B.Sc. Course(First Semester)

University of Babylon-College of Engineering

Environmental Engineering Department

Chapter Three (Solid Waste Management)

Physical, Chemical, And Biological Properties Of Municipal Solid Waste

The purpose of this chapter is to introduce the reader to the physical, chemical, and biological properties of MSW and to the transformations that can affect the form and composition of MSW.

3.1 Physical properties of MSW

Important physical characteristics of MSW include specific weight, moisture content, particle size and size distribution, field capacity, and compacted waste porosity. The discussion is limited to an analysis of residential, commercial, and some industrial solid wastes.

3.1.1 Specific weight

Specific weight is defined as the weight of a material per unit volume (e.g., Ib/ft^3. Ib/yd^3). (It should be noted that-specific weight expressed as Ib/yd^3 is commonly referred to in the solid waste literature incorrectly as density.

Because the specific weight of MSW is often reported as loose, as found in containers, uncompacted, compacted, and the like, the basis used for the reported values should always be noted. Specific weight data are often needed to assess the total mass and volume of waste that must be managed. Typical specific weights for various wastes as found in containers, compacted, or uncompacted are reported in Table(3.1).

Table 3.1: Typical specific weight and moisture content data for residential, commercial, industrial, and agricultural wastes.

Type of waste	Specific weight Ib/yd^3		Moisture content % by weight	
	Range	Typical	Range	Typical
Residential uncompacted				
Food wastes (mixed)	220-810	490	50-80	70
Paper	70-220	150	4-10	6
Cardboard	70-135	85	4-8	5
Plastics	70-220	110	1-4	2
Textiles	70-170	110	6-15	10

Rubber	170-340	220	1-4	- 2
Leather	170-440	270	8-12	10
Yard wastes	100-380	170	30-80	60
Wood	220-540	400	15-40	20
Glass	270-810	330	1-4	2
Tin cans	85-270	150	2-4	3
Aluminum	110-405	270	2-4	2
Other metals	220-1940	540	2-4	3
. Dirt, ashes, etc.	540-1685	810	6-12	8
Ashes	1095-1400	1255	6-12	6
Rubbish	150-305	220	. 5-20	15
Residential yard wastes				
Leaves (loose and dry)	50-250	100	20-40	30
Green grass loose and moist	350-500	400	40-80	60
Green grass wet and compacted	1000-1400	1000	50-90	80
Yard waste (shredded)	450-600	500	20-70	50
Yard waste (composted)	450-650	550	40-60	50
Municipal				
In compactor truck	300-760	500	15-40	20
In landfill				
Normally compacted	610-640	760	15-40	25
Well compacted	995-1250	1010	15-40	25

Because the specific weights of solid wastes vary markedly with geographic location, season of the year, and 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 vary from 300 to 700 Ib/yd^3; a typical value is about 500 Ib/yd^3.

3.1.2 Moisture content

The moisture content of solid wastes usually is expressed in one of two ways. In the wet-weight method of measurement, the moisture in a sample is expressed as a percentage of the wet weight of the material; in the dry-weight method, it is expressed as a percentage of the dry weight of the material. The wet-weight method is used most commonly in the field of solid waste management. In equation form, the wet-weight moisture content is expressed as follows:

$$M = \frac{A - B}{A} \times 100$$

Where:

M=moisture content,%

A=initial weight of sample as delivered, Ib(kg)

B=weight of sample after drying at 105°C, Ib(kg)

Typical data on the moisture content for the solid waste components given in Table below. The moisture content will vary from (15 to 40) percent, depending on the composition of the wastes, the season of the year, and the humidity and weather conditions, particularly rain.

Example 3.1:Estimation of moisture content of typical residential MSW

Estimate the overall moisture content of a sample of as collected residential MSW with the typical composition given Table1.

Solution:

1. Set up the computation table to determine dry weights of the solid waste components using the data given in Tabel3.1

Component	weight%	Moisture content, %	Dry weight,* Ib
Organic Food	9.0	70	2.7
Paper	34.0	6.	32.0
Cardboard	6.0	5	5.7
Plastics	7.0	2	6.9
Textiles	2.0	10	1.8
Rubber	0-5	2	0.5
Leather	0.5	10	0.4
Yard wastes	18.5	60	7.4
Wood	2.0	20	1.6
Misc. organics			
Inorganic Glass	8.0	2	7.8
Tin cans	6.0	3	5.8
Aluminum	0.5	2	0.5
Other metal	3.0	3	2.9
Dirt, ash, etc.	3.0	8	2.8
Total	100-0		78.8

Based on an as delivered sample weight of 100 1b.

$$\text{Moisture content on wet weight} = \frac{100-78.8}{100} \times 100 = 21.2\%$$

3.1.3 Particle size and distribution

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

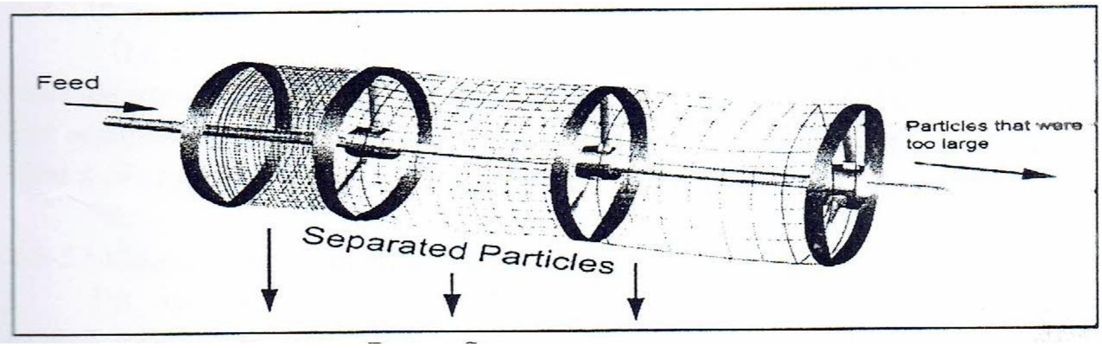


Fig.3.1 Trommel Screen or Rotary Screen

3.1.4 Field capacity

The field capacity of solid waste is the total amount of moisture that can be retained in a waste sample subject to the downward pull of gravity. The field capacity of waste materials is of critical importance in determining the formation of leachate in landfills. Water in excess of the field capacity will be released as leachate.

3.2 Chemical properties of MSW

Information on the chemical composition of the components that constitute MSW is important in evaluating alternative processing and recovery options. For example, the feasibility of combustion depends on the chemical composition of the solid wastes. If solid wastes are to be used as fuel, the four most important properties to be known are:

1. Proximate analysis.
2. Fusing point of ash

3. Ultimate analysis(major elements)
4. Energy content

3.2.1 Proximate analysis

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

1. Moisture (loss of moisture when heated to 105°C for 1 h)
2. Volatile combustible matter (additional loss of weight on ignition at 950°C in a covered crucible)
3. Fixed carbon (combustible residue left after volatile matter is removed)
4. Ash (weight of residue after combustion in an open crucible)

3.2.2 Fusing point of ash

The fusing point of 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 temperatures for the formation of clinker from solid waste range from 2000 to 2200°F (1100 to 1200°C).

3.2.3 Ultimate analysis of solid waste components

The ultimate analysis of a waste component typically involves the determination of the percent C(carbon), H(hydrogen), O(oxygen), N(nitrogen), S(sulfur), and ash. Because of the concern over the emission of chlorinated compounds during combustion, the determination of halogens is often included in an ultimate analysis. The results of the ultimate analysis 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.

Example 3.2: 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 1.

Typical data on the ultimate analysis of the combustible components in residential MSW Percent by weight (dry basis)

Organic	Carbon	Hydrogen	Oxyge	Nitrog	sulfur	Ash
Food wastes	48.0	6.4	37.6	2.6	0.4	5.0
Paper	43.5	6.0	44.0	0.3	0.2	6.0
Cardboard	44.0	5-9	44.6	0.3	0.2	5.0
Plastics	60.0	7.2	22.8	—	—	10.0
Textiles	55.0	6.6	31.2	4.6	0.15	2.5
Rubber	78.0	10.0	—	2.0	—	10.0
Leather	60.0	8.0	11.6	10.0	0.4	10.0
Yard wastes	47.8	6.0	38.0	3.4	0.3	4.5
Wood	49.5	6.0	42.7	0.2	0.1	1.5
Inorganic						
Glass	0.5	0.1	0.4	<0.1	—	98.9
Metals	4.5	0.6	4.3	<0-1	—	90.5
Dirt, ash, etc.	26.3	3.0	2.0	0.5	0.2	68.0

Solution:

1. Set up a computation table to determine the percentage distribution of the major elements composing the waste. The necessary computations are presented below:

Component	Wet weight, lb	Dry weight, lb	Composition, lb					
			C	H	O	N	S	Ash
Food wastes	9.0	2.7	1.30	0.17	1.02	0.07	0.01	0.14
Paper	34.0	32.0	13.92	1.92	14.08	0.10	0.06	1.92
Cardboard	6.0	5.7	2.51	0.34	2.54	0.02	0.01	0.28
Plastics	7.0	6.9	4.14	0.50	1.57	–	–	0.69
Textiles	2.0	1.8	0.99	0.12	0.56	0.08	–	0.05
Rubber	0.5	0.5	0.39	0.05	–	0.01	–	0.05
Leather	0.5	0.4	0.24	0.03	0.05	0.04	–	0.04
Yard wastes	18.5	6.5	3.11	0.39	2.47	0.22	0.02	0.29
Wood	2.0	1.6	0.79	0.10	0.68	–	–	0.02
Total	79.5	58.1	27.39	3.62	22.97	0.54	0.10	3.48

$$moisture\ content = 21.4\ Ib\ (79.5\ Ib - 58.1\ Ib)$$

2. Prepare a summary table of the percentage distribution of the element with the water contained in the waste.

Component	Weight, lb	
	Without H_2O	With H_2O
Carbon	27.39	27.39
Hydrogen	3.62	6.00
Oxygen	22.97	41.99
Nitrogen	0.54	0.54
Sulfur	0.10	0.10
Ash	3.48	3.48

3. Compute the molar composition of the elements neglecting the ash.

Component	Atomic weight, lb/mole	Moles	
		Without H_2O	With H_2O
Carbon	12.01	2.280	2.280
Hydrogen	1.01	3.584	5.940
Oxygen	16.00	1.436	2.624
Nitrogen	14.01	0.038	0.038
Sulfur	32.07	0.003	0.003

4. Determine an approximate chemical formula without and with sulfur and without and with water. Set up a computation table to determine normalized mole ratios.

Component	Mole ratio (Nitrogen = 1)		Mole ratio (Sulfur = 1)	
	Without H_2O	With H_2O	Without H_2O	With H_2O
Carbon	60.0	60.0	760.0	760.0
Hydrogen	94.3	156.3	1194.7	1980.0
Oxygen	37.8	69.1	478.7	874.7
Nitrogen	1.0	1.0	12.7	12.7
Sulfur	0.1	0.1	1.0	1.0

(*a*) The chemical formulas without sulfur are:

1. Without water $C_{60.0}H_{94.3}O_{37.8}N$
2. With water $C_{60.0}H_{156.3}O_{69.1}N$

(*b*) The chemical formulas with sulfur are:

1. Without water $C_{760.0}H_{1194.7}O_{478.7}N_{12.7}S$
2. With water $C_{760.0}H_{1980.0}O_{874.7}N_{12.7}S$

3.3 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.

Typical data for energy content and inert residue for the components of residential wastes are reported in table below. The Btu values given in the table may be converted to a dry basis by using Eq.(3.1).

$$Btu/Ib\ (dry\ basis) = Btu/Ib\ (as\ discarded)\left(\frac{100}{100 - \%moisture}\right) \dots\dots\dots\dots\dots\dots..(3.1)$$

The corresponding equation for the Btu per pound on a dry ash-free basis is Btu/Ib (dry ash-free basis)

$$= Btu/Ib\ (as\ discarded)\left(\frac{100}{100 - \%moisture - \%ash}\right) \dots\dots\dots\dots\dots\dots\dots\dots\dots.\dots.\dots.(3.2)$$

Table3.5:Typical values for inert residue and energy content of residential MSW

Components	Residue% After combustion	Energy Btu/lb
Organic		BTU
Food wastes	5.0	2,000
Paper	6.0	7,200
Cardboard	5.0	2,000
Plastics	10.0	14,000
Textiles	2.5	7,500
Rubber	10.0	10,000
Leather	10.0	7,500
Yard wastes	4.5	2,800
Wood	1.5	8,000
Inorganic		
Glass	98.0	60
Tin cans	98.0	300
Aluminum	96.0	—
Other metal	98.0	300
Dirt, ashes, etc.	70.0	3.000

Example3.3: Estimation of energy content of typical residential MSW.

Determine the energy value of a typical residential MSW with the average composition shown in Table (1).

Solution:

1. Assume the heating value will be computed on an as discarded basis.
2. Determine the total energy content using the data given in Table(2). The necessary computations are presented below.

Component	Solid wastes Ib	Energy Btu/Ib	Total energy Btu
Organic			
Food wastes	9.0	2,000	18,000
Paper	34.0	7,200	244,800
Cardboard	6.0	7,000	42,000
Plastics	-7.0	14,000	98,000
Textiles	2.0	7.500	15,000
Rubber	0-5	10.000	5,000
Leather	0.5	7,500	3,750
Yard wastes	18.5	2,800	51,800
Wood	2.0	8,000	16,000
Inorganic			
Glass	8.0	60	480
Tin cans	6.0	300	1,800
Aluminum	0.5	—	-
Other metal	3.0	300	900
Dirt, ashes, etc.	3.0	3.000	9.000
Total	100.0	506.530	

Determine the as discarded energy content per Ib of waste

$$Energy\ content = 505{,}530\ Btu/100Ib = (5065\ Btu/Ib) = (11{,}782\ kJ/kg)$$

The computed value compares well with the typical value given in Table3.5. If Btu values are not available, approximate Btu values for the individual waste materials can be determined by using Eq.(3.3), known as the modified Dulong formula, and the data in Tables(3.1 and 3.2).

$$Btu/Ib = 145C + 610(H_2 - 1/8\,O_2) + 40S + 10N \quad (3.3)$$

Where:

C=carbon, percent by weight

H2= hydrogen, percent by weight,

O2= oxygen, percent by weight,

S= sulfur, percent by weight,

N= nitrogen, percent by weight.

Example3.4: Estimation of energy content of typical residential MSW based on chemical composition. Determine the energy value of typical residential MSW with the average composition determined in example 3.2 including sulfur and water.

Solution:

1. The chemical composition of the waste including sulfur and water is:

$$C_{760.0}H_{1980.0}O_{874.7}N_{12.7}S$$

2. Determine the total energy content using Eq.(3.3).

a. Determine the percentage distribution by weight of the elements composing the waste, using coefficients that have been rounded off.

Component	Number of atoms / mole	Atomic weight	Weight contribution of each element	%
Carbon	760	12	9120	36.03
Hydrogen	1980	1	1980	7.82
Oxygen	875	16	14.000	55.30
Nitrogen	13	14	182	0.72
Sulfur	1	32	32	0.13
Total			25314	100.00

$$Btu/Ib = 145(36.0) + 610\left(7.8 - \frac{55.3}{8}\right) + 40(0.1) + 10(0.7)$$

$$Btu/Ib = 5772$$

Comment: The computed energy content of the waste is higher than the value computed in Example3.3 because only the organic fraction of the residential MSW was considered in Example 3.2.

<u>3.4 Biodegradability of organic waste components</u>

Volatile solids (VS)content, determined by ignition at 550°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:

$$BF = 0.83 - 0.028LC \quad \ldots\ldots\ldots (3.4)$$

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

The biodegradability of several of the organic compounds found in MSW, based on lignin content, is reported in Table (3.7).

Table3.7: 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)
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

As shown in table3.7, wastes with high lignin contents, such as newsprint, are significantly less biodegradable than the other organic wastes found in MSW. 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.

3.4.1 Production of odors

Odors can develop when solid wastes are stored for long periods of time on-site between collections, in transfer stations, and in landfills. The development of odors in on-site storage facilities is more significant in warm climates. Typically, the formation of odors results from the anaerobic decomposition of the readily decomposable organic components found in MSW. For example, under anaerobic (reducing) conditions, sulfate can be reduced to sulfide (S^{-2}), which subsequently combines with hydrogen to form H_2S The formation of H_2S can be illustrated by the following two series of reactions.

$$2CH_3CHOHCOOH(Lactate) + SO_4^{2-}(Sulfate)$$
$$\rightarrow 2CH_3COOH(Acetate) + S^{2-}(Sulfide\ ion) + H_2O + CO_2 \ldots\ldots\ldots\ldots\ldots (3.5)$$

$$4H_2 + SO_4^{2-} \rightarrow S^{2-} + 4H_2O \ldots\ldots\ldots\ldots\ldots (3.6)$$

$$S^{2-} + 2H^+ \rightarrow H_2S \ldots\ldots\ldots\ldots\ldots (3.7)$$

The sulfide ion can also combine with metal salts that may be present, such as iron, to form metal sulfides.

$$S^{2-} + Fe^{+2} \rightarrow FeS \ldots\ldots\ldots\ldots\ldots (3.8)$$

The black color of solid wastes that have undergone anaerobic decomposition in a landfill is primarily due to the formation of metal sulfides. If were not for the formation of a variety of sulfides, odor problems at landfills could be quite significant.

The biochemical reduction of an organic compound containing a sulfur radical can lead to the formation of malodorous compounds such as methyl mercaptan and amino butyric acid.

The methyl mercaptan can be hydrolyzed biochemically to methyl alcohol and hydrogen sulfide:

$$CH_3SH + H_2O \rightarrow CH_4OH + H_2S$$

<u>3.5 Physical ,Chemical, And Biological Transformations Of Solid Waste</u>

3.5.1 Physical transformations

The principal physical transformations that may occur in the operation of solid waste management systems include:

1. Component separation,
2. Mechanical volume reduction, and
3. Mechanical size reduction.

Physical transformations do not involve a change in phase(e.g., solid to gas), unlike chemical and biological transformation processes.

3.5.1.1 Component separation

Component separation is the term used to describe the process of separating, by manual and/or mechanical means. Component separation is used to transform a heterogeneous waste into a number of more-or-less homogeneous components. Component separation is a necessary operation in the recovery of reusable and recyclable materials from MSW, in the removal of contaminants from separated materials to improve specifications of the separated material, in the removal of hazardous wastes from MSW, and where energy and conversion products are to be recovered from processed wastes.

3.5.1.2 Mechanical volume reduction

Volume reduction (sometimes known as densification) is the term used to describe the process whereby the initial volume occupied by waste is reduced, usually by the application of force or pressure.

In most cities, the vehicles used for the collection of solid wastes are equipped with compaction mechanisms to increase the amount of waste collected per trip. Paper, cardboard, plastics, and aluminum and tin cans removed from MSW for recycling are baled to reduce storage volume, handling costs and shipping costs to processing centers as shown in figure3.1. At disposal sites solid wastes are compacted to use the available land effectively.

3.5.1.3 Mechanical size reduction

Size reduction is the term applied to the transformation processes used to reduce the size of the waste materials. The objective of size reduction is to obtain a final product that is reasonably uniform and considerably reduced in size in comparison with its original form. Note that size reduction does not necessarily imply volume reduction. In some situations, the total volume of the material after size reduction may be greater than that of the original volume (e.g., the shredding of office paper as shown in figure 3.2). in practice , the terms shredding, grinding, and milling are used to describe mechanical size-reduction operations.

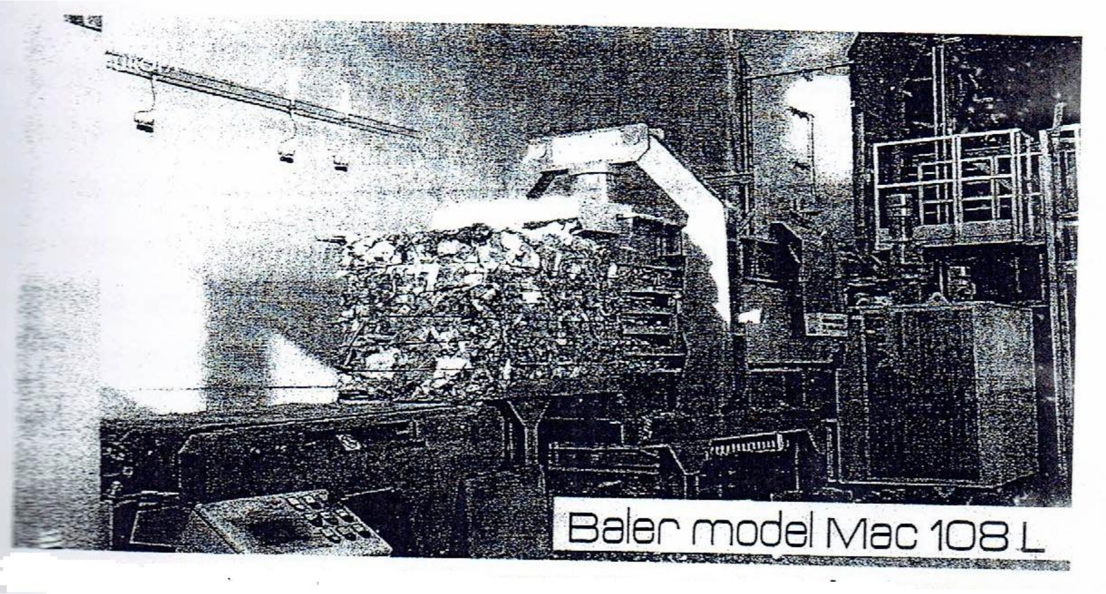


Fig.3.1: Baler to bale plastics paper, cardboard and aluminum cans.

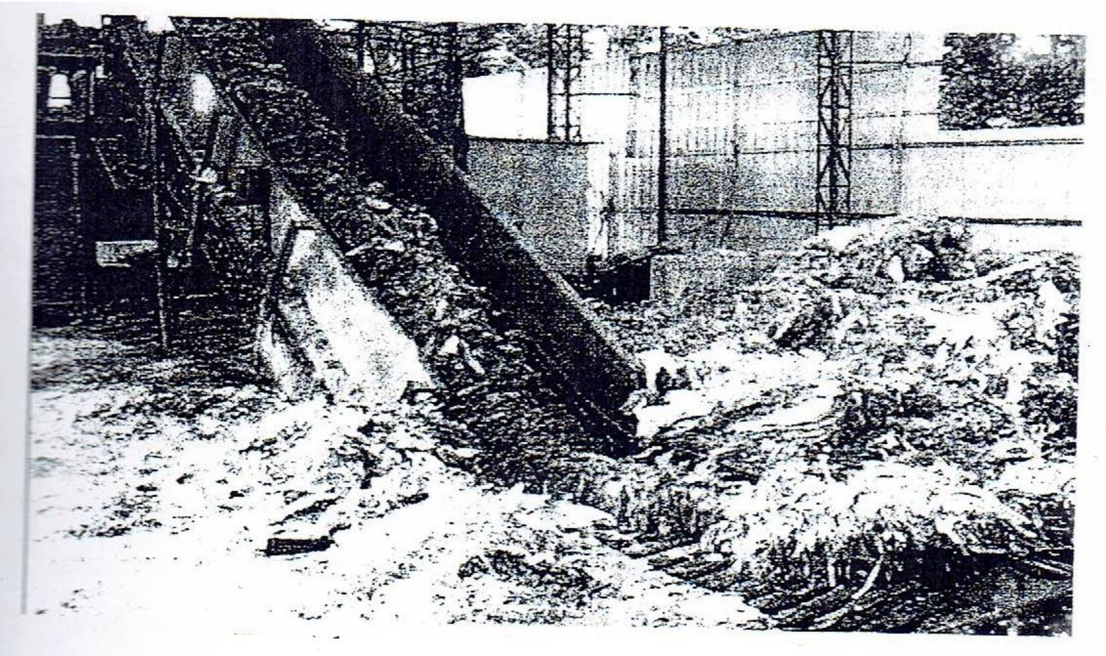


Fig.3.2: Paper and cardboard shredding.

3.5.2 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 principle chemical processes used to transform MSW include:

1. Combustion(chemical oxidation),
2. Pyrolysis, and
3. Gasification.

All three of these processes are often classified as thermal processes.

Combustion(chemical oxidation):combustion is defined as the chemical reaction of oxygen with organic materials, to produce oxidized compounds accompanied by the emission of light and rapid generation of heat. In the presence of excess air and under ideal conditions, the combustion of the organic fraction of MSW can be represented by the following equation:

$$Organic\ matter + excess\ air \rightarrow N_2 + CO_2 + H_2O + O_2 + ash + heat \ldots\ldots\ldots\ldots\ldots.\ldots (3.9)$$

Excess air is used to ensure complete combustion. The end products derived from the combustion of MSW, Eq.(3.9), include hot combustion gases-composed primarily of nitrogen(N_2), carbon dioxide(CO_2), water(H_2O, flue gas), and oxygen (O_2)-and noncombustible residue. In practice, small amounts of ammonia (NH_3). Sulfur dioxide (SO_2), nitrogen oxides (NO_x), and other trace gases will also be present, depending on the nature of the waste materials.

Pyrolysis: Because most organic substances are thermally unstable, they can be split, through a combination of thermal cracking and condensation reactions in an oxygen-free atmosphere, into gaseous, liquid, and solid fractions. In contrast with the combustion process, which is highly exothermic, the pyrolytic process is highly endothermic. For this reason, destructive distillation is often used as an alternative term for pyrolysis.

The characteristics of the three major component fractions resulting from the pyrolysis of the organic portion of MSW are:

1. A gas stream containing primarily hydrogen(H_2). Methane (CH_4), carbon monoxide (CO), carbon dioxide (CO_2), and various other gases, depending on the organic characteristics of the waste material being pyrolyzed;
2. A tar and/or oil stream that is liquid at room temperature and contains chemicals such as acetic acid, acetone, and metham and
3. A char consisting of almost pure carbon plus any inert material that may have entered the process.

Gasification: The gasification process involves partial combustion of a carbonaceous fuel so as to generate a combustible fuel gas rich in carbon monoxide, hydrogen, and some saturated hydrocarbons, principally methane. The combustible fuel gas can then be combusted in an internal combustion engine or boiler. When a gasifier is operated at atmospheric pressure with air as the oxidant, the end products of the gasification process are:

1. A low-Btu gas typically containing carbon dioxide (CO_2), carbon monoxide (CO), hydrogen(H_2), methane (CH_4). And nitrogen (N_2);
2. A char containing carbon and the inerts originally in the fuel, and
3. Condensable liquids resembling pyrolytic oil as shown in figure3.3.

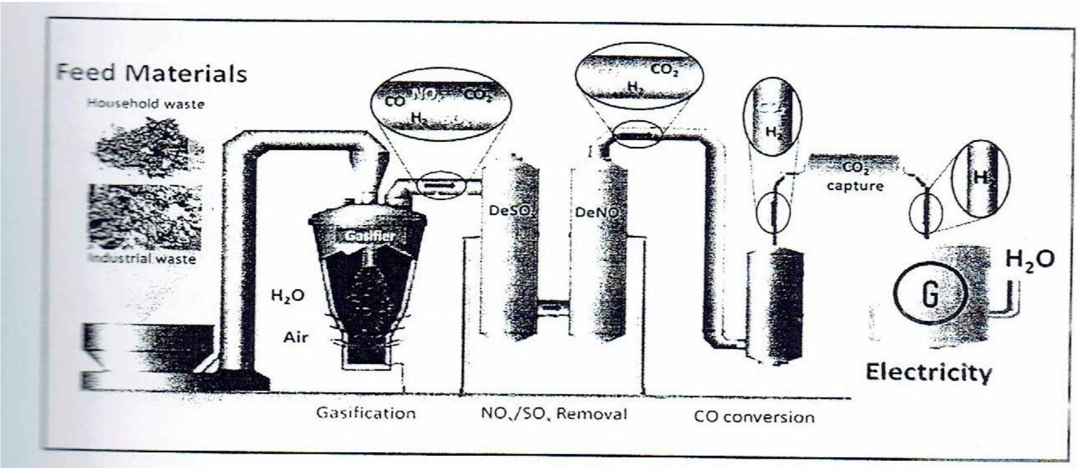


Fig3.3: Pyrolysis Process

Other chemical transformation processes: The hydrolytic conversion of cellulose to glucose, followed by the fermentation of glucose to ethyl alcohol, is an example of such a process.

3.5.3 Biological transformations

The biological transformations of the organic fraction of MSW may be used to reduce the volume and weight of the material; to produce compost, a humus-like material that can be used as a soil conditioner; and to produce methane. The principal organisms involved in the biological transformations of organic wastes are bacteria, fungi, yeasts, and actinomycetes. These transformations may be accomplished either aerobically or anaerobically depending on the availability of oxygen. The principal differences between the aerobic and anaerobic conversion reactions are the nature of the end products and the fact oxygen must be provided to accomplish the aerobic conversion. Biological processes that have been used for the conversion of the organic fraction of MSW include aerobic composting, anaerobic digestion, and high-solids anaerobic digestion.

3.5.3.1 Aerobic composting:

The organic fraction of MSW will undergo biological decomposition. The extent and the period of time over which the decomposition occurs will depend on the nature of the waste, the moisture content, the available nutrients, and other environmental factors. Yard wastes and the organic fraction of MSW can he converted to a stable organic residue known as compost (see Fig.3.4 and Fig.3.5) in a reasonably short period of time(four to six weeks).

Composting the organic fraction of MSW under aerobic conditions can be represented by the following equation:

$$Organic\ matter + O_2 + nutrients \rightarrow new\ cells + Resistant\ organic\ matter + CO_2 + H_2O + NH_3 + SO_2 + heat \ldots\ldots \quad (3.10)$$

In Eq.(3.10), the principal end products are new cells, resistant organic matter, carbon dioxide, water, ammonia, and sulfate. Compost is the resistant organic matter that remains. The resistant organic matter usually contains a high percentage of lignin, which is difficult to convert biologically in a relatively short time. Lignin, found most commonly in newsprint, is the organic polymer that holds together the cellulose fibers in trees and certain plants.

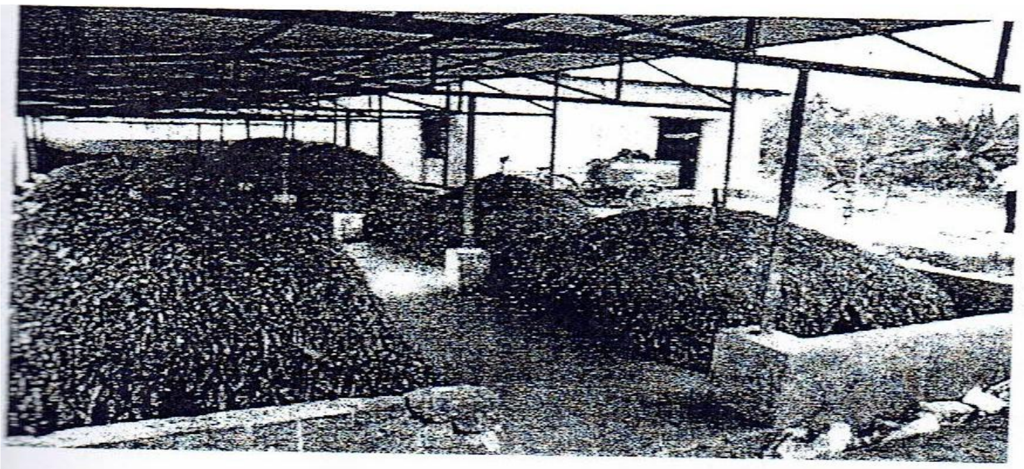


Fig.3.4:Aerobic composting

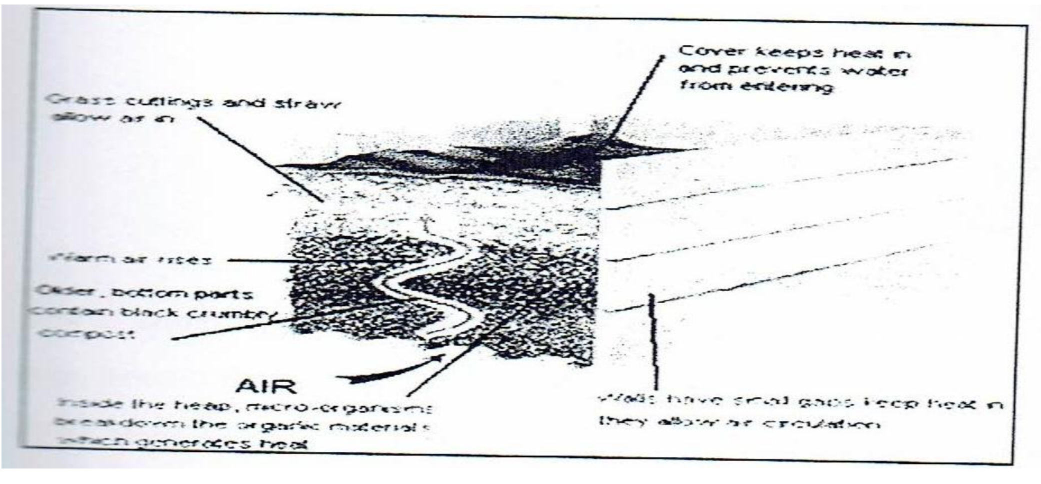
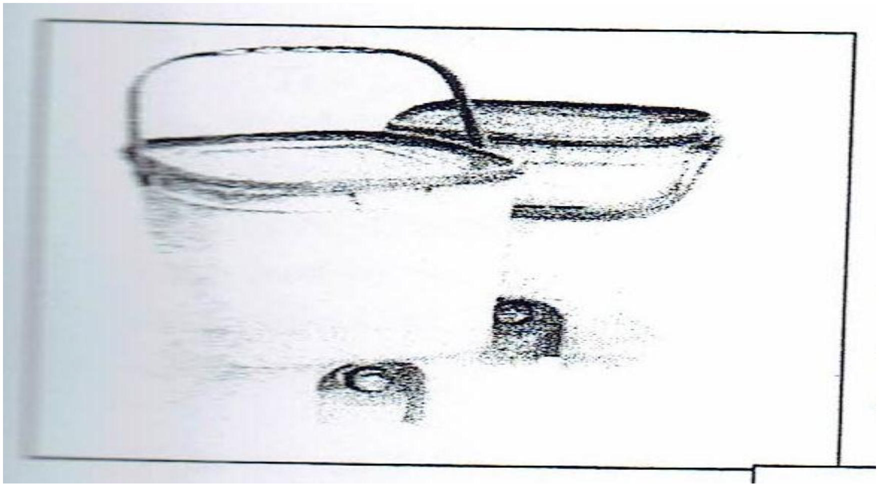


Fig.3.5:Aerobic composting

3.5.3.2 Anaerobic digestion: The biodegradable portion of the organic fraction of MSW can be converted biologically under anaerobic conditions to a gas containing carbon dioxide and methane (CH_4). This conversion can be represented by the following equation:

$$Organic\ matter + H_2O + nutrients \rightarrow new\ cells + Resistant\ organic\ matter + CO_2 + CH_4 + NH_3 + H_2S + heat \ldots \quad (3.11)$$

Thus, the principal end products are carbon dioxide, methane, ammonia, hydrogen sulfide and resistant organic matter. In most anaerobic conversion processes carbon dioxide and methane constitute over 99 percent of the total gas produced.



3.5.4 Recovery of materials for reuse and recycling: As a practical matter, components that are most amenable to recovery are those for which markets exist and which are present in the wastes in sufficient quantity to justify their separation. Materials most often recovered from MSW include paper, cardboard, plastic, garden trimmings, glass, ferrous metal, aluminum, and other nonferrous metal.