Physical, chemical, and biological transformations of solid waste

Engineering for Solid Waste Treatment

Physical transformation

- Do not involve a change in phase: component separation, mechanical volume reduction, mechanical size reduction
- Component separation
  - Transform a heterogeneous waste into a number of more or less homogeneous components
  - 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
- Mechanical volume reduction (densification)
  - The process whereby the initial volume occupied by a waste is reduced, usually by the application of force or pressure



- Mechanical size reduction:
  - To obtain a final product that is reasonably uniform and considerably reduced in size in comparison with its original form
  - Does not necessarily imply volume reduction
  - Shredding, grinding, and milling



Chemical transformation

- Involve a change of phase (e.g. solid to liquid, solid to gas, etc.)
- Combustion (chemical oxidation)
  - The chemical reaction of oxygen with organic materials, to produce oxidized compounds accompanied by the emission of light and rapid generation of heat.

$$\text{Organic matter} + \text{excess air} \rightarrow N_2 + CO_2 + H_2O + O_2 + \text{ash} + \text{heat}$$

  - In practice, small amounts of ammonia (NH_3), sulfur dioxide (SO_2), nitrogen oxides (NO_x), and other trace gases



- Pyrolysis (destructive distillation)
  - A combination of thermal cracking and condensation reactions in an oxygen-free atmosphere, into gaseous, liquid, and solid fractions.
  - Highly endothermic.
  - Three major component fractions resulting from pyrolysis
    - 1) A gas stream containing primarily hydrogen, methane, carbon monoxide, carbon dioxide, and various other gases
    - 2) A tar/oil stream containing acetic acid, acetone, and methanol
    - 3) A char containing almost pure carbon plus any inert materials

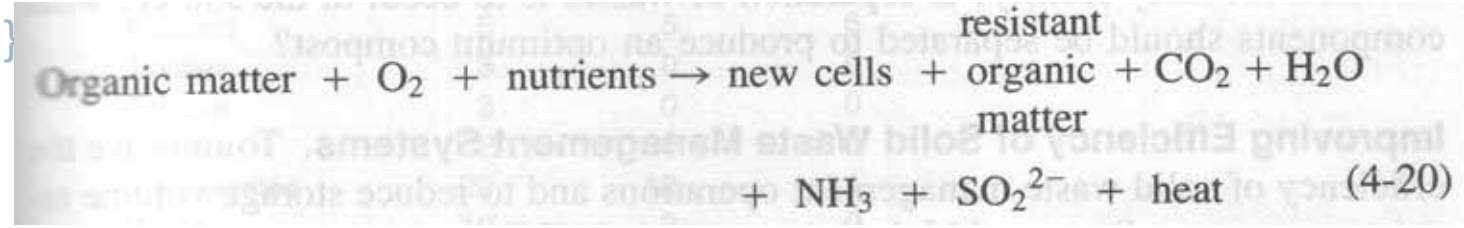
$$3(C_6H_{10}O_5) \rightarrow 8H_2O + C_6H_8O + 2CO + 2CO_2 + CH_4 + H_2 + 7C$$



- Gasification
  - Involve 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 end products are 1) a low-Btu gas (carbon dioxide, carbon monoxide, hydrogen, methane, nitrogen), 2) a char containing carbon and the inerts, and 3) condensible liquids (pyrolytic oil)
- Others
  - The hydrolytic conversion of cellulose to glucose, followed by the fermentation of glucose to ethyl alcohol (see Chapter 14)



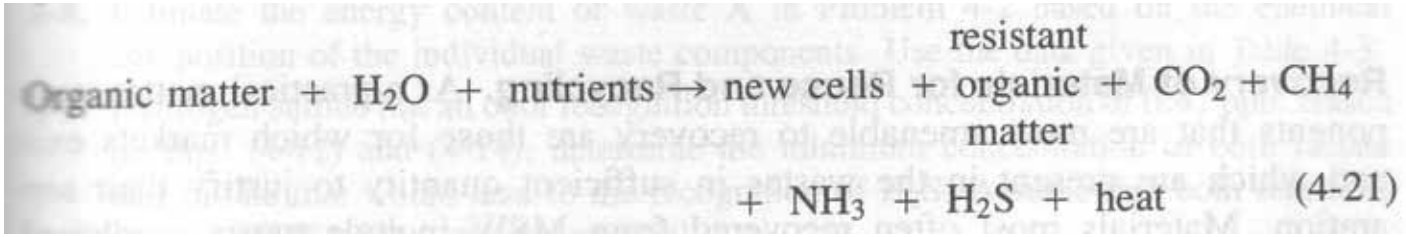
Biological transformation

- Reduce the volume and weight
- Produce compost(a humus-like materials: soil conditioner)
- Produce methane
- Aerobic composting
  - Composting under aerobic conditions
  - 

  - The resistant organic matter: Compost
  - The resistant organic matter usually contains a high percentage of lignin



- Anaerobic digestion



  - The resistant organic matter (or digested sludge) must be dewatered before it can be disposed of by land spreading or landfilling
  - Dewatered sludge is often composted aerobically to stabilize it further



Sources, types, and properties of hazardous wastes found in MSW

Engineering for Solid Waste Treatment

- Three general categories
- Listed wastes: it is presumed toxic regardless of the concentration
- Characteristic hazardous wastes
- Other hazardous wastes



Properties and classification of hazardous wastes

- Safety-related properties
  - **Corrosivity**, Explosivity, Flammability, **Ignitability**, **Reactivity**
- Health-related properties
  - **Carcinogenicity**, Infectivity, Irritant(allergic response), Mutagenicity, **Toxicity**(poisons: acute toxicity, chronic toxicity), Radioactivity, Teratogenicity

- Properties to defined hazardous waste



Hazardous characteristics

Characteristic	40 CRF subpart[a]	Considerations	Hazard code
Ignitability	261.21	1. Liquids with flashpoints of less than 140°F (60°C) 2. Nonliquids liable to cause fires through friction, spontaneous chemical change, etc. 3. Ignitable compressed gas 4. Is an oxidizer	I
Corrosivity	261.22	1. Aqueous wastes exhibiting a pH of <3 or >12.5 2. Liquid wastes capable of corroding steel at a rate greater than 0.250 in/year	C
Reactivity	261.23	1. Instability and readiness to undergo violent change 2. Violent reactions when mixed with water 3. Formation of potentially explosive mixtures when mixed with water 4. Generation of toxic fumes when mixed with water 5. Cyanide or sulfide-bearing material that generates toxic fumes when exposed to acidic conditions 6. Ease of detonation or explosive reaction when exposed to pressure or heat 7. Ease of detonation or explosive decomposition or reaction at standard temperature and pressure 8. Defined as a forbidden explosive or a Class A or B explosive by U.S. Department of Transportation	R

(From Tchobanoglous et al.,1993)

Toxicity characteristic (TC), as defined by the toxicity characteristics leaching procedure test (TCLP)	261.24	The following steps are required in the TCLP test: 1. If the waste is liquid (i.e., contains less than 0.5% solids), after it is filtered the waste itself is considered the extract (simulated leachate). 2. If the waste contains greater than 0.5% solid material, the solid phase is separated from the liquid phase, if any. If required, the particle size of the solid phase is reduced until it passes through a 9.5 mm sieve. 3. For analysis other than for volatiles, the solid phase is then placed in an acidic solution and rotated at 30 rev/min for 18 hours. The pH of the solution is approximately 5, unless the solid is more basic, in which case a solution with a pH of approximately 3 is used. After extraction (rotation), solids are filtered from the liquid extract and discarded. 4. For volatiles analysis a solution of pH 5 is used, and a zero headspace extraction vessel is used for liquid/solid separation, agitation, and filtration. 5. Liquid extracted from the solid/acid mixture is combined with any original liquid separated from the solid material and is analyzed for the presence of specified contaminants. 6. If *any* of the contaminants in the extract meets or exceeds any of the maximum concentration levels allowed for the specified contaminants, the waste is classified as a TC hazardous waste.	E

(From Tchobanoglous et al.,1993)

- Other hazardous wastes
  - The mixtures of hazardous and nonhazardous wastes
  - Wastes derived from the management of other wastes, such as treatment plant residues (Derived-From Rule)
  - Hazardous materials contained in nonhazardous wastes (Contained-In Rule)
  - Medical wastes
  - Low-level radioactive mixed wastes



Typical hazardous wastes from residential sources

Product	Concern	Disposal
Household cleaners		
Abrasive scouring powders	Corrosive	Hazardous waste facility
Aerosols	Flammable	Hazardous waste facility
Ammonia and ammonia-based cleaners	Corrosive[b]	Hazardous waste facility, or dilute small amounts
Chlorine bleach	Corrosive[a]	Hazardous waste facility, or dilute small amounts
Drain openers	Corrosive	Hazardous waste facility
Furniture polish	Flammable	Hazardous waste facility
Glass cleaners	Irritant	Dilute small amounts
Outdated medicines	Hazardous to others in family	Dilute small amounts and flush down toilet
Oven cleaner	Corrosive	Hazardous waste facility
Shoe polish	Flammable	Hazardous waste facility
Silver polish	Flammable	Hazardous waste facility
Spot remover	Flammable	Hazardous waste facility
Toilet bowl cleaner	Corrosive	Hazardous waste facility
Upholstery and carpet cleaner	Flammable and/or corrosive	Hazardous waste facility
Personal care products		
Hair-waving lotions	Poison	Dilute small amounts and flush down toilet
Medicated shampoos	Poison	Dilute small amounts and flush down toilet
Nail polish remover	Poison, flammable	Hazardous waste facility
Rubbing alcohol	Poison	Dilute small amounts and flush down toilet

(From Tchobanoglous et al.,1993)

Product	Concern	Disposal
Automotive products		
Antifreeze	Poison	Hazardous waste facility
Brake and transmission fluid	Flammable	Hazardous waste facility
Car batteries	Corrosive	Recycling center/repair
Diesel fuel	Flammable	Recycling center
Kerosene	Flammable	Recycling center
Gasoline	Flammable, poison	Hazardous waste facility
Waste oil	Flammable	Recycling center
Paint products		
Enamel, oil-based, latex or water-based paints	Flammable	Donate or hazardous waste facility
Paint solvents and thinners	Flammable	Reuse or hazardous waste facility
Miscellaneous products		
Batteries	Corrosive	Recycling center or hazardous waste facility
Photographic chemicals	Corrosive, poison	Hazardous waste facility, or donate to photo shop
Pool acids and chlorine	Corrosive	Hazardous waste facility
Pesticides, herbicides, and fertilizers		
Including garden insecticides, ant and roach killers, weed killers, etc.	Poison: some are flammable	Hazardous waste facility or County Department of Agriculture
Chemical fertilizers	Poison	Hazardous waste facility or County Department of Agriculture
Houseplant insecticide	Poison	Hazardous waste facility

(From Tchobanoglous et al.,1993)

Hazardous waste compounds from commercial, industrial, and agricultural sources

Name	Formula or symbol	Use	Concern
Nonmetals			
Arsenic	As	Alloying additive for metals, especially lead and copper as shot, battery grids, cable sheaths, boiler tubes	Carcinogen and mutagen. Long-term: Sometimes can cause fatigue and loss of energy; dermatitis
Selenium	Se	Electronics, xerographic plates, TV cameras, photocells, magnetic computer cores, solar batteries, rectifiers, relays, ceramics (colorant for glass), steel and copper, vulcanizing agent, catalyst, trace element in animal feeds	Long-term: Red staining of fingers, teeth, and hair; general weakness; depression; irritation of nose and mouth
Metals			
Barium	Ba	Getter alloys in vacuum tubes, deoxidizer for copper, Frary's metal, lubricant for anode rotors in x-ray tubes, spark plug alloys	Flammable at room temperature in powder form. Long-term: Increased blood pressure and nerve block
Cadmium	Cd	Electrodeposited and dipped coatings on metals, bearing and low-melting alloys, brazing alloys, fire protection system, nickel-cadmium storage batteries, power transmission wire, TV phosphors, basis of pigments used in ceramic glazes, machinery enamels, fungicide, photography and lithography, selenium rectifiers, electrodes for cadmium-vapor lamps and photoelectric cells	Flammable in powder form. Toxic by inhalation of dust or fume. A carcinogen. Soluble compounds of cadmium are highly toxic. Long-term: Concentrates in the liver, kidneys, pancreas, and thyroid; hypertension suspected effect
Chromium	Cr	Alloying and plating element on metal and plastic substrates for corrosion resistance, chromium-containing and stainless steels, protective coating for automotive and equipment accessories, nuclear and high-temperature research, constituent of inorganic pigments	Hexavalent chromium compounds are carcinogenic and corrosive on tissue. Long-term: Skin sensitization and kidney damage
Lead	Pb	Storage batteries, gasoline additive, paint pigments, cable covering, ammunition, piping, tank linings, solder and fusible alloys, vibration damping in heavy construction, foil, babbitt, and other bearing alloys	Toxic by ingestion or inhalation of dust or fumes. Long-term: Brain, nervous system, and kidney damage; birth defects

(*continued*)

(From Tchobanoglous et al.,1993)

Name	Formula or symbol	Use	Concern
Metals (*cont.*)			
Mercury	Hg	Amalgams, catalyst, electrical apparatus, cathodes for production of chlorine and caustic soda, instruments, mercury-vapor lamps, mirror coating, arc lamps, boilers	Highly toxic by skin absorption and inhalation of fume or vapor. Long-term: Toxic to central nervous system; may cause birth defects
Silver	Ag	Manufacture of silver nitrate, silver bromide, photo chemicals; lining vats and other equipment for chemical reaction vessels, water distillation, etc.; mirrors, electric conductors, silver plating, electronic equipment; sterilant; water purification; surgical cements; hydration and oxidation catalyst, special batteries, solar cells, reflectors for solar towers; low-temperature brazing alloys; table cutlery; jewelry; dental, medical, and scientific equipment; electrical contacts; bearing metal; magnet windings; dental amalgams. Colloidal silver is used as a nucleating agent in photography and medicine, often combined with protein	Toxic metal. Long-term: Permanent grey discoloration of skin, eyes, and mucous membranes
Organic compounds			
Benzene[b] (Benzol)	C_6H_6	Manufacturing of ethylbenzene (for styrene monomer); dodecylbenzene (for detergents); cyclohexane (for nylon); phenol; nitrobenzene (for aniline); maleic anhydride; chlorobenzene hexachloride; benzene sulfonic acid; as a solvent	A carcinogen. Highly toxic. Flammable; dangerous fire risk
Ethylbenzene[b] (Phenylethane)	$C_6H_5C_2H_5$	Intermediate in production of styrene; solvent	Toxic by ingestion, inhalation, and skin absorption; irritant to skin and eyes. Flammable, dangerous fire risk
Toluene[b] (Methylbenzene)	$C_6H_5CH_3$	Aviation gasoline and high-octane blending stock; manufacture of benzene, phenol, and caprolactam; solvent for paints and coatings, gums, resins, most oils, rubber, vinyl organosols; diluent and thinner in nitrocellulose lacquers; adhesive solvent in plastic toys and model airplanes; chemicals (benzoic acid, benzyl and benzoyl derivatives, saccharine, medicines, dyes, perfumes); source of toluenediisocyanates (polyurethane resins); explosives (TNT); toluene sulfonates (detergents); scintillation counters	Flammable, dangerous fire risk. Toxic by ingestion, inhalation, and skin absorption

(From Tchobanoglous et al.,1993)

Halogenated compounds			
Chlorobenzene (Phenylchloride)	C_6H_5Cl	Phenol, chloronitrobenzene, aniline, solvent carrier for methylene diisocyanate, solvent, pesticide intermediate, heat transfer	Moderate fire risk. Toxic by inhalation and skin contact
Chloroethene[b] (Vinyl chloride)	CH_2CHCl	Polyvinyl chloride and copolymers, organic synthesis, adhesives for plastics	Extremely toxic and hazardous by all avenues of exposure. A carcinogen
Dichloromethane[b] (Methylene chloride)	CH_2Cl_2	Paint removers, solvent degreasing, plastics processing, blowing agent in foams, solvent extraction, solvent for cellulose acetate	Toxic. A carcinogen, narcotic
Tetrachloroethene (Tetrachloroethylene, perchloroethylene)	CCl_2CCl_2	Dry-cleaning solvent, vapor-degreasing solvent, drying agent for metals and certain other solids, vermifuge, heat transfer medium, manufacture of fluorocarbons	Irritant to eyes and skin
Pesticides, herbicides, insecticides[c]			
Endrin™	$C_{12}H_8OCl_6$	Insecticide and fumigant	Toxic by inhalation and skin absorption, carcinogen
Lindane™	$C_6H_6Cl_6$	Pesticide	Toxic by inhalation, ingestion, skin absorption
Methoxychlor™	$Cl_3CCH(C_6H_4OCH_3)_2$	Insecticide	Toxic material
Toxaphene™	$C_{10}H_{10}Cl_8$, approximately	Insecticide and fumigant	Toxic by ingestion, inhalation, skin absorption
Silvex	$Cl_3C_6H_2OCH(CH_3)COOH$	Herbicide, plant growth regulator	Toxic material; use has been restricted

(From Tchobanoglous et al.,1993)



- Significance of hazardous wastes in MSW
  - The small amounts of hazardous wastes found in MSW are of significance because of their occurrence in all solid waste management facilities and their persistence when discharged to the environment.
  - Long-term persistence

Typical compounds	Hazards
Nonpersistent organic wastes Oil, low molecular-weight solvents, some biodegradable pesticides (organophosphates, carbamates, triazines, anilines, ureas), waste oils, most detergents	Toxicity problems primarily to environment and biota at the source or point of release. Toxic effects occur rapidly after exposure (acute and subacute).
Persistent organic wastes High molecular-weight chlorinated and aromatic hydrocarbons, some pesticides (chlorinated insecticides like hexachlorobenzene, DDT, DDE, lindane); PCBs, phthalates	Immediate toxic effects (acute and subacute) may occur at the source or point of release. Long-term chronic toxicity may result. Transport of organic waste from the source can result in widespread contamination and bioconcentration in the food chain. Environmental transport may expose biota to lower levels of the pollutant, resulting in chronic toxicity.

(From Tchobanoglous et al.,1993)

- The half-life concept if assumed as the first-order

$$\frac{d[C]}{dt} = -k_T C$$

where $[C]$ = concentration at time t
t = time
k_T = first order reaction rate constant

$$\ln \frac{[C_o]}{[C]} = k_T t$$

where $[C_o]$ = concentration at time zero

$$t_{1/2} = \frac{\ln 2}{k_T} = \frac{0.69}{k_T}$$



Physical, chemical, and biological transformations of hazardous waste constituents found in MSW

- Physical transformation: volatilization and phase distribution
- Volatilization
  - Volatilization of chemical wastes(a function of exposed surface area, time, diffusion coefficients, vapor pressures, molecular weight, and temperature)
  - Volatilization of liquid chemical wastes in water and leachate (Henry's law constant, temperature, liquid turbulence, trace constituent concentration in the gas phase, and wind speed)
  - Volatilization of chemical wastes adsorbed on soil or other solids(surface area, strength of adsorption, vapor pressure, and type of soil or solid)
  - Other factors(pH, solubility, the amount and type of organics present, the size of particles, the density of the solid wastes, reactivity, and leaching)



- Chemical transformation
  - Chemical reactions in combustion: If the combustion process is not ideal, the products of incomplete combustion can be quite varied and toxic.
  - Chemical reactions in landfills: simple substitution, dehydrogenation(hydrolysis), oxidation(auto-oxidation), reduction
- Biological transformation
  - Involving biodegradable organic compounds
  - Involving persistent organic compounds (e.g. dehalogenation, ring cleavage, etc)

- Management of hazardous wastes in MSW
  - The most effective way to eliminate the small quantities of hazardous wastes now found in municipal solid waste is to separate them at the point of generation.



Solid waste generation and collection rates

Engineering for Solid Waste Treatment

- Importance of waste quantities
  - In selecting specific equipment
  - In designing of waste collection routes, materials recovery facilities (MRFs), and disposal facilities
- Measures and methods used to assess solid waste quantities
- Measures used to quantify solid waste quantities
  - Volume and weight: volume must be related to either the degree of compaction of the wastes or the specific weight of the waste under the conditions of storage. Note that volume and weight are equally important with respect to the capacity of landfills.



- Methods used to estimate waste quantities: load-count analysis, weight-volume analysis, materials-balance analysis
- 1) Load-count analysis
- 2) Weight-volume analysis



Example 6-1 Estimation of unit solid waste generation rates for a residential area. From the following data estimate the unit waste generation rate per week for a residential area consisting of 1200 homes. The observation location is a local transfer station that receives all of the wastes collected for disposal. The observation period was one week.

1. Number of compactor truck loads = 9
2. Average size of compactor truck = 20 yd^3
3. Number of flatbed loads = 7
4. Average flatbed volume = 2 yd^3
5. Number of loads from individual residents' private cars and trucks = 20
6. Estimated volume per domestic vehicle = 8 ft^3

Solution

1. Set up the computation table to estimate the total weight. Use the specific weight data given in Table 4-1 to convert the measured waste volumes to weight.

Item	Number of loads	Average volume, yd^3	Specific weight,[a] lb/yd^3	Total weight, lb
Compactor truck	9	20	500	90,000
Flatbed truck	7	2	225	3,150
Individual private vehicle	20	0.30	150	900
Total, lb/wk				94,050

[a]Based on limited on-site weight and volume measurements.

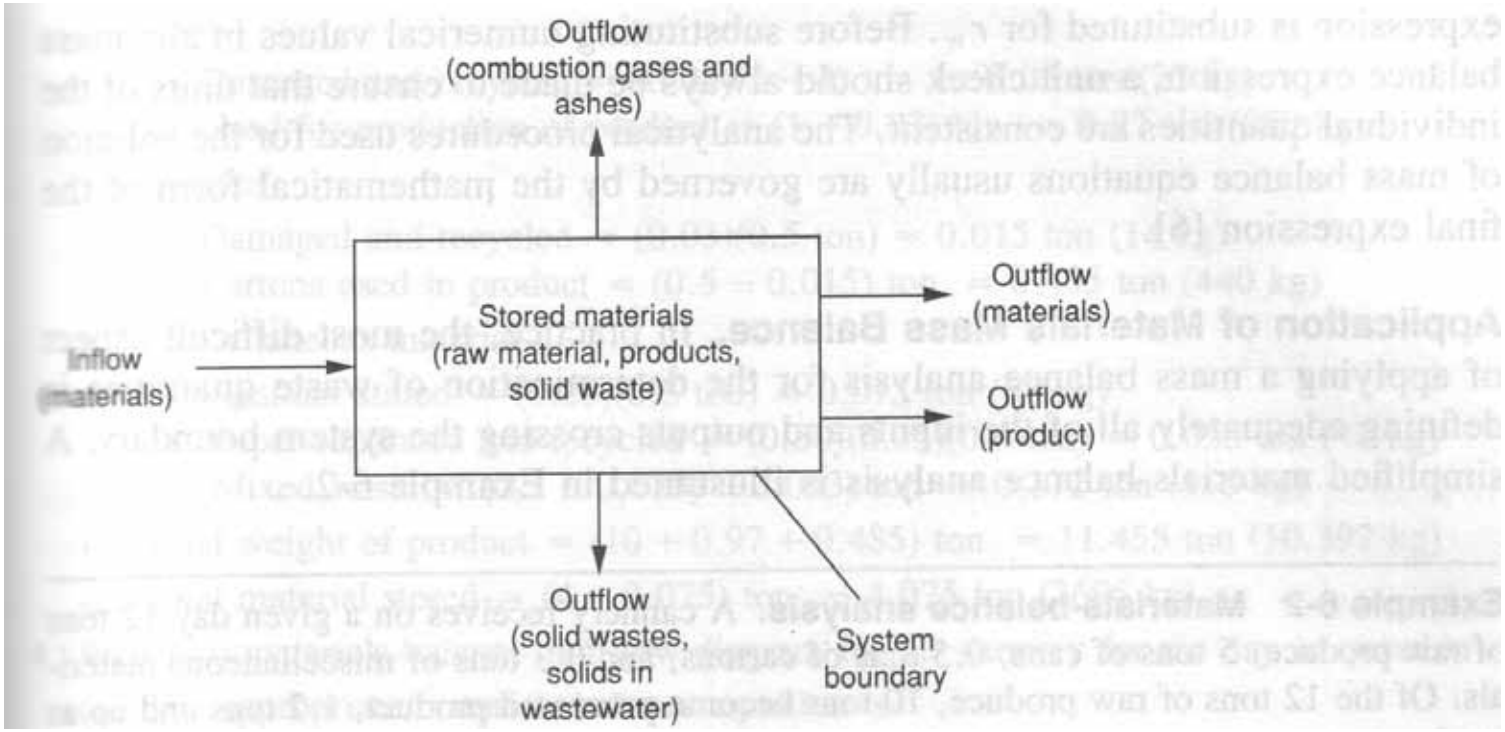
2. Determine the unit waste collection rate based on the assumption that each household is comprised of 3.5 people.

$$\text{Unit rate} = \frac{94{,}050 \text{ lb/wk}}{(1200 \times 3.5)(7 \text{ d/wk})}$$

$$= 3.2 \text{ lb/capita} \cdot \text{d} = 1.45 \text{ kg/capita} \cdot \text{d}$$

(From Tchobanoglous et al.,1993)

Materials mass balance analysis



(From Tchobanoglous et al.,1993)

1. General word statement:

$$\begin{array}{l}\text{Rate of accumulation of material within the system boundary}\end{array} = \begin{array}{l}\text{rate of flow of material into the system boundary}\end{array} - \begin{array}{l}\text{rate of flow of material out of the system boundary}\end{array} + \begin{array}{l}\text{rate of generation of waste material within the system boundary}\end{array} \quad (6\text{-}1)$$

2. Simplified word statement:

$$\text{Accumulation} = \text{inflow} - \text{outflow} + \text{generation} \quad (6\text{-}2)$$

3. Symbolic representation (refer to Fig. 6-3):

$$\frac{dM}{dt} = \Sigma M_{\text{in}} - \Sigma M_{\text{out}} + r_w \quad (6\text{-}3)$$

where dM/dt = rate of change of the weight of material stored (accumulated) within the study unit, lb/d

ΣM_{in} = sum of all of the material flowing into study unit, lb/d

ΣM_{out} = sum of all of the material flowing out of study unit, lb/d

r_w = rate of waste generation, lb/d

t = time, d



Example

Example 6-2 Materials-balance analysis. A cannery receives on a given day 12 tons of raw produce, 5 tons of cans, 0.5 tons of cartons, and 0.3 tons of miscellaneous materials. Of the 12 tons of raw produce, 10 tons become processed product, 1.2 tons end up as produce waste, which is fed to cattle, and the remainder is discharged with the wastewater from the plant. Four tons of the cans are stored internally for future use, and the remainder is used to package the product. About 3 percent of the cans used are damaged. Stored separately, the damaged cans are recycled. The cartons are used for packaging the canned product, except for 5 percent that are damaged and subsequently separated for recycling. Of the miscellaneous materials, 25 percent is stored internally for future use; 50 percent becomes waste paper, of which 35 percent is separated for recycling with the remainder being discharged as mixed waste; and 25 percent becomes a mixture of solid waste materials. Assume the materials separated for recycling and disposal are collected daily. Prepare a materials balance for the cannery on this day and a materials flow diagram accounting for all of the materials. Also determine the amount of waste per ton of product.

(From Tchobanoglous et al.,1993)



Solution

1. On the given day, the cannery receives

   12 tons of raw produce
   5 tons of cans
   0.5 tons of cartons
   0.3 tons of miscellaneous materials

2. As a result of internal activity,
   (*a*) 10 tons of product is produced, 1.2 tons of produce waste is generated, and the remainder of the produce is discharged with the wastewater
   (*b*) 4 tons of cans are stored and the remainder is used, of which 3 percent are damaged
   (*c*) 0.5 tons of cartons are used of which 3 percent are damaged
   (*d*) 25 percent of the miscellaneous materials is stored; 50 percent becomes paper waste, of which 35 percent is separated and recycled, with the remainder disposed of as mixed solid waste; the remaining 25 percent of the miscellaneous materials are disposed of as mixed waste.
3. Determine the required quantities
   (*a*) Wastes generated from raw produce
      i. Solid waste fed to cattle = 1.2 ton (1089 kg)
      ii. Waste produce discharged with wastewater = (12 − 10 − 1.2) ton = 0.8 ton (726 g)

(From Tchobanoglous et al.,1993)



(*b*) Cans

i. Damaged and recycled = (0.03)(5 − 4) ton = 0.03 ton (27 kg)

ii. Used for production of product = (1 − 0.03) ton = 0.97 ton (880 kg)

(*c*) Cartons

i. Damaged and recycled = (0.03)(0.5 ton) = 0.015 ton (14 kg)

ii. Cartons used in product = (0.5 − 0.015) ton = 0.485 ton (440 kg)

(*d*) Miscellaneous material

i. Amount stored = (0.25)(0.3 ton) = 0.075 ton (68 kg)

ii. Paper separated and recycled = (0.50)(0.35)(0.3 ton) = 0.053 ton (48 kg)

iii. Mixed waste = (0.3 − 0.075) − 0.053) ton = 0.172 ton (156 kg)

(*e*) Total weight of product = (10 + 0.97 + 0.485) ton = 11.455 ton (10,392 kg)

(*f*) Total material stored = (4 + 0.075) ton = 4.075 ton (3696 kg)

4. Prepare a materials balance and flow diagram for the cannery for the day in question

(*a*) The appropriate materials balance equation is

Amount of material stored = inflow − outflow − waste generation

(From Tchobanoglous et al.,1993)



(*b*) The materials balance quantities are as follows:

i. Material stored = (4.0 + 0.075) ton = 4.075 ton

ii. Material input = (12.0 + 5.0 + 0.5 + 0.3) ton = 17.8 ton

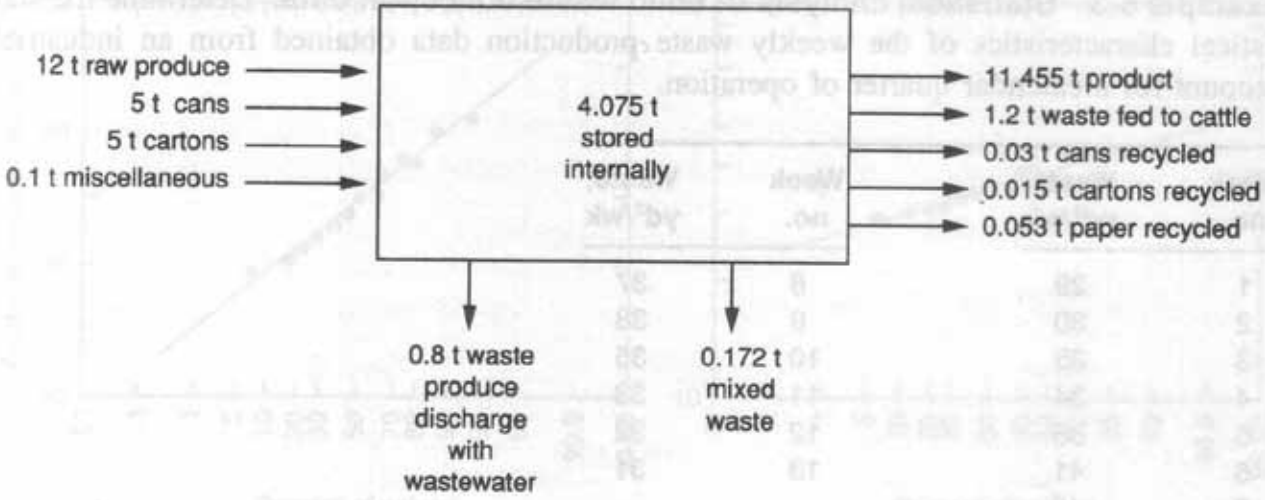
iii. Material output = (10.0 + 0.97 + 0.485 + 1.2 + 0.03 + 0.015 + 0.053) ton = 12.753 ton

iv. Waste generation = (0.8 + 0.172) ton = 0.972 ton

v. The final materials balance is

$$4.075 = 17.8 - 12.753 - 0.972 \text{ (mass balance checks)}$$

(*c*) Materials balance flow diagram is given below



5. Determine the amount of waste per ton of product:

(*a*) Recyclable material = (1.2 + 0.03 + 0.015 + 0.053) ton/11.455 ton = 0.11 ton/ton

(*b*) Mixed waste = (0.8 + 0.172) ton/11.455 ton = 0.085 ton/ton

(From Tchobanoglous et al.,1993)

Solid waste generation and collection rates

- Solid waste generation

Waste category[b]	Distribution of MSW, percent of total		Solid waste generation rate			
			lb/capita · yr		lb/capita · d	
	Range	Typical	Range	Typical	Range	Typical
Residential and commercial, excluding special and hazardous wastes	50–75	62.0	1125–1700	1395.0	3.1–4.7	3.82
Special (bulky items, consumer electronics, white goods, yard wastes collected separately, batteries, oil, and tires)	3–12	5.0	65–180	112.5	0.2–0.5	0.31
Hazardous	0.01–1.0	0.1	0.15–30	2.3	0.0004–0.082	0.0063
Institutional	3–5	3.4	65–110	76.5	0.2–0.3	0.21
Construction and demolition	8–20	14.0	180–450	315.0	0.5–1.2	0.86
Municipal services						
Street and alley cleanings	2–6	3.8	45–135	85.5	0.1–0.4	0.23
Tree and landscaping	2–5	3.0	45–110	67.5	0.1–0.3	0.19
Parks and recreational areas	1.5–3	2.0	30–65	45.0	0.08–0.2	0.12
Catch basin	0.5–1.2	0.7	10–30	15.7	0.03–0.08	0.04
Treatment plant sludges	3–8	6.0	68–180	135.0	0.2–0.5	0.37
Total		100.0		2250.0		6.16

(From Tchobanoglous et al.,1993)

- Solid waste collection
  - The difference between the amount generated and collected can be accounted for by the amount of material 1) composted, 2) burned in fireplaces, 3) discharged to sewers, 4) given to charitable agencies, 5) sold at garage sales, 6) delivered to drop-off and recycling centers, and 7) directly recycled.

- Factors that affect waste generation rates: source reduction and recycling activities, public attitudes and legislation, geographic and physical factors

