Solid Waste Characteristics

- Physical and chemical composition of solid wastes vary depending on sources and types of solid wastes.

- The nature of the deposited waste in a landfill will affect gas and leachate production and composition by virtue of relative proportions of degradable and non-degradeable components, the moisture content and the specific nature of the bio-degradeable element.

- The waste composition will effect both the bulk gases and the trace components.

Determination of Characteristics in the Field:

- Solid wastes are complex, multiphase mixtures.
- Because of the heterogeneous nature of solid wastes, determination of composition is not easy. Statistical procedures are difficult and usually procedures based on random sampling techniques are used to determine composition.
- To obtain a sample for analysis the waste is reduced to about 100 kg by coning and quartering.

Waste Characteristics

In order to identify the exact characteristics of municipal wastes, it is necessary that we analyse them using physical and chemical parameters.

Physical Characteristics

Chemical Characteristics

Chemical Characteristics

- Proximate analysis
- Fusing point of ash
- Ultimate analysis
- Energy content

Physical Characteristics

Density/Specific weight	Color
Moisture content	Voids
Particle size	Shape of components
Size distribution	Optical property
Field capacity	Magnetic properties
Compacted waste porosity	Electric properties

Physical Characteristics

Information and data on the **physical characteristics of solid wastes** are important for the **selection and operation of equipment and for the analysis and design of disposal facilities**.

The **major physical characteristics** measured in waste are:

(1) density

(2) size distribution of components and

(3) moisture content.

Other characteristics which may be used in making decision about solid waste management are:

(1) colour

(2) voids

(3) shape of components

(4) optical property

(5) magnetic properties and

(6) electric properties.

Physical Characteristics

The required information and data include the following:

Density or Specific weight:

Density of waste, i.e. its mass per unit volume (kg/m^3) is a critical factor in the design of a SWM system e.g., the design of sanitary landfills, storage, types of collection and transport vehicles etc.

To explain, an efficient operation of a landfill demands compaction of wastes to optimum density.

Any normal compaction equipment can achieve reduction in volume of wastes by 75%, which increases an initial density of 100 kg/m^3 to 400 kg/m^3.

Because the densities of solid wastes vary markedly with geographic location, season of the year, the length of time in storage, great care should be used in selecting typical values. Municipal solid wastes as delivered in compaction vehicles have been found to have a typical value about 300 kg/m^3.

Physical Characteristics

In other words, a waste collection vehicle can haul four times the weight of waste in its compacted state than when it is uncompacted.

A high initial density of waste precludes the achievement of a high compaction ratio and the compaction ratio achieved is no greater than 1.5:1.

Significant changes in density occur spontaneously as the waste moves from source to disposal, due to scavenging, handling, wetting and drying by the weather, vibration in the collection vehicle and decomposition.

Note that:

- the effect of increasing the moisture content of the waste is detrimental in the sense that dry density decreases at higher moisture levels
- soil-cover plays an important role in containing the waste
- there is an upper limit to the density, and the conservative estimate of in-place density for waste in a sanitary landfill is about 600 kg/m^3

Physical Characteristics

Moisture content:

Moisture content is defined as the ratio of the weight of water (wet weight - dry weight) to the total weight of the wet waste.

Note: Dry weight is the weight of sample after drying at 105 ^{0}C

Moisture increases the weight of solid wastes and thereby, the cost of collection and transport.

In addition, moisture content is a critical determinant in the economic feasibility of waste treatment by incineration because wet waste consumes energy for evaporation of water and in raising the temperature of water vapour.

In the main, wastes should be insulated from rainfall or other extraneous water.

Physical Characteristics

We can calculate the moisture percentage, using the formula given below:

$$\text{Moisture content (\%)} = \frac{\text{Wet weight - Dry weight}}{\text{Wet weight}} \times 100$$

$$M = \left(\frac{w-d}{w}\right)100$$

Where M = moisture content, %
W= initial weight of sample as delivered, kg
D=weight of sample after drying at 105 ^{0}C, kg

A typical range of moisture content is 20 to 40%, representing the extremes of wastes in an arid climate and in the wet season of a region of high precipitation. However, values greater than 40% are not uncommon.

Physical Characteristics

Size:

The size and size distribution of the component materials in solid wastes are an important consideration in the recovery of materials especially with mechanical means such as trommel screens and magnetic separators.

Measurement of size distribution of particles in waste stream is important because of its significance in the design of mechanical separators and shredders.

Generally, the results of size distribution analysis are expressed in the manner used for soil particle analysis.

That is to say, they are expressed as a plot of particle size (mm) against percentage, less than a given value.

Physical Characteristics

Size:

The size of waste component may be defined by one or more of the following measures:

$$S_C = l$$

$$S_C = \left(\frac{l + w}{2}\right)$$

$$S_C = \left(\frac{l + w + h}{3}\right)$$

$$S_C = (l \times w)^{1/2}$$

$$S_C = (l \times w \times h)^{1/3}$$

Where
S_C = size of component in mm
l= length in mm
w = width in mm
h = height in mm

Physical Characteristics

- The major means of controlling particle size is through shredding.
- Shredding increases homogeneity, increases the surface area/volume ratio and reduces the potential for preferential liquid flow paths through the waste.
- Particle size will also influence waste packing densities and particle size reduction (by shredding) could increase biogas production through the increased surface area available to degradation by bacteria.
- But the smaller particles allow higher packing density which decrease water movement, bacterial movement and the bacterial access to substrate

Physical Characteristics

- **Optical property** can be used to segregate opaque materials from transparent substances which would predominately contain glass and plastic.
- **Magnetic separators** are designed based on the magnetic characteristics of the waste.
- **Moisture content** is essential for leachate calculation and composting.
- **Density** is used to assess volume of transportation vehicle and size of the disposal facility.
- **Shape** can be used for segregation as flaky substance will behave differently compared to non-flaky substance.

Physical Characteristics

The physical properties that are essential to analyse wastes disposed at landfills are:

Field capacity:

The field capacity of MSW is the total amount of moisture which can be retained in a waste sample subject to gravitational pull.

It is used to determine the formation of leachate in landfills.

It is a critical measure because water in excess of field capacity will form leachate and leachate can be a major problem in landfills.

Field capacity varies with the degree of applied pressure and the state of decomposition of the wastes.

Physical Characteristics

Permeability of compacted wastes:

The hydraulic conductivity of compacted wastes is an important physical property because it governs the movement of liquids and gases in a landfill.

Permeability depends on the other properties of the solid material include pore size distribution, surface area and porosity.

The coefficient of permeability is normally written as $K = cd^2 \frac{\gamma}{\mu} = k \frac{\gamma}{\mu}$

Where

K = coefficient of permeability

ɔ = specific weight of water

C = dimensionless constant or shape factor

µ = dynamic viscosity of water

d = average size of pores

k = intrinsic permeability

Physical Characteristics

The term Cd^2 is known as the **intrinsic permeability**.

The intrinsic permeability depends solely on the properties of the solid material including pore size distribution, tortuosity, specific surface and porosity.

Typical values for the intrinsic permeability for compacted solid waste in a landfill are in the range between about **10^{-11} and 10^{-12} m^2** in the **vertical direction** and about **10^{-10} m^2** in the **horizontal direction**.

The reported range of permeability of refuse is 10^{-1} to 10^{-5} cm/sec.

Porosity:

It represents the amount of voids per unit overall volume of material.

The porosity of MSW varies typically from 0.40 to 0.67 depending on the compaction and composition of the waste.

Porosity of solid waste $n = e/(1+e)$ Where e is void ratio of solid waste

Physical Characteristics

Compressibility of MSW:

Degree of physical changes of the suspended solids or filter cake when subjected to pressure.

$\Delta H_T = \Delta H_i + \Delta H_c + \Delta H_\alpha$

ΔH_T= total settlement
ΔH_i=immediate settlement
ΔH_c = consolidation settlement
ΔH_α = secondary compression or creep

$C'_\alpha = \Delta H / [H_0 \text{ X } (\text{Log}(t_2/t_1))] = C_\alpha / (1+e_0)$

Cα, C'α = Secondary compression index and Modified secondary Compression index; and t1, t2= Starting and ending time of secondary settlement respectively

Physical Characteristics

Determine the moisture content of the sample from the following data:

Waste Composition	% by Weight	Moisture Content
Food wastes	15	70
Paper	45	6
Cardboard	10	5
Plastic	10	2
Garden trimmings	10	60
Wood	5	20
Tin, cans	3	3

Based on 100 kg's

Hint: Compute dry weight (i.e., individual constituent wet weight – moisture).
Moisture content of the sample (wet weight – dry weight)* 100/wet weight.

Physical Characteristics

Component	Percent by mass	Moisture content (%)	Dry mass, kg
Food waste	15	70	4.5
Paper	45	6	42.3
Cardboard	10	5	9.5
Plastics	10	2	9.8
Garden trimmings	10	60	4.0
Wood	5	20	4.0
Tin cans	5	3	4.9
Total	100		79.0

Physical Characteristics

Using the formula:

$$\textit{Moisture content} = \frac{\textit{Wet weight} - \textit{Dry weight}}{\textit{Wet weight}} \times 100$$

$$\textit{Therefore, moisture content} = \frac{(100 - 79)}{100} \times 100 = 21\%$$

Chemical Characteristics

Chemical characteristics:

Knowledge of the classification of chemical compounds and their characteristics is essential for the proper understanding of the behaviour of waste, as it moves through the waste management system.

The products of decomposition and heating values are two examples of chemical characteristics. If solid wastes are to be used as fuel, or are used for any other purpose, we must know their chemical characteristics, including the following:

Å Lipids
Å Carbohydrates
Å Proteins
Å Natural fibres
Å Synthetic organic material (Plastics)
Å Non-combustibles
Å Heating value
Å Ultimate analysis
Å Proximate analysis

Important chemical properties measured for solid waste are: (1) moisture (water content can change chemical and physical properties) (2) volatile matter (3) ash (4) fixed carbon (5) fusing point of ash (6) calorific value (7) percent of carbon, hydrogen, oxygen, sulphur and ash.

Chemical Characteristics

Lipids:

This class of compounds includes fats, oils and grease and the principal sources of lipids are garbage, cooking oils and fats.

Lipids have high heating values, about 38,000 kJ/kg (kilojoules per kilogram), which makes waste with high lipid content suitable for energy recovery.

Since lipids become liquid at temperatures slightly above ambient, they add to the liquid content during waste decomposition.

Though they are biodegradable, the rate of biodegradation is relatively slow because lipids have a low solubility in water.

Chemical Characteristics

Carbohydrates:

These are found primarily in food and yard wastes, which encompass sugar and polymer of sugars (e.g., starch, cellulose, etc.) with general formula $(CH_2O)_x$.

Carbohydrates are readily biodegraded to products such as carbon dioxide, water and methane.

Decomposing carbohydrates attract flies and rats and therefore, should not be left exposed for long duration.

Proteins:

These are compounds containing carbon, hydrogen, oxygen and nitrogen and consist of an organic acid with a substituted amine group (NH_2).

They are mainly found in food and garden wastes. The partial decomposition of these compounds can result in the production of amines that have unpleasant odours.

Chemical Characteristics

Natural fibres:

These are found in paper products, food and yard wastes and include the natural compounds, cellulose and lignin that are resistant to biodegradation. (Note that paper is almost 100% cellulose, cotton over 95% and wood products over 40%.)

Because they are a highly combustible solid waste, having a high proportion of paper and wood products, they are suitable for incineration.

Calorific values of oven-dried paper products are in the range of 12,000 - 18,000 kJ/kg and of wood about 20,000 kJ/kg, i.e., about half that for fuel oil, which is 44,200 kJ/kg.

Chemical Characteristics

Synthetic organic material (Plastics):

Accounting for 1 ï 10%, plastics have become a significant component of solid waste in recent years.

They are highly resistant to biodegradation and therefore, are objectionable and of special concern in SWM.

Hence the increasing attention being paid to the recycling of plastics to reduce the proportion of this waste component at disposal sites.

Plastics have a high heating value, about 32,000 kJ/kg, which makes them very suitable for incineration.

But, you must note that polyvinyl chloride (PVC), when burnt, produces dioxin and acid gas.

The latter increases corrosion in the combustion system and is responsible for acid rain..

Chemical Characteristics

Non-combustibles:

This class includes glass, ceramics, metals, dust and ashes, and accounts for 12 ï 25% of dry solids.

Energy Content of Solid Waste Components:

The energy content of the organic components in MSW can be determined (1) by using a full scale boiler as a calorimeter (2) by using a laboratory bomb calorimeter, and (3) by calculation, if the elemental composition is known.

Because of the difficulty in instrumenting a full-scale boiler, most of the data on the energy content of the organic components of MSW are based on the results of bomb calorimeter tests.

Chemical Characteristics

Heating value:

An evaluation of the potential of waste material for use as fuel for incineration requires a determination of its heating value expressed as kilojoules per kilogram (kJ/kg).

The heating value is determined experimentally using the Bomb calorimeter test, in which the heat generated, at a constant temperature of 25 ^{0}C from the combustion of a dry sample is measured.

Since the test temperature is below the boiling point of water (100 ^{0}C), the combustion water remains in the liquid state.

However, during combustion, the temperature of the combustion gases reaches above 100 ^{0}C, and the resultant water is in the vapour form.

Chemical Characteristics

Typical Heating and Inert Residue Values

Component	Inert Residue %		Heating Value (kJ/kg)	
	Range	Typical	Range	Typical
Food wastes	2-8	5	3500-7000	4500
Paper	4-8	6	11500-18500	16500
Cardboard	3-6	5	14000-17500	16000
Plastics	2-20	10	28000-37000	32500
Textiles	2-4	2.5	15000-20000	17500

Component	Inert Residue %		Heating Value (kJ/kg)	
	Range	Typical	Range	Typical
Rubber	8-20	10	21000-28000	18500
Leather	8-20	10	15000-20000	17500
Garden trimmings	2-6	4.5	2300-18500	6500
Wood	0.6-2	1.5	17500-20000	18500
Glass	96-99	98	120-240	140
Tin cans	96-99	96	-	-
Nonferrous metals	90-99	96	240-1200	700
Ferrous metals	94-99	98	240-1200	700
Dirt, ash, bricks, etc.	60-80	70	2300-11500	7000
Municipal solid waste			9500-13000	10500

Chemical Characteristics

Note that while evaluating incineration as a means of disposal or energy recovery, we need to consider the heating values of respective constituents.

For example:

- Organic material yields energy only when dry.

- The moisture content in the waste reduces the dry organic material per kilogram of waste and requires a significant amount of energy for drying.

- The ash content of the waste reduces the proportion of dry organic material per kilogram of waste and retains some heat when removed from the furnace.

Chemical Characteristics

Ultimate analysis:

Å This refers to an analysis of waste to determine the proportion of **carbon, hydrogen, oxygen, nitrogen and sulphur** and the analysis is done to make mass balance calculation for a chemical or thermal process.

Å Besides, it is necessary to determine **ash fraction** because of its potentially harmful environmental effects, brought about by the presence of toxic metals such as cadmium, chromium, mercury, nickel, lead, tin and zinc.

Å Note that other metals (e.g., iron, magnesium, etc.) may also be present but they are non-toxic.

Å The results are use **to characterize the chemical composition of the organic matter** in MSW.

Å Used to define proper mix of waste material to achieve **suitable C/N ratios** for **biological conversion processes**.

Chemical Characteristics

Analysis for solid waste for carbon, hydrogen, nitrogen and sulphur can be done using CHNS analyser.

In the absence of such equipment chemical formula for solid waste can be calculated.

CHNS analyser used for analysis of carbon, hydrogen, nitrogen and sulphur

Chemical Characteristics

Municipal Solid Waste: A Typical Ultimate Analysis

Element	Range (%dry weight)
Carbon	25-30
Hydrogen	2.5-6.0
Oxygen	15-30
Nitrogen	0.25-1.2
Sulphur	0.02-0.12
Ash	12-30

Chemical Characteristics

Proximate analysis:

Proximate analysis of waste aims to determine moisture, volatile matter, ash and fixed carbon. This is important in evaluating the combustion properties of wastes or refuse derived fuel.

The fractions of interest are:

- moisture content which adds weight to the waste without increasing its heating value, and the evaporation of water reduces the heat released from the fuel

- ash which adds weight without generating any heat during combustion

- volatile matter i.e. that portion of the waste that is converted to gases before and during combustion

- fixed carbon which represents the carbon remaining on the surface grates as charcoal. A waste or fuel with a high proportion of fixed carbon requires a longer retention time on the furnace grates to achieve complete combustion than a waste or fuel with a low proportion of fixed carbon

Chemical Characteristics

Proximate analysis:

Proximate analysis for the combustible components of MSW includes the following tests

- Å Loss of moisture (loss at 105 ^{0}C for 1 h)
- Å Volatile Combustible Matter (VCM) (additional loss of weight on ignition at 950 ^{0}C in a closed crucible i.e. additional loss on ignition at 950 ^{0}C)
- Å Fixed Carbon (combustible residue left after volatile matter is recovered i.e. residue after burning)
- Å Ash (weight of residue after combustion in an open crucible i.e. remainder)

Chemical Characteristics

Municipal Solid Waste: A Typical Proximate Analysis

Components	Value, percent	
	Range	Typical
Moisture	15-40	20
Volatile matter	40-60	53
Fixed carbon	5-12	7
Glass, metal, ash	15-30	20

Chemical Characteristics

Fusing Point of Ash

The fusing point ash is defined as that temperature at which the ash resulting from the burning of waste will form a solid (clinker) by fusion and agglomeration.

Typical fusing temperature for the formation of clinker from solid waste range from 2000 to 2200 ^{o}F (1100 to 1200 ^{o}C).

Example: Estimation of the chemical composition of a solid waste sample. Determine the chemical composition of the organic fraction, without and with sulfur and without and with water of a residential MSW with the typical composition shown in Table

Component	Wet weight	MC %	% by weight (Dry Basis)					
			C	H	O	N	S	Ash
Food Waste	9	70	48	6.4	37.6	2.6	0.4	5.0
Paper	34	6	43.5	6.0	44	0.3	0.2	6.0
Card Board	6.0	5	44	5.9	44.6	0.3	0.2	5.0
Plastics	7.0	2	60.0	7.2	22.8	-	-	10
Textiles	2	10	55	6.6	31.2	4.6	-	2.5
Rubber	0.5	2	78	10	-	2.0	-	10
Leather	0.5	10	60	8.0	11.6	10	-	10
Yard Waste	18.5	60	47.8	6	38	3.4	0.3	4.5
Wood	2.0	20	49.5	6	42.7	0.2	0.1	1.5

Component	Wet weight, lb	Dry Weight, lb	Composition, lb					
			C	H	O	N	S	Ash
Food waste	9	2.7	1.3	0.17	1.02	0.07	0.01	0.14
Paper	34	32	13.92	1.92	14.08	0.10	0.06	1.92
Cardboard	6	5.7	2.51	0.34	2.54	0.02	0.01	0.28
Plastics	7	6.86	4.14	0.50	1.57	-	-	0.69
Textiles	2	1.8	0.99	0.12	0.56	0.08	-	0.05
Rubber	0.5	0.49	0.39	0.05	-	0.01	-	0.05
Leather	0.5	0.45	0.24	0.03	0.05	0.04	-	0.04
Yard wastes	18.5	7.4	3.11	0.39	2.47	0.22	0.02	0.29
Wood	2	1.6	0.79	0.10	0.68	-	-	0.02

Biological Properties of MSW

Biological Properites

Biodegradability of OWC
Odors
Breeding of flies

The most important biological characteristic of the organic fraction of MSW is that almost all of 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 found in MSW (e.g., food wastes).

Biological Properties of MSW

Excluding plastic, rubber and leather components, the organic fraction of most MSW can be classified as follows:

- Water-soluble constituents such as sugars, starches, amino acids, and various organic acids.
- Hemicelluloses, a condensation product of five- and six-carbon sugars
- Cellulose, a condensation product of the six-carbon sugar glucose
- Fats, oils, and waxes which are esters of alcohols and long-chain fatty acids
- Lignin, a polymeric material containing aromatic rings with methoxyl groups ($-OCH_3$), the exact chemical nature of which is still not known (present in some paper products such as newsprint and fibreboard)
- Lignocelluloses, a combination of lignin and cellulose
- Proteins, which are composed of chains of amino acids

Biological Properties of MSW

Biodegradability of Organic Waste Components

Volatile solids (VS) content, determined by ignition at 550 ^{o}C, is often used as a measure of the biodegradability of the organic fraction of MSW.

The use of VS in describing the biodegradability of the organic fraction of MSW is misleading, as some of the organic constituents of MSW are highly volatile but low in biodegradability (e.g., newsprint and certain plant trimmings).

Alternatively, the lignin content of a waste can be used to estimate the biodegradable fraction, using the following relationship:

$$BF = 0.83 - 0.028\ LC$$

where BF= biodegradable fraction expressed on a volatile solids (VS) basis

0.83 = empirical constant

0.028 = empirical constant

LC = lignin content of VS expressed as a percent of dry weight

Wastes with high lignin contents, such as newsprint, are significantly less biodegradable than the other organic wastes found in MSW.

Waste Characteristics

Physical, chemical and biological characteristics vary hugely from place to place