Chapter 4

Physical, Chemical and Biological Properties of MSW

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/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.

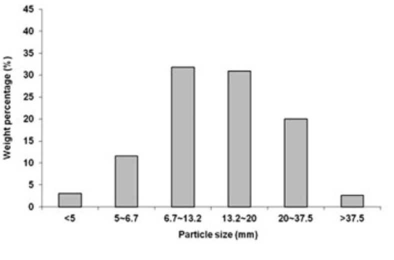
Typical Moisture Contents of Wastes

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

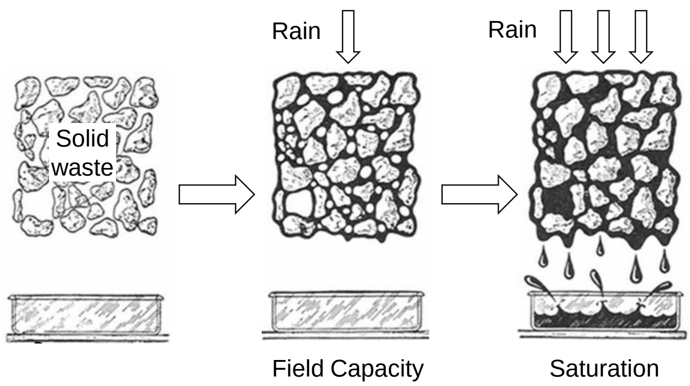
Particle Size and Distribution

- 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.



Field Capacity

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



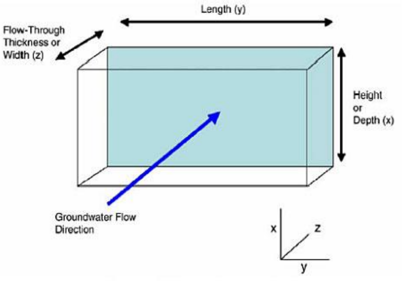
Field Capacity

- 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 ^oC for 1 h)
  - Volatile combustible matter (ignition at 950 ^oC in the absence of oxygen)
  - Fixed carbon (combustible residue left after Step 2)
  - Ash (weight of residue after combustion in an open crucible)

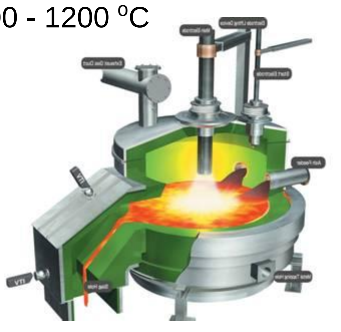
Typical Proximate Analysis Values (% by weight)

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 ^{o}C



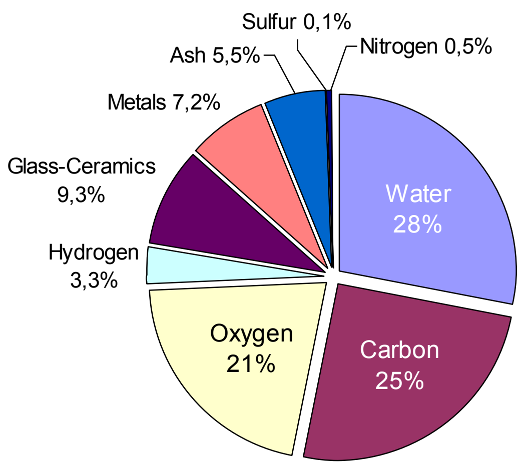
Ultimate Analysis

- 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[c]	0.5	0.1	0.4	<0.1	—	98.9
Metals (mixed)[c]	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

Chemical composition of typical MSW



Typical data in elemental analysis

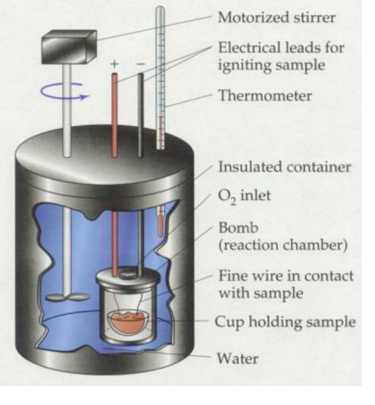
(% by weight)

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



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

Energy content of MSW~10,000 kJ/kg (2390 kcal/kg or 2.78 kWh/kg)

Waste Component	Weight %	Heating Value		
		kJ/kg	kcal/kg	kWh/kg
Paper & paper products	37.8	17700	4230	4.9
Plastic	4.60	33500	8007	9.3
Rubber and leather	2.20	23500	5617	6.5
Textiles	3.30	32500	7768	9.0
Wood	3.00	20000	4780	5.6
Food wastes	14.2	15100	3609	4.2
Yard wastes	14.6	17000	4063	4.7
Glass and ceramics	9.00	0	0	0
Metals	8.20	0	0	0
Miscellaneous inorganic	3.10	0	0	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 CH_4

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

		Feed substrate (dry basis)			
Constituent	**Unit**	**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 found in food wastes
- Hemicellulose – green (food, yard etc.) wastes
- Cellulose – waste paper, green (food, yard etc.) wastes
- Fats, oils and waxes – food wastes
- Lignin – waste paper, yard waste (brown-woody)
- Lignocellulose – combination of lignin and cellulose
- Proteins – food wastes

Biodegradability of MSW

- Almost all of the organic components in MSW can be converted biologically to gases (CH_4 & CO_2), inert organic and inorganic solids.
- Volatile solids (VS), determined by ignition at 550 ^{o}C, is often used as a measure of the biodegradability.
- Components such as Newsprint are highly volatile but low in biodegradability due to their high lignin content.
- Practically, organic waste components in MSW are often classified as rapidly and slowly decomposable.

Biodegradable fraction of selected organic waste components

$$BF = 0.83 - 0.028\ LC \qquad (4\text{-}11)$$

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

[a] Computed using Eq. (4-11).

Calculation of biodegredable fraction of MSW

Component	Percent of MSW	Percent of each component that is biodegredable
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.

Transformation Processes used for 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 digestion in landfills	anaerobic biological conversion	methane, CO_2, digested waste

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

EXAMPLE 4-1 Estimation of moisture content of typical residental MSW.

- Estimate the overall moisture content of a sample of as collected residential MSW with the typical composition given in Table 3-4.
- Set up the computation table to determine dry weights of the components using the data given in table 4-1.
- Determine the moisture content of the MSW sample
- $\frac{100-78,78}{100}$ = 21.2%

Component	Percent by weight	Moisture content,%	Dry weight, kg
Organic			
Food wastes	9	70	2,7
Paper	34	6	32,0
Cardboard	6	5	5,7
Plastics	7	2	6,9
Textiles	2	10	1,8
Rubber	0,5	2	0,5
Leather	0,5	10	0,5
Yard wastes	18,5	60	7,4
Wood	2	20	1,6
Inorganic			
Glass	8	2	7,8
Tin cans	6	3	5,8
Aluminum	0,5	2	0,5
Other metal	3	3	2,9
Dirt, ash, etc	3	8	2,8
Total	**100**		**78,8**

EXAMPLE 4-3 Estimation of energy content of typical residential MSW.

- Determine the energy value of a typical residental MSW with the average composition shown in Table 3-4.
- Determine the total energy content using the data given in Table 4-5.
- Determine the as discarded energy content kg of waste
- 1178189 kJ ~ 11782 kJ/kg
  100 kg

Component	% by weight	Energy content, kJ/kg	Total Energy, kJ
Organic			
Food wastes	9	4652	41868
Paper	34	16747	569405
Cardboard	6	16282	97692
Plastics	7	32564	227948
Textiles	2	17445	34890
Rubber	0,5	23260	11630
Leather	0,5	17445	8723
Yard wastes	18,5	6513	120487
Wood	2	18608	37216
Inorganic			
Glass	8	140	1116
Tin cans	6	698	4187
Aluminum	0,5	-	-
Other metal	3	698	2093
Dirt, ash, etc	3	6978	20934
Total	**100**		**1178189**