Chapter 9&14

Biological and Chemical Conversion Technologies

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Biological conversion of MSW

- With the exception of plastic, rubber and leather components, the organic fraction of MSW (OFMSW) is composed of proteins, lipids, carbohydrates, cellulose, lignin and ash.
- The two common biological processes used to transform these organic materials into gaseous, liquid and solid conversion products are;
  - Aerobic Composting
  - Anaerobic Digestion (AD)

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Comparison of composting and AD

Table 14-5. Comparison of aerobic composting and anaerobic digestion for processing the OFMSW

Characteristic	Aerobic composting	Anaerobic digestion
Energy use	Net energy consumer	Net energy producer
End products	Humus, CO_2, H_2O	Sludge, CO_2, CH_4
Volume reduction	Up to 50%	Up to 50%
Processing time	20 to 30 days	20 to 40 days
Primary goal	Volume reduction	Energy production
Secondary goal	Compost production	Volume reduction, waste stabilization

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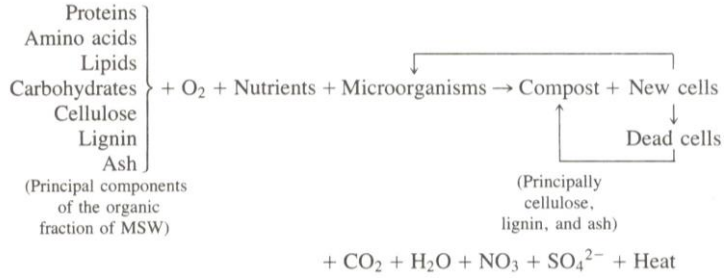
Composting

- Composting is the most commonly used biological process for the conversion of OFMSW to a stable humus-like material known as *compost*.



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General objectives of composting

- To transform the biodegradable organic materials into a biologically *stable product* and *reduce* the *volume* of waste
- To *destroy pathogens*, insect eggs and other unwanted organisms and weed seeds that may be present in MSW
- To *retain* the maximum *nutrient* (nitrogen, phophorus and potassium) content, and
- To produce a product that can be used to *support plant growth* and as a soil amendment.

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Properties of compost

The typical properties of compost are;

- A brown to very dark brown color
- A low carbon-nitrogen (C/N) ratio
- A continually changing nature due to activities of mo's
- A high capacity for cation exchange and water absorption

- When added to soil, compost has been found to *lighten heavy soils*, to *improve* the *texture* of light sandy soils and to *increase* the *water retention* capacity of most soils.

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Process description

Composting operations consist of three basic steps:

1. Pre-processing of the MSW
   - Receiving
   - Removal of recoverable materials
   - Size reduction
   - Adjustment of waste properties (C/N ratio, addition of moisture and nutrients and etc.)
2. Decomposition of the OFMSW
3. Preparation and marketing of the final compost product

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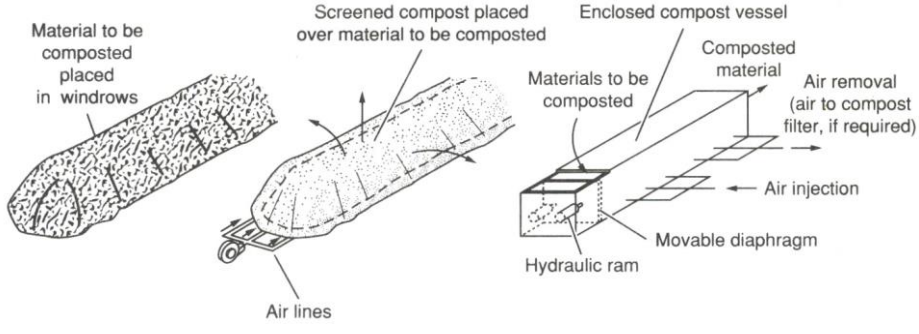
Composting Techniques



Windrow | Aerated static pile | In-vessel plug flow

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1. Windrow composting

- A high-rate windrow composting system employs rows typically *1-2 m high* by *3-4 m wide*.
- Before the windrows are formed organic material is processes by *shredding* and *screening* it to approximately *25-75 mm* and the *moisture content* is adjusted to *50-60%*.
- Windrows are *turned* up to *twice per week* while temperature is maintained at or slightly above *55 ^{o}C*.
- Complete composting can be accomplished in *3-4 weeks*.
- Afterwards, the compost is allowed to cure for an *additional 3-4 weeks* without turning.

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1. Windrow composting

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1. Windrow composting

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2. Aerated static pile composting

- Used to compost ww sludge, yard waste or separated MSW.
- The system is composed of a *grid* of *aeration* or exhaust piping over which the processed solid waste is placed.
- Typical pile heights are *2-2,5 m*.
- A layer of *screened compost* is often placed on top of the newly formed pile for *insulation* and *odor control*.
- Air is introduced to *provide* the *oxygen* needed for biological conversion and to *control* the *temperature* within the pile.
- For improved process and odor control newer facilities are *fully* or *partially covered*.

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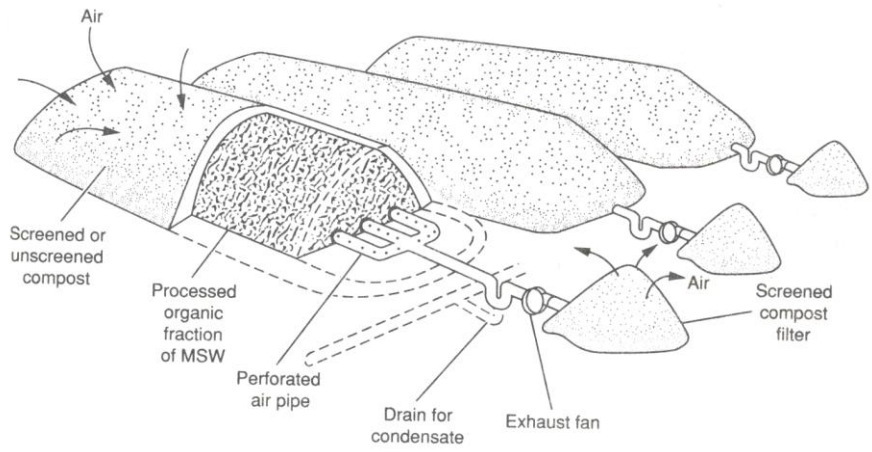
2. Aerated static pile composting



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3. In-vessel composting

- It is accomplished inside an enclosed container or vessel.
- Different vessels (vertical towers, horizontal rectangular and circular tanks and circular rotating tanks) have been used.
- Major categories are *plug flow* and *dynamic* (agitated bed).
- The *plug flow* systems operate on a *first-in, first-out* principle.
- In *dynamic* systems, the composting material is *mixed mechanically* during the processing.
- The reasons for increasing popularity of in-vessel composting are process and *odor control*, *faster* throughout, lower *labor cost* and *smaller area* requirement.

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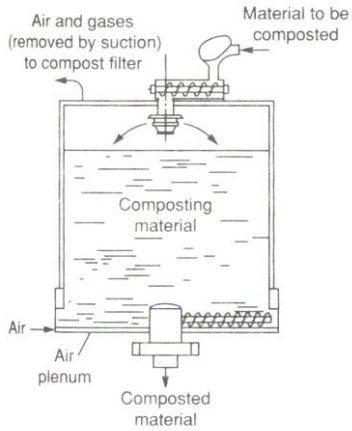
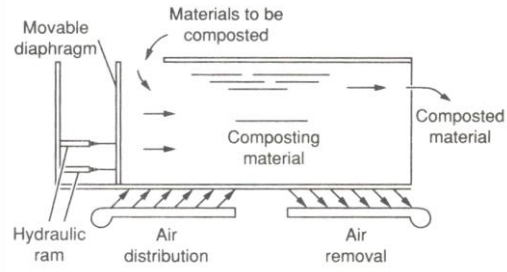
3. In-vessel composting



Unmixed vertical *plug flow* reactor



Unmixed horizontal *plug flow* reactor

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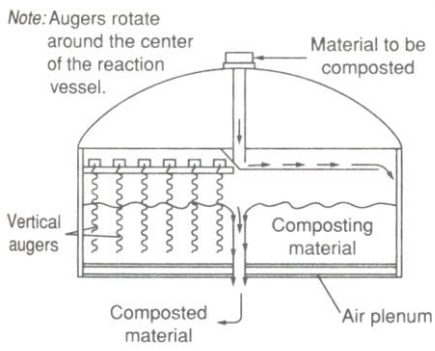
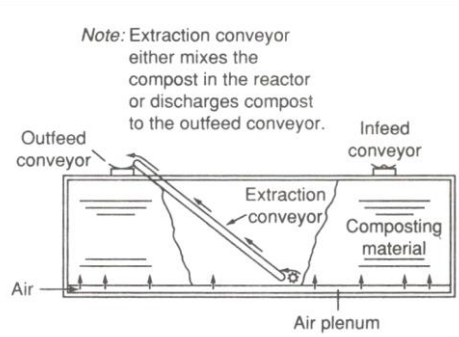
3. In-vessel composting



Mixed (*dynamic*) vertical reactor



Mixed (*dynamic*) horizontal reactor

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Important design considerations

- Particle Size
  - For optimum results the size of SW should be 25-75 mm
- Carbon/Nitrogen Ratio
  - Initial C/N ratios (optimum): 25-50
  - At lower ratios, ammonia is given off. Also, biological activity is impeded.
  - At higher ratios, nitrogen may be a limiting nutrient
- Blending & Seeding
  - Composting time can be reduced by seeding with partially decomposed SW to the extent of about 1 to 5 %wt.

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Important design considerations

- Moisture content
  - In the range of 50-60% during the composting process
- Mixing/Turning
  - To prevent drying, caking, and air channeling
  - Frequency of mixing or turning depends on the type of composting operation
- Air requirement
  - Air should reach all the parts of composting material

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Important design considerations

- Temperature
  - 50-55^{o}C → for the first few days
  - 55-60^{o}C → for the remainder of the active composting period
  - Temperatures > 65^{o}C reduce the biological activity significantly
- pH Control
  - pH 7-7.5 → For optimum aerobic decomposition
  - pH < 8.5 → To minimize the loss of nitrogen in form of NH_3 gas
- Control of pathogens
  - 60-70^{o}C for 24 h kills all pathogens, weeds and seeds.

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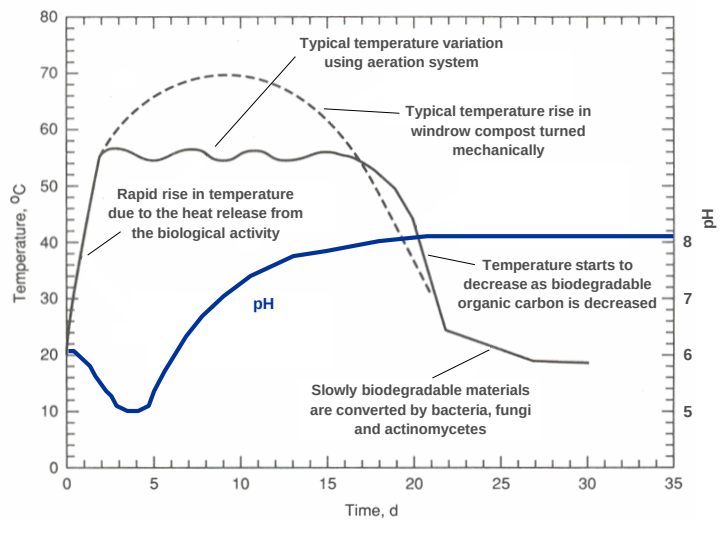
Temperature and pH control



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Control of pathogens (Table 14-8)

Organism	Observations
Salmonella typhosa	No growth beyond 46°C; death within 30 minutes at 55–60°C and within 20 minutes at 60°C; destroyed in a short time in compost environment.
Salmonella sp.	Death within 1 hour at 55°C and within 15–20 minutes at 60°C.
Shigella sp.	Death within 1 hour at 55°C.
Escherichia coli	Most die within 1 hour at 55°C and within 15–20 minutes at 60°C.
Entamoeba histolytica cysts	Death within a few minutes at 45°C and within a few seconds at 55°C.
Taenia saginata	Death within a few minutes at 55°C.
Trichinella spiralis larvae	Quickly killed at 55°C; instantly killed at 60°C.
Brucella abortus or *Br. suis*	Death within 3 minutes at 62–63°C and within 1 hour at 55°C.
Micrococcus pyogenes var. *aureus*	Death within 10 minutes at 50°C.
Streptococcus pyogenes	Death within 10 minutes at 54°C.
Mycobacterium tuberculosis var. *hominis*	Death within 15–20 minutes at 66°C or after momentary heating at 67°C.
Corynebacterium diphtheriae	Death within 45 minutes at 55°C.
Necator americanus	Death within 50 minutes at 45°C.
Ascaris lumbricoides eggs	Death in less than 1 hour at temperatures over 50°C.

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Control of pathogens (Table 14-9)

EPA requirements for pathogen control in compost processes[a]

Requirement	Remarks
Processes to significantly reduce pathogens (PSRP)	Using the in-vessel, aerated static pile, or windrow composting methods, the solid waste is maintained at minimum operating conditions of 40°C for 5 days. For four hours during this period, the temperature exceeds 55°C.
Processes to further reduce pathogens (PFRP)	Using the in-vessel or aerated static pile composting methods, the solid waste is maintained at operating conditions of 55°C or greater for three days.
	Using the windrow composting method, the solid waste is maintained at operating conditions of 55°C or greater for at least 15 days during the composting period. Also, during the high-temperature period there will be a minimum of five turnings of the windrow.

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Important design considerations

- Degree of decomposition can be measured by;
  - measuring the final drop in temperature
  - degree of self heating capacity
  - amount of decomposable and resistant organic matter in the composted material
  - rise in redox potential
  - oxygen uptake
  - growth of the fungus *Chaetomium gracilis*, and
  - the starch-iodine test.
- Land Requirement
  - For a highly mechanized windrow composting plant with a capacity of 50 ton/day → 6,000-8,000 m^2

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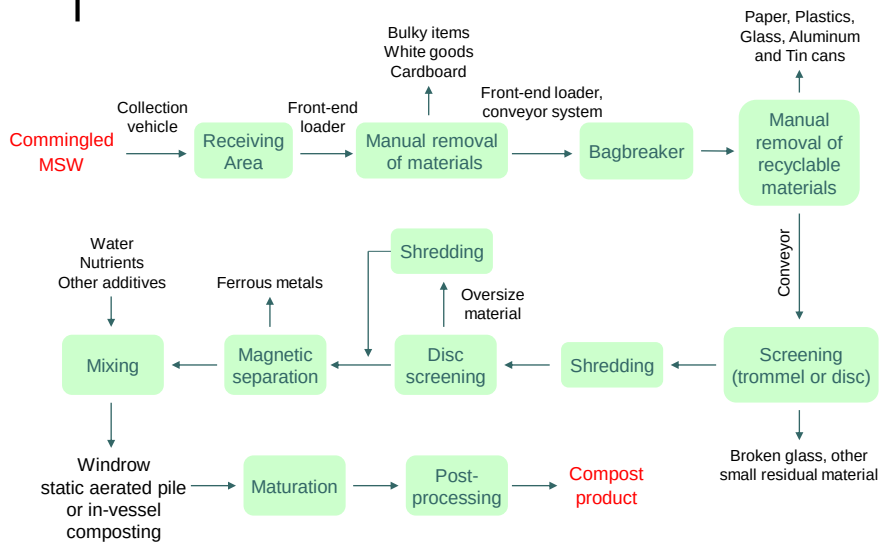
Production of compost from commingled MSW



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Comparison of composting processes

Table 14-10. Comparison of aerobic composting processes

Item	Windrow	Aerated static pile	In-vessel, forced aeration	
			With agitation (dynamic)	No agitation (plug flow)
Capital costs	Generally low	Generally low in small systems, can become high in large systems	Generally high	Generally high
Operating costs	Generally low	High (in sludge systems where bulking agents are used)	Generally low	Generally low
Land requirements	High	High	Low, but can increase if windrow drying or curing required	Low, but can increase if windrow drying or curing required
Control of air	Limited unless forced aeration is used	Complete	Complete	Complete
Operational control	Turning frequency, amendment, or compost recycle addition	Airflow rate	Airflow rate, agitation, amendment, or compost recycle addition	Airflow rate, amendment, or compost recycle addition
Sensitivity to cold or wet weather	Sensitive unless in housing	Demonstrated in cold and wet climates	Demonstrated in cold and wet climates	Demonstrated in cold and wet climates
Control of odors	Depends on feedstock, potential large-area source	May be large-area source but can be controlled	Potentially good	Potentially good
Potential operating problems	Susceptible to adverse weather	Control of airflow rate is critical, potential for channeling or short-circuiting of air supply	High operational flexibility, system may be mechanically complex	Potential for channeling or short circuiting of air supply, system may be mechanically complex

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Issues in implementation of composting facilities

- Production of odors
- Blowing of papers and plastic materials in windrow composting
- Presence of pathogens and heavy metals in compost product
- Definition of what constitutes an acceptable compost.

Unless the questions related to these issues are resolved, composting may not be a viable technology in the future

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Example 14.3 Blending of wastes to achieve an optimum C/N ratio

- Leaves, with a C/N ratio of 50, are to blended with waste-activated sludge from a wastewater treatment plant, with a C/N ratio of 6.3.
- Determine the proportions of each component to achieve a blended C/N ratio of 25.
- Assume that the following conditions apply:
  - Moisture content of sludge = 75%
  - Moisture content of leaves = 50%
  - Nitrogen content of sludge = 5.6%
  - Nitrogen content of leaves = 0.7%

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Example 14.3 Blending of wastes to achieve an optimum C/N ratio

Solution

1. Determine the percentage composition for leaves and sludge.

   For kg of leaves:

   Water = 1 kg (0.50) = 0.50 kg

   Dry matter = 1 kg – 0.50 kg = 0.50 kg

   N = 0.50 kg (0.007) = 0.0035 kg

   C= 50 (0.0035 kg) = 0.175 kg

   For kg of sludge:

   Water = 1 kg (0.75) = 0.75 kg

   Dry matter = 1 kg – 0.75 kg = 0.25 kg

   N = 0.25 kg (0.056) = 0.014 kg

   C= 6.3 kg (0.014) =0.0882 kg

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Example 14.3 Blending of wastes to achieve an optimum C/N ratio

Solution

2. Determine the amount of sludge to be added to lb of leaves to achieve a C/N ratio of 25:

$$\frac{C}{N} = 25 = \frac{C\ in\ kg\ of\ leaves + x(C\ in\ kg\ of\ sludge)}{N\ in\ kg\ of\ leaves + x(N\ in\ kg\ of\ sludge)}$$

where x = weight of sludge required

$$25 = \frac{0.175 + x(0.0882)}{0.0035 + x(0.014)} \qquad x = 0.33\ kg\ sludge/kg\ leaves$$

2. Check the C/N ratio and moisture content of resultant mixture.

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Example 14.3 Blending of wastes to achieve an optimum C/N ratio

2. Check the C/N ratio and moisture content of resultant mixture.

a) For 0.33 kg sludge:
Water = 0.33 kg (0.75) = 0.25 kg
Dry matter = 0.33 kg (0.25) = 0.08 kg
N = 0.33 kg (0.014) = 0.0046 kg ~ 0.005 kg
C= 0.33 kg (0.0882) = 0.029 kg ~ 0.03 kg

b) For 0.33 kg sludge + 1 kg leaves:
Water = 0.25 kg + 0.50 kg = 0.75 kg
Dry matter = 0.08 kg + 0.50 kg =0.58 kg
N = 0.005 kg + 0.0035 kg = 0.008 kg
C = 0.03 kg + 0.175 kg = 0.205 kg

c) Find the C/N ratio: $\frac{C}{N} = \frac{0.205\ kg\ C}{0.008\ kg\ N} = 25.6 \quad ok$

d) Find the moisture content:

$$Moisture = \frac{0.75\ kg\ water}{0.75\ kg\ water + 0.58\ kg\ dry\ matter} = \frac{0.75\ kg}{1.33\ kg} = 56\% \quad ok$$

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Example 14.4 Air requirements for in-vessel composting

- Determine the amount of air required to compost 1 ton of MSW using in-vessel composting with forced aeration.
- Assume that the composition of the organic fraction of the MSW to be composted is given by $C_{60.0}H_{94.3}O_{37.8}N$.
- Assume that the following conditions and data apply:
  - Moisture content of organic fraction of MSW = 25 %
  - Volatile solids, VS = 0.93 * TS (total solids)
  - Biodegradable volatile solids, BVS = 0.60 * VS
  - Expected BVS conversion efficiency = 95%
  - Composting time = 5 d
  - Oxygen demand is 20, 35, 25, 15, 5 % for the successive days of the 5-day composting period.
  - Air contains 23% O_2 by mass and the specific weight of air is equal 1.2 kg / m^3.
  - A factor of 2 times the actual air supplied will be needed to be assumed that the oxygen content of the air does not drop below 50 percent of its original value.

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Example 14.4 Air requirements for in-vessel composting

Solution

1. Determine the mass of biodegradable volatile solids in one ton of organic waste.

   Mass BV = 1 ton * 1000 kg/ton * 0.75 * 0.93 *0.60

   = 418.5 kg
2. Determine the expected BVS mass conversion.

   Expected BVS mass conversion = 418.5 kg * 0.95 = 397.6 kg
3. Determine the amount of oxygen required for decomposition of 1 kg of BVS

$$C_aH_bO_cN_d + \left(\frac{4a+b-2c-3d}{4}\right)O_2 \rightarrow aCO_2 + \left(\frac{b-3d}{2}\right)H_2O + dNH_3$$

$C_{60.0}H_{94.3}O_{37.8}N + 63.93\ O_2 \rightarrow 60.0\ CO_2 + 45.7\ H_2O + NH_3$

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Example 14.4 Air requirements for in-vessel composting

Solution

$C_{60.0}H_{94.3}O_{37.8}N + 63.93\ O_2 \rightarrow 60.0\ CO_2 + 45.7\ H_2O + NH_3$

1433.1 g/mol 2045.8 g/mol

O_2 required = 2045.8 / 1433.1 = 1.43 kgO_2/kgBVS converted

4. Determine the total amount of air required for one ton of MSW, containing 397.6 kg of BVS, as determined in Step 2

$$Air\ required = \frac{\left(397.6\ kg\ BVS * 1.43\ \frac{kg\ O_2}{kg\ BVS\ converted}\right)}{\left(0.23\ \frac{kg\ O_2}{kg\ air} * 1.2\ \frac{kg\ air}{m^3\ air}\right)} = 2060\ m^3\ air$$

5. Determine the required capacity of the aeration equipment, expressed in m^3/min.

$$Air\ required = \frac{(2060\ m^3 air * 2 * \frac{0.35}{d})}{1440\ \mathrm{min}/d} = 1.0 m^3/min$$

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Example 14.4 Air requirements for in-vessel composting

Comment.

- The flow rate is computed using 35% of the total oxygen requirement, the most critical day.
- In an actual composting operation, some of the BVS would have been converted to cell tissue.
- However, because air is also required for the conversion of BVS to cell tissue the computations presented in this example, which are based on the assumption that all of the BVS is converted, are reasonable.

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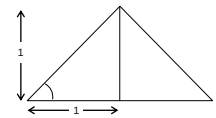
Problem 9.18 How much land area would be required to compost processed MSW.

How much land area would be required per ton to compost 100 ton/d of processed (sorted and shredded) residential and commercial MSW subject to the following conditions?

- Windrow composting with mechanical turning is to be used
- Maximum width = 5 m
- Maximum length of windrows = 150 m
- Average distance between windrows = 2.5 m
- Angle repose of waste in windrows = 1 to 1
- Specific weight of the processed MSW as placed in windrows before water is added = 325 kg/m^3
- Actice composting period = 1 month
- Curing period = 4 month
- A staging/storage area equal to 15% of the area used for composting will be required



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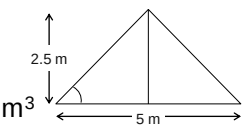
Problem 9.18 How much land area would be required to compost processed MSW.

Solution



Total compost cycle = 1+4 = 5 mo

Vol. of compost = [(5*2.5)/2] * 150 = 937.5 m^3

MSW per cycle = 100 ton/d * 30 d/mo * 5 mo = 15000 ton

Vol. of MSW = 15000 ton * 1000 kg/ton / 325 kg/m^3 = 46154 m^3

# of windrows = 46154 m^3 / 937,5 m^3 = 49.2 (~ 50)

Area required = [(50 * 5m) + ((50-1) * 2.5m)] * 150m = 55875 m^2

Area for staging/storage = 55875 m^2 * 0.15 = 8381 m^2

Total area = 55875 m^2 + 8381 m^2 = 64256 m^2

Land requirement = 64256 m^2 / 15000 ton = 4,28 m^2/ton

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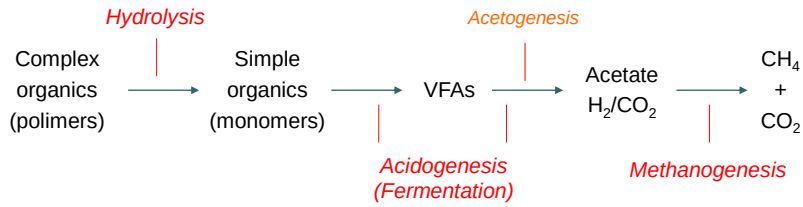
Anaerobic Digestion (AD)

- Anaerobic digestion of organic material is basically a 3-stage process: large organic polymers are first hydrolyzed and then fermented into short-chain volatile fatty acids (VFAs).
- These acids are then converted into CH_4 and CO_2.



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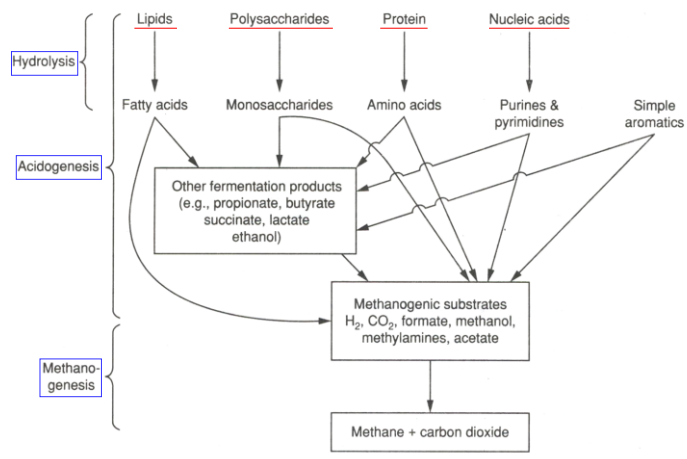
Anaerobic Digestion (AD)



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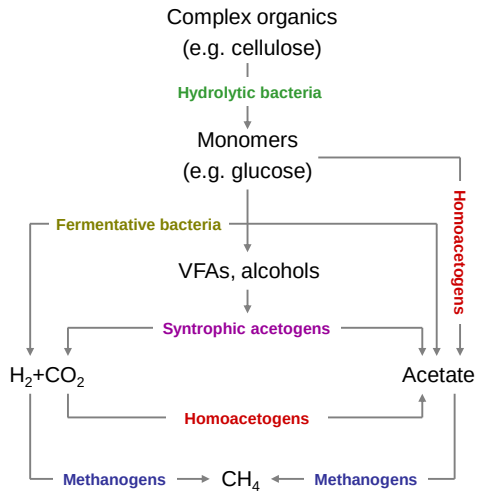
Microorganisms in AD



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Biogas production

Organic matter + H_2O + nutrients → New cells + resistant organic matter

+ CO_2 + CH_4 + NH_3 + H_2S + heat

If it is assumed that organic matter is stabilized completely, the overall conversion of OFMSW waste to CH_4, CO_2 and NH_3 can be represented as follows;

$$C_aH_bO_cN_d + \frac{(4a-b-2c+3d)}{4}H_2O \rightarrow \frac{(4a+b-2c-3d)}{8}CH_4 + \frac{(4a-b+2c+3d)}{8}CO_2 + dNH_3$$

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Low-solids (wet) AD

- An anaerobic process in which organic wastes are fermented at solids concentrations of 4-8%.
- Used to generate CH_4 from human, animal and agricultural wastes and from OFMSW.
- A disadvantage is that considerable amounts of water must be added to wastes to bring the solids content to 4-8%
- The addition of water results in a very dilute digested sludge which has to be dewatered prior to disposal.

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Low-solids AD process

The basic steps of low-solids AD of MSW:

- Preparation of OFMSW; receving, sorting, separation, size reduction
- Addition of moisture and nutrients
- Blending and pH adjustment
- Anaerobic digestion
- Capture, storage (if necessary) separation of gas components
- Dewatering and disposal of digested sludge

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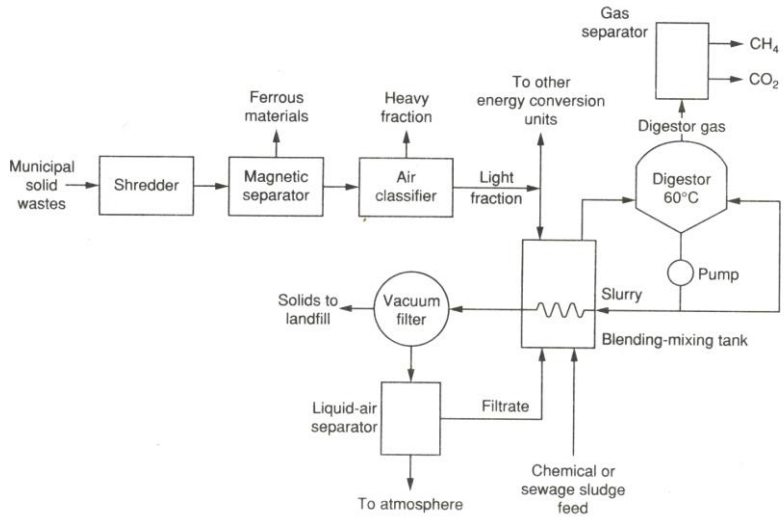
Flow diagram for low-solids AD



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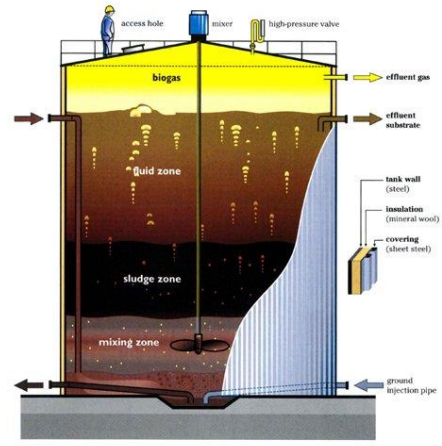
Low-solids anaerobic digesters



Egg-shaped digesters

Conventional circular digesters

Video: https://www.youtube.com/watch?v=N2ocqvhEFrw

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Design considerations: Low-solids AD

TABLE 14-11
Important design considerations for the low-solids anaerobic digestion of the organic fraction of MSW

Waste component	Comment
Size of material	Wastes to be digested should be shredded to a size that will not interfere with the efficient functioning of pumping and mixing operations.
Mixing equipment	To achieve optimum results and to avoid scum buildup, mechanical mixing is recommended.
Percentage of solid wastes mixed with sludge	Although amounts of waste varying from 50 to 90+ percent have been used, 60 percent appears to be a reasonable compromise.
Hydraulic and mean cell-residence time	Washout time is in the range of 3 to 4 d. Use 10 to 20 d for design, or base design on results of pilot plant studies.
Loading rate	0.04 to 0.10 lb/ft^3 · d (0.6 to 1.6 kg/m^3 · d). Not well defined at present time. Significantly higher rates have been reported.
Solids concentration	Equal to or less than 8 to 10% (4 to 8% typical).
Temperature	Between 85 and 100°F (30 to 38°C) for mesophilic and between 131 and 140°F (55 and 60°C) for thermophilic reactor.
Destruction of volatile solid wastes	Depends on the nature of the waste characteristics. Varies from about 60 to 80 percent; 70 percent can be used for estimating purposes.
Total solids destroyed	Varies from 40 to 60 percent, depending on amount of inert material present originally.
Gas production	8 to 12 ft^3/lb (0.5 to 0.75 m^3/kg) of volatile solids destroyed (CH_4 = 55 percent; CO_2 = 45 percent).

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High-solids (dry) AD

- An anaerobic process in which fermentation occur at a total solids content of higher than 20%.
- Two important advantages are;
  - Lower water requirements,
  - Higher gas production per unit volume of reactor size.
- The challenges in high-solids AD are keeping the biochemical reactions going at high TS values, as well as handling, pumping and mixing the solid streams.

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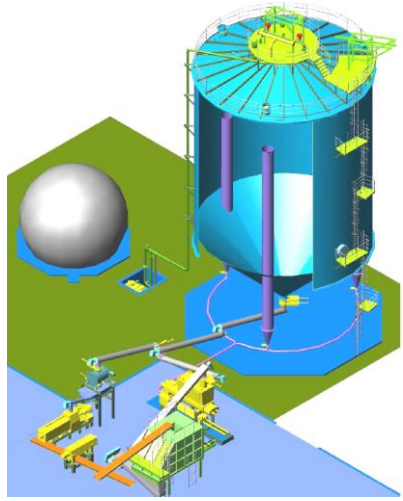
Dranco technology



- Consists of a thermophilic, one-phase high-solids anaerobic fermentation step followed by a short aerobic maturation phase.
- The final product is a hygienically safe and stabilised product.
- Mesophilic operation can also be applied for specific waste streams.
- The process takes place in a vertical plug-flow reactor during ~ 20 days.
- There is no mixing, stirring or gas injection in the digester, but leachate from the bottom is recirculated.

Video: https://www.youtube.com/watch?v=F8qiMu9Q-eo

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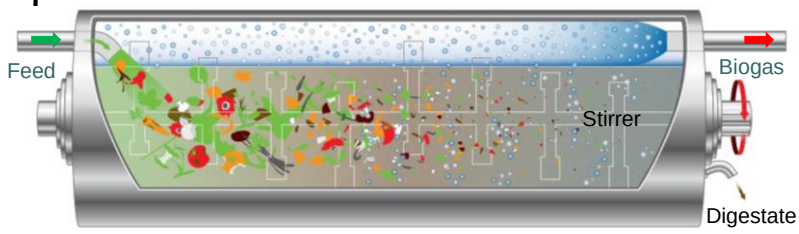
Kompogas technology



- Anaerobic thermophilic dry fermentation of fruit, vegetable and yard waste takes place at ~ 55°C and an average moisture of ~75%.
- Fermenter is a horizontal plug flow reactor through which the substrate flows continuously and horizontally.
- A slowly rotating stirrer gently mixes the substrate and ensures optimum degassing.
- The plug flow system guarantees that the solid waste remains in the reactor for a defined time, so it is ensured that it is properly sanitised.

Video: https://www.youtube.com/watch?v=EBJgatDt8yA

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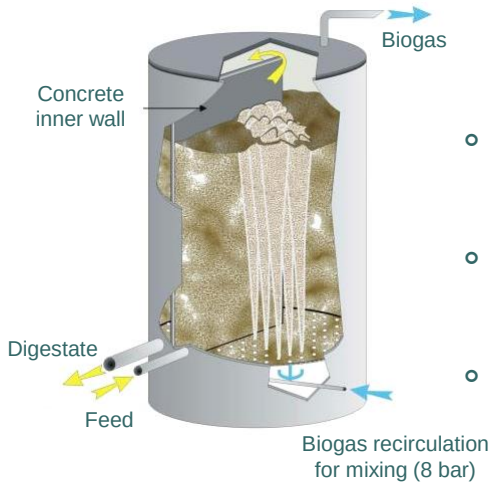
Valorga technology



- Consists of a single-stage, vertical plug-flow reactor with an inner wall that forces material to go up & around it before being extracted from bottom.
- This geometry guarantees a residence time of 3 weeks ensuring complete hygenization.
- The biogas, periodically injected with high pressure at the bottom of the reactor, allows efficient vertical mixing.
- The dewatered digestate is treated aerobically for about two weeks for complete stabilization.

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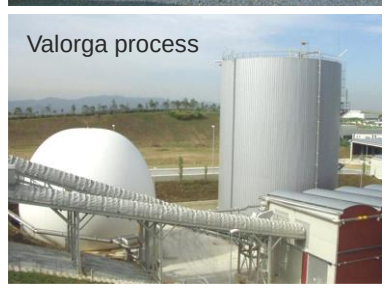
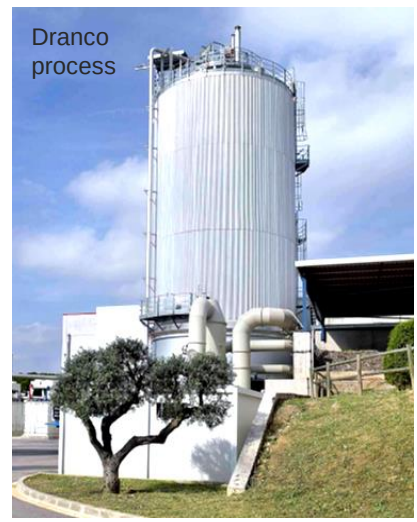
High-solids anaerobic digesters





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Design considerations: High-solids AD

TABLE 14-12
Important design considerations for the high-solids anaerobic digestion of the organic fraction of MSW

Item	Comment
Size of material	Wastes to be digested should be shredded to a size that will not interfere with the efficient functioning of feeding and discharging mechanisms.
Mixing equipment	The mixing equipment will depend on the type of reactor to be used.
Percentage of solid wastes mixed with sludge	Depends on the characteristics of the sludge.
Mass retention time	Use 20 to 30 d for design, or base design on results of pilot plant studies.
Loading rate based on biodegradable volatile solids, BVS	0.375 to 0.4 lb/ft^3 · d (6 to 7 kg/m^3 · d). Not well defined at present time. Significantly higher rates have been reported.
Solids concentration	Between 20 and 35% (22 to 28% typical).
Temperature	Between 85 and 100°F (30 and 38°C) for mesophilic and between 131 and 140°F (55 and 60°C) for thermophilic reactor.
Destruction of BVS	Varies from about 90 to 98+ percent depending on the mass retention time and the BVS loading rate.
Total solids destroyed	Varies depending on the lignin content of the feedstocks.
Gas production	10 to 16 ft^3/lb of biodegradable volatile solids destroyed (0.625 to 1.0 m^3/kg), (CH_4 = 50 percent; CO_2 = 50 percent).

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Comparison of Low- & High-solids AD

Table 14-3 Page 704

Design and/or operational parameter	Comment	
	Low-solids	High-solids
Reactor design	Complete-mix reactors have been used in large-scale systems for organic fraction of MSW. Plug-flow reactors are used widely other organic materials, especially cow manure.	Complete-mix, plug-flow, and batch reactors have been studied experimentally. None of these reactor types have been used commercially for processing MSW.
Solids content	4 to 8 percent.	22 to 32 percent.
Reactor volume	Large reactor volume is required per unit volume of organic waste.	A much smaller reactor volume is required for the same volume of organic waste than in the low-solids digestion process.
Water addition	A large volume of water is required to increase the moisture content of the organic fraction of MSW.	Water requirement is much less, because of the high solids concentration.
Organic loading rate	Relatively low organic loading rates per unit of reactor volume.	Relatively high organic loading rates per unit of reactor volume.
Gas production rate	Maximum gas production rates of up to 2 volumes per active reactor volume have been reported.	Maximum gas production rates of up to 6 volumes per active reactor volume have been achieved.
Mass removal rate	Mass removal rate is low due to higher water content.	A significantly higher mass removal rate can be achieved in the same retention time period as compared to low-solids digestion.
Mechanisms for feeding and discharging the effluent	Pumps of all types have been used.	Because this is a relatively new technology, appropriate mechanisms for feeding and discharging effluent from the anaerobic reactor are not well defined. High-solids pumps and screw conveyors have been used.
Toxicity problems	Toxicity problems in a low-solids anaerobic digester are less severe due to dilute nature of organic waste materials.	Salts and heavy metal toxicity are more common in high-solids anaerobic digestion due to large concentrations of these compounds and chemical elements. Ammonia toxicity is a major problem with low C/N ratios (less than 10 to 15).
Leachate problem	Due to high water content, the stabilized effluent can generate leachate problem.	Effluent from a high-solids digester normally contains 25 to 30 percent solids, which minimize the leachate generation potential.
Effluent dewatering	Large and expensive facilities are required to separate solids. For final disposal, the separated water should also be treated.	Inexpensive dewatering equipment is adequate.
Technology status	Not commercialized for energy recovery from organic fraction of MSW. The commercial use of the low-solids anaerobic digester for energy production from agricultural waste is worldwide.	Not commercialized for energy recovery from organic fraction of MSW.

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Combined High-Solids AD/Composting

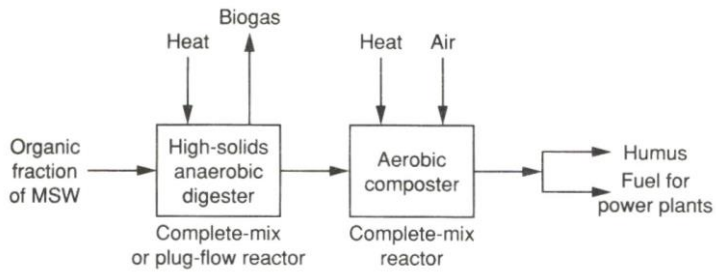

Figure 14.10 Flow diagram for high-solids AD/aerobic composting process

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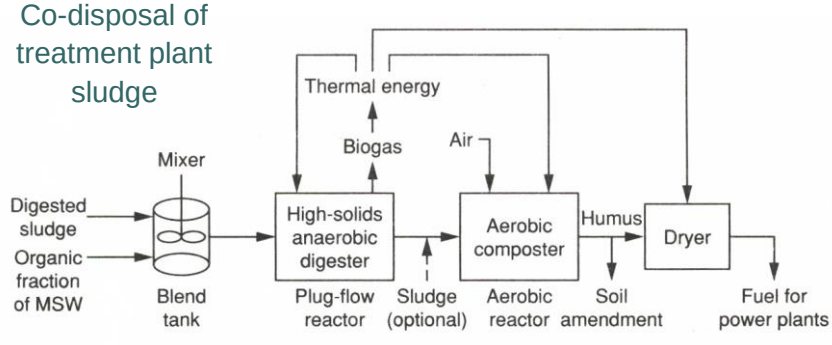
Combined High-Solids AD/Composting

Co-disposal of treatment plant sludge



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Other biological processes

Table 14-15 Biological processes for the recovery of conversion products from the organic fraction of MSW

Process	Conversion product	Preprocessing
Aerobic conversion	Compost (soil conditioner)	Separation of organic fraction, particle size reduction
Anaerobic digestion (in landfill)	Methane and carbon dioxide	None, other than placement in containment cells
Anaerobic digestion (low-solids, 4 to 8 percent solids)	Methane and carbon dioxide, digested solids	Separation of organic fraction, particle size reduction
Anaerobic digestion (high-solids, 22 to 35 percent solids)	Methane and carbon dioxide, digested solids	Separation of organic fraction, particle size reduction
Enzymatic hydrolysis	Glucose from cellulose	Separation of cellulose-containing materials
Fermentation (following acid or enzymatic hydrolysis)	Ethanol, single-cell protein	Separation of organic fraction, particle size reduction, acid or enzymatic hydrolysis to produce glucose

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Chemical transformation of MSW

- Chemical transformation processes include a number of hydrolysis process used to recover glucose and furfural.
- With some other chemical processes products such as bio-diesel, methanol and cellucose acetate can also be recovered.
- However, these processes are not used routinely for transformation of OFMSW because these compounds can also be manufactured from other cellulose-containing agricultural wastes (wheat straw, sugar beet bagasse)

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Chemical processes for the recovery of conversion products from SW

Table 14-16

Process	Conversion product	Pre-processing
Acid hydrolysis	Glucose, other sugars	Separation of organic fraction, particle size reduction
Alkaline hydrolysis	Glucose, other sugars	
Various chemical conversion processes	Synthetic oil, gas, cellulose acetate	

Acid hydrolysis at 180-230 ^{o}C and under slight pressure is used to recover glucose from cellulose containing waste (e.g., newsprint).

$$(C_6H_{10}O_5)_n + H_2O \rightarrow nC_6H_{12}O_6$$

cellulose glucoce

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Example 14.2 Estimation of the amounts of biogas produced from the organic fraction of MSW under anaerobic conditions

- Estimate the total theoretical amount of biogas that could be produced under anaerobic conditions in a sanitary landfill per unit weight of solid waste.
- Assume that the wastes are of the composition shown in Table 3-4 and that the overall chemical formula for the organic constituents is $C_{60.0}H_{94.3}O_{37.8}N$.
- If the individual organic constituents found in MSW (with the exception of plastics) are represented by a generalized formula of the form CaHbOcNd, then the total volume of gas can be estimated using Eq.(11-2):

$$C_aH_bO_cN_d + \left(\frac{4a-b-2c+3d}{4}\right)H_2O \rightarrow \left(\frac{4a+b-2c-3d}{8}\right)CH_4 + \left(\frac{4a-b+2c+3d}{8}\right)CO_2 + dNH_3$$

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Example 14.2 Estimation of the amounts of biogas produced from the organic fraction of MSW under anaerobic conditions

Solution

1. The total wet weight of organic components in 100 kg of MSW is equal to 79.5 kg (see Example 4-2)
   The dry weight (TS) is equal to 59.1 kg
2. Determine the amount of dry decomposable organic waste, assuming that 5% of the decomposables will remain as ash.
   Decomposable dry matter (dTS) = 59.1 kg * 0.95 = 56.15 kg
3. Estimate the amount of CH_4 and CO_2 that can be produced using Eq.(11-2)
   The resulting equation is

$$C_{60.0}H_{94.3}O_{37.8}N + 18.28H_2O \rightarrow 31.96CH_4 + 28.04CO_2 + NH_3$$

1433.1g/mol 511.4 g/mol 1233.8 g/mol

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Example 14.2 Estimation of the amounts of biogas produced from the organic fraction of MSW under anaerobic conditions

Solution

1. Determine the weight of CH_4 and CO_2 from the equation
   CH_4 = (511.4 / 1433.1) * 56,15 kg = 20,0 kg
   CO_2 = (1233.8 / 1433.1) * 56,15 kg = 48.3 kg
2. Convert the weight of gases to volume
   CH_4 = (20,0 kg / 0.718 kg/m^3) = 27.86 m^3
   CO_2 = (48.3 kg / 1.978 kg/m^3) = 24.42 m^3
3. Determine the % composition of the resulting gas mixture
   CH_4, % = 27.86 m^3 / (27.86 m^3 + 24.42 m^3) = 53.3%
   CO_2, % = 100% - 53.3% = 46.7%
4. Determine the theoretical biogas generation per kg of waste
   (27.86 m^3 + 24.42 m^3) / 56,15 kg = 0.93 m^3/kg of organic TS
   (27.86 m^3 + 24.42 m^3) / 100 kg = 0.52 m^3/kg of MSW

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Example 14.5 Methane recovery from the high solids AD of the organic fraction of MSW

- Estimate the amount of biogas that can be recovered from one ton of waste, consisting of the organic fraction of MSW, and its USD value.
- Assume that the following conditions and data apply :
  - Moisture content of organic fraction of MSW = 20%
  - Mass retention time = 30 d
  - Volatile solids, VS = 0.93 * TS (total solids)
  - Biodegradable volatile solids, BVS = 0.70 * VS
  - Expected BVS conversion efficiency = 95%
  - Biogas production = 0.65 m^3/kg BVS destroyed
  - Energy content of biogas = 6.0 kWh/m^3
  - The value of one kWh power = $0.133/kWh

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Example 14.5 Methane recovery from the high solids AD of the organic fraction of MSW

Solution

1. Determine the mass of VS in 1 ton of OFMSW
   Mass VS = 1.0 ton * 1000 kg/ton * 0.80 * 0.93 = 744 kg
2. Determine the mass of BVS destroyed
   Mass of BVS destroyed = 744 kg * 0.70 * 0.95 = kg
3. Determine the volume of biogas produced494.8
   Biogas produced = 494.8 kg * 0.65 m^3/kg = 321.6 m^3
4. Determine total energy value of the biogas
   Energy value = 321.6 m^3 * 6.0 kWh/m^3 = 1929.6 kWh
6. Determine total value of the biogas produced
   Value = 1929.6 kWh * 0.133 USD/kWh = 256.6 USD/ton

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