


Chapter 4

Physical, Chemical and Biological Properties of MSW

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- ### Physical Properties 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/m ³)
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

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

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
Residential	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
	Chemical sludge (wet)	75 - 99	80
Industrial	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

<http://www.aggregatepros.com/DoppstadtSM518TrommelScreen.html>

- 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

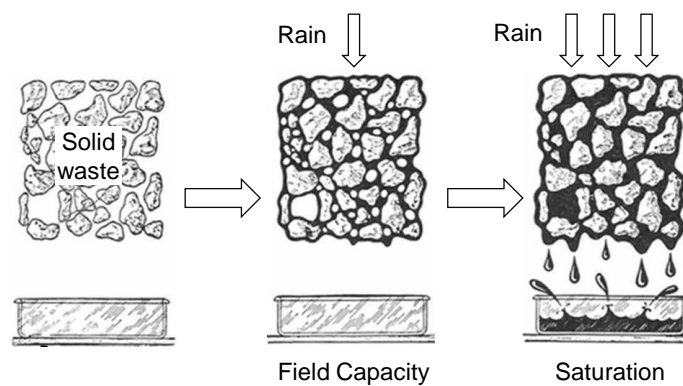
W : width, mm

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





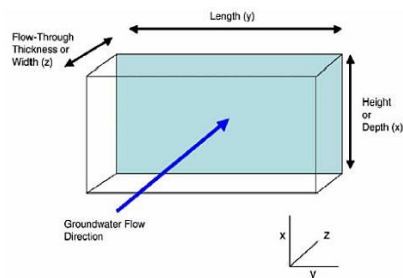
Field Capacity

- 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

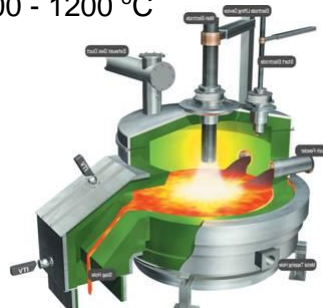
(% by weight)

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

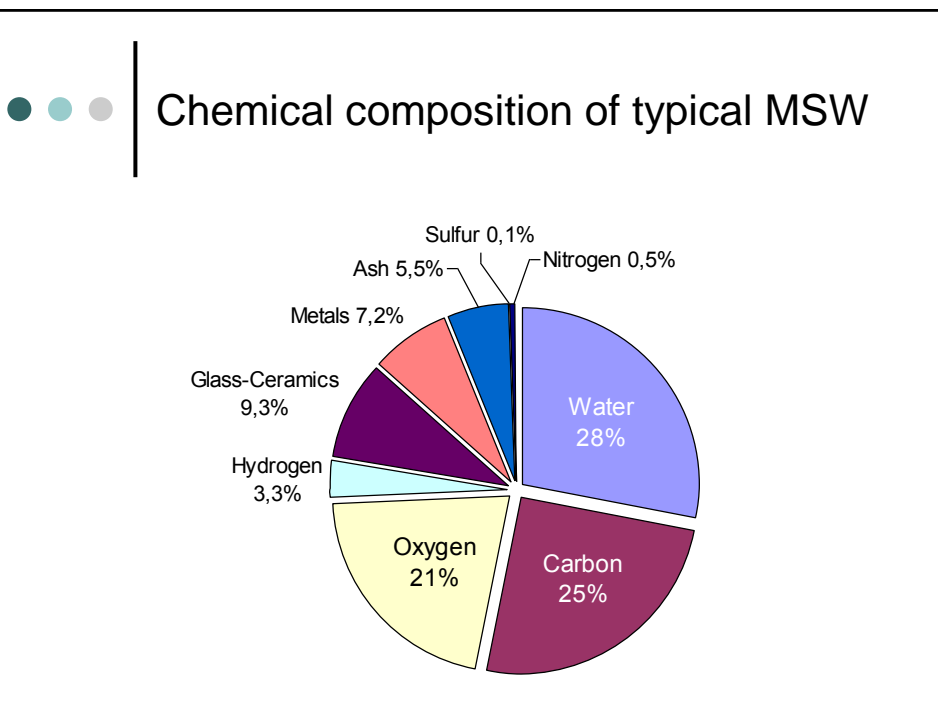


Ultimate Analysis

- 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.

Table 4-3. Typical data on ultimate analysis of combustible materials found in SW

Type of waste	Percent by weight (dry basis)					
	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur	Ash
Food and food products						
Fats	73.0	11.5	14.8	0.4	0.1	0.2
Food wastes (mixed)	48.0	6.4	37.6	2.6	0.4	5.0
Fruit wastes	48.5	6.2	39.5	1.4	0.2	4.2
Meat wastes	59.6	9.4	24.7	1.2	0.2	4.9
Paper products						
Cardboard	43.0	5.9	44.8	0.3	0.2	5.0
Magazines	32.9	5.0	38.6	0.1	0.1	23.3
Newsprint	49.1	6.1	43.0	<0.1	0.2	1.5
Paper (mixed)	43.4	5.8	44.3	0.3	0.2	6.0
Waxed cartons	59.2	9.3	30.1	0.1	0.1	1.2
Plastics						
Plastics (mixed)	60.0	7.2	22.8	—	—	10.0
Polyethylene	85.2	14.2	—	<0.1	<0.1	0.4
Polystyrene	87.1	8.4	4.0	0.2	—	0.3
Polyurethane ^b	63.3	6.3	17.6	6.0	<0.1	4.3
Polyvinyl chloride ^b	45.2	5.6	1.6	0.1	0.1	2.0
Textiles, rubber, leather						
Textiles	48.0	6.4	40.0	2.2	0.2	3.2
Rubber	69.7	8.7	—	—	1.6	20.0
Leather	60.0	8.0	11.6	10.0	0.4	10.0
Wood, trees, etc.						
Yard wastes	46.0	6.0	38.0	3.4	0.3	6.3
Wood (green timber)	50.1	6.4	42.3	0.1	0.1	1.0
Hardwood	49.6	6.1	43.2	0.1	<0.1	0.9
Wood (mixed)	49.5	6.0	42.7	0.2	<0.1	1.5
Wood chips (mixed)	48.1	5.8	45.5	0.1	<0.1	0.4
Glass, metals, etc.						
Glass and mineral ^a	0.5	0.1	0.4	<0.1	—	98.9
Metals (mixed) ^a	4.5	0.6	4.3	<0.1	—	90.5
Miscellaneous						
Office sweepings	24.3	3.0	4.0	0.5	0.2	68.0
Oils, paints	66.9	9.6	5.2	2.0	—	16.3
Refuse-derived fuel (RDF)	44.7	6.2	38.4	0.7	<0.1	9.9



Typical data in elemental analysis (% by weight)

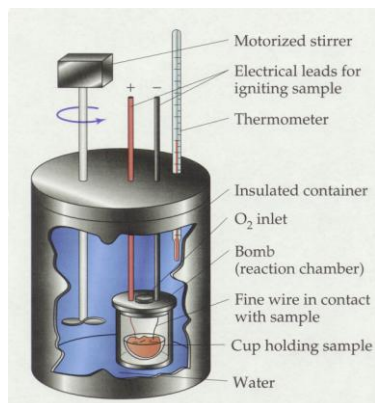
Type	C	H	O	N	S	Ash
Mixed food	73.0	11.5	14.8	0.4	0.1	0.2
Mixed paper	43.3	5.8	44.3	0.3	0.2	6.0
Mixed plastic	60.0	7.2	22.8	-	-	10.0
Yard waste	46.0	6.0	38.0	3.4	0.3	6.3
Refuse Derived Fuel (RDF)	44.7	6.2	38.4	0.7	<0.1	9.9

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



<http://chemistry.umeche.maine.edu/~amar/fall2007/bomb.html>

Table 4-5. Inert residue and energy content of residential MSW

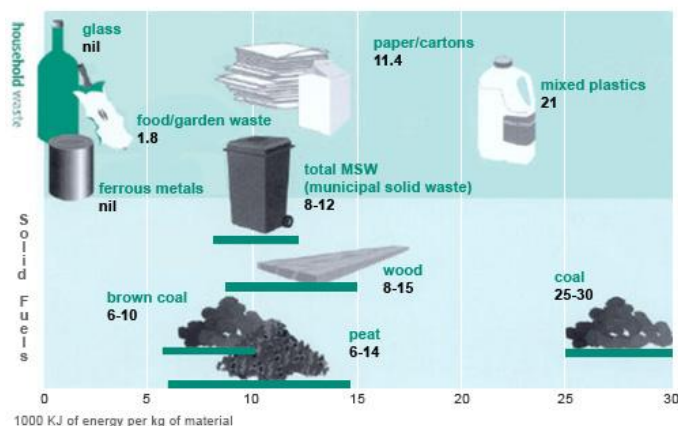
Components	Inert Residue Percentage		Energy, kJ/kg	
	Range	Typical	Range	Typical
Organic				
Food wastes	2-8	5	3489-6978	4652
Paper	4-8	6	11630-18608	16747
Cardboard	3-6	5	13956-17445	16282
Plastics	6-20	10	27912-37216	32564
Textiles	2-4	2.5	15119-18608	17445
Rubber	8-20	10	20934-27912	23260
Leather	8-20	10	15119-19771	17445
Yard wastes	2-6	4.5	2326-18608	6513
Wood	0.6-2	1.5	17445-19771	18608
Misc. organics	-	-	-	-
Inorganic				
Glass	96-99 +	98	116-233	140
Tin cans	96-99 +	98	233-1163	698
Aluminum	90-99 +	96	-	-
Other metal	94-99 +	98	233-1163	698
Dirt, ashes, etc	60-80	70	2326-11630	6978
Municipal solid waste	-	-	9304-13956	11630

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

Energy content of MSW components





Essential nutrients & other elements

Important if organic fraction of MSW is to be used for production of compost or CH₄

TABLE 4-6
Elemental analysis of the organic materials used as the feedstock for biological conversion processes

Constituent	Unit	Feed substrate (dry basis)			
		Newsprint	Office paper	Yard waste	Food waste
NH ₄ -N	ppm	4	61	149	205
NO ₃ -N	ppm	4	218	490	4278
P	ppm	44	295	3500	4900
PO ₄ -P	ppm	20	164	2210	3200
K	%	0.35	0.29	2.27	4.18
SO ₄ -S	ppm	159	324	882	855
Ca	%	0.01	0.10	0.42	0.43
Mg	%	0.02	0.04	0.21	0.16
Na	%	0.74	1.05	0.06	0.15
B	ppm	14	28	88	17
Se	ppm	—	—	<1	<1
Zn	ppm	22	177	20	21
Mn	ppm	49	15	56	20
Fe	ppm	57	396	451	48
Cu	ppm	12	14	7.7	6.9
Co	ppm	—	—	5.0	3.0
Mo	ppm	—	—	1.0	<1
Ni	ppm	—	—	9.0	4.5
W	ppm	—	—	4.0	3.3



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.

Biodegradable fraction of selected organic waste components

$$BF = 0.83 - 0.028 LC \quad (4-11)$$

where BF = biodegradable fraction expressed on a volatile solids (VS) basis
 0.83 = empirical constant
 0.028 = empirical constant
 LC = lignin content of the VS expressed as a percent of dry weight

TABLE 4-7
Data on the biodegradable fraction of selected organic waste components based on lignin content

Component	Volatile solids (VS), percent of total solids (TS)	Lignin content (LC), percent of VS	Biodegradable fraction (BF) ^a
Food wastes	7–15	0.4	0.82
Paper			
Newsprint	94.0	21.9	0.22
Office paper	96.4	0.4	0.82
Cardboard	94.0	12.9	0.47
Yard wastes	50–90	4.1	0.72

^aComputed using Eq. (4-11).

Calculation of biodegradable fraction of MSW

Component	Percent of MSW	Percent of each component that is biodegradable
Paper and paperboard	37.6	0.50
Glass	5.5	0
Ferrous metals	5.7	0
Aluminum	1.3	0
Other nonferrous metals	0.6	0
Plastics	9.9	0
Rubber and leather	3.0	0
Textiles	3.8	0.5
Wood	5.3	0.7
Other materials	1.8	0.5
Food waste	10.1	0.82
Yard trimmings	12.8	0.72
Miscellaneous inorganic	1.5	0.8
Total	100	



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