted into the mould using a circular tamping plate and placed in between the porous stones. Since the MSW constituted of fine sand and silt like particles the oedometer tests were conducted.

3.3 Hydraulic conductivity

To determine kydraulic conductivity of MSW laboratory tests were conducted by constant head and falling head methods. Small-scale laboratory tests were conducted to determine hydraulic conductivity by constant head and falling head methods. Fresh waste was collected from a landfill site. The tests were performed according to ASTM D2434 and ASTM D5084 (2007). The waste was compacted into the mould of 85 mm diameter and 127.3 mm height. The permeability was calculated based on the Darcy's law. The water content and the bulk density of MSW were 45% and 11 kN/m^3 MSW samples were tested at confining pressures 50, 100 and 200 kPa.

3.4 Direct Shear tests

Shear resistance is a geotechnical parameter of primary concern in describing the properties of MSW. Direct shear tests were conducted to determine the shear strength parameters (cohesion and friction angles) of municipal solid waste. Tests were performed in accordance to ASTM D3080. The samples were compacted in a square shear box of 60 mm x 60 mm. The height of the box is 50 mm. In the present study the direct shear tests were performed with bulk density 1100 kg/m^3 and for confining pressures of 50, 100 and 200 kPa. The size of sample was 60 mm in length, 60 mm in width and 30 mm in height. The stress-strain response of the waste are plotted and the cohesion and the friction angle values were obtained.

Characteristics of hazardous wastes

The regulations define characteristic hazardous wastes as wastes that exhibit measurable properties posing sufficient threats to warrant regulation. For a waste to be deemed a characteristic hazardous waste, it must cause, or significantly contribute to, an increased mortality or an increase in serious irreversible or incapacitating reversible illness, or pose a substantial hazard or threat of a hazard to human health or the environment, when it is improperly treated, stored, transported, disposed of, or otherwise mismanaged.

In other words, if the wastes generated at a facility are not listed in the F, K, P, or U lists, the final step to determine whether a waste is hazardous is to evaluate it against the following 4 hazardous characteristics:

(i) **Ignitability** (EPA Waste Identification Number D001): A waste is an ignitable hazardous waste, if it has a flash point of less than 60°C; readily catches fire and burns so vigorously as to create a hazard; or is an ignitable compressed gas or an oxidiser. A simple method of determining the flash point of a waste is to review the material safety data sheet, which can be obtained from the manufacturer or distributor of the material. Naphtha, lacquer thinner, epoxy resins, adhesives and oil based paints are all examples of ignitable hazardous wastes.

(ii) **Corrosivity** (EPA Waste Identification Number D002): A liquid waste which has a pH of less than or equal to 2 or greater than or equal to 12.5

considered to be a corrosive hazardous waste. Sodium hydroxide, a caustic solution with a high pH, is often used by many industries to clean or degrease metal parts. Hydrochloric acid, a solution with a low pH, is used by many industries to clean metal parts prior to painting. When these caustic or acid solutions are disposed of, the waste is a corrosive hazardous waste.

(iii) **Reactivity** (EPA Waste Identification Number D003): A material is considered a reactive hazardous waste, if it is unstable, reacts violently with water, generates toxic gases when exposed to water or corrosive materials, or if it is capable of detonation or explosion when exposed to heat or a flame. Examples of reactive wastes would be waste gunpowder, sodium metal or wastes containing cyanides or sulphides.

(iv) **Toxicity** (EPA Waste Identification Number D004): To determine if a waste is a toxic hazardous waste, a representative sample of the material must be subjected to a test conducted in a certified laboratory. The toxic characteristic identifies wastes that are likely to leach dangerous concentrations of toxic chemicals into ground water.

9.1.2 Classification

From a practical standpoint, there are far too many compounds, products and product combinations that fit within the broad definition of hazardous waste. For this reason, groups of waste are considered in the following five general categories:

(i) **Radioactive substance:** Substances that emit ionising radiation are radioactive. Such substances are hazardous because prolonged exposure to radiation often results in damage to living organisms. Radioactive substances are of special concern because they persist for a long period. The period in which radiation occurs is commonly measured and expressed as *half-life*, i.e., the time required for the radioactivity of a given amount of the substance to decay to half its initial value. For example, uranium