Chapter 11
Disposal of Solid Wastes and Residual Material

Landfills are physical facilities used for the disposal of residual solid wastes in the surface soils of earth.

Sanitary landfill is an engineered facility for the disposal of MSW, designed and operated to minimize public health and environmental impacts.

Landfilling is the process by which residual solid waste is placed in a landfill. It includes;
- Monitoring of the incoming waste stream
- Placement and compaction of waste, and
- Installation of landfill environmental monitoring and control facilities.
Landfilling terms

**Cell** is the volume of material placed in a landfill during one operating period.

**Lift** is a complete layer of cells over the active area of landfill.

Intermediate cover is the soil or alternative materials such as compost that are applied to the working faces of the landfill at the end of each operating period.

**Final cover** is the entire landfill surface after all landfilling operations are complete.
Landfilling terms

**Bench (or terrace)** is used to maintain the slope stability of the landfill, for placement of surface water drainage channels and for the location of landfill gas recovery piping. **Landfill gas** is a mixture of gases found within landfill. It mainly consists of CH₄ & CO₂.

Liquid that collects at the bottom of a landfill is known as **leachate**. It is a result of percolation of **precipitation** and uncontrolled **runoff**. It can also include water initially contained in the waste as well as infiltrating **groundwater**.
**Landfilling terms**

Environmental monitoring involves the activities associated with collection and analysis of water and air samples, that are used to monitor the movement of landfill gases and leachate at the landfill site.

**Landfill planning, design and operation**

The principle elements that must be considered;

- Landfill layout and design
- Landfill operations and management
- Reactions occurring in landfill
- Management of landfill gases
- Management of leachate
- Environmental monitoring
- Landfill closure and post-closure care
Landfill planning, design and operation

Landfill operations and processes
(Figure 11-3)
**Development and completion of landfill**

- **Preparation of the site for landfilling**
  - Site drainage is modified to route any runoff away from the intended landfill area
  - Access roads and weighing facilities are constructed and fences are installed
  - Landfill bottom and subsurface sides are excavated and prepared. Excavations are carried out over time, rather than preparing the entire landfill bottom at once
  - The bottom is shaped to provide drainage of leachate and a low-permeability (clay, geomembrane) liner is installed.
  - Leachate collection and extraction facilities are placed within or top of the liner.

- **Placement of solid waste in landfill**

- **Cutaway through completed landfill**
Preparation of site for landfilling

1. Landfill bottom is prepared
2. Geomembrane liner is installed
3. Leachate collection system is placed
4. Ready for disposal

Placement of wastes

- Waste is placed in cells beginning along the compaction face, continuing outward and upward from the face.
- Wastes deposited by transfer vehicles are spread out in 50-60 cm layers and compacted.
- Successive lifts are placed on top of one another until the final design grade is reached.
- As organic materials within the landfill decompose, completed sections may settle. Refilling until the design grade is possible.
- Final cover is designed to minimize infiltration of precipitation and to route drainage away from the active section of landfill.
- Finally, the site is landscaped and prepared for other uses.
Placement of wastes

1. MSW is deposited
2. Spread, compacted and covered with soil
3. When the final design grade is reached, landfill is capped with a final cover
4. And then landscaped

Reactions occurring in landfills

**Biological reactions**
- Organic material in MSW leads to the evolution of landfill gases and leachate.

**Physical reactions**
- Lateral diffusion of gases in landfill and emission of landfill gases to the surrounding environment
- Movement of leachate within landfill & into underlying soils
- Settlement caused by consolidation and decomposition of landfilled material
Reactions occuring in landfills

Chemical reactions

- Dissolution and suspension of landfill material and biological conversion products in leachate
- Evaporation and vaporization of chemical compounds into landfill gas
- Sorption of volatile and semi volatile organic compounds into landfilled material
- Dehalogenetation and decomposition of organic compounds
- Oxidation reduction reactions affecting metals and solubility of metal salts

Concerns with landfilling

- Uncontrolled release of landfill gases might cause odor and other potential dangerous conditions
- Impact of uncontrolled discharge of landfill gases on greenhouse effect in the atmosphere
- Uncontrolled release of leachate might migrate down to underlying groundwater or to surface water
- Breeding and harboring of disease vectors in improperly managed landfills
- Health and environmental impacts associated with the release of the trace gases arising from hazardous materials placed in the landfills in the past
**Landfilling Methods**

**Excavated cell/trench Method**
- It is ideally suited to areas where an adequate depth of cover material is available at the site and where water table is not near the surface.
- The soil excavated is used for daily and final cover.
- Excavated cells are typically square and trenches are long ditches.

**Area Method**
- It is used when the terrain is unsuitable for excavation.
- High-groundwater conditions necessitate the use of this type.
- Cover material must be hauled by truck or earthmoving equipment from adjacent land or from borrow-pit areas.
- Compost produced from MSW can be used as intermediate cover material.
Landfilling Methods

Canyon/depression Method
- Canyons, ravines, dry borrow pits, and quarries are used.
- Control of surface drainage often is critical factor in the development of canyon/depression sites.
- Filling for each lift starts at the head end of the canyon and ends at the month, so as to prevent the accumulation of water behind the landfill.
- Cover material is excavated from the canyon walls or floor before the liner is installed.

Landfill Siting Considerations
- Haul distance
- Location restrictions
- Available land area
- Site access
- Soil conditions and topography
- Climatologic conditions
- Surface water hydrology
- Geologic and hydrogeologic conditions
- Local environmental conditions
- Ultimate use of completed landfills
Composition and Characteristics, Generation, Movement and Control of Landfill Gases

- A landfill can be conceptualized as a **biochemical reactor**, with **solid waste** and **water** as the major inputs and with **landfill gas** and **leachate** as principle outputs.
- Material stored in the landfill includes partially degraded **organics** and other **inorganic wastes** originally placed in landfill.
- Landfill gas control systems are employed to prevent unwanted **movement** of landfill gas into the **atmosphere** or the lateral and vertical movement through the **surrounding soil**.
- Recovered **landfill gas** can be used to produce **energy** or can be **flared** under controlled conditions to eliminate the discharge of harmful constituent to the atmosphere.

### Typical composition of landfill gas

**Table 11-2**

<table>
<thead>
<tr>
<th>Component</th>
<th>Percent (dry volume basis)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>45-60</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>40-60</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>2-5</td>
</tr>
<tr>
<td>Oxygen</td>
<td>0.1-1.0</td>
</tr>
<tr>
<td>Sulfides, disulfides, mercaptanes, etc.</td>
<td>0-1.0</td>
</tr>
<tr>
<td>Ammonia</td>
<td>0.1-1.0</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>0-0.2</td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>0-0.2</td>
</tr>
<tr>
<td>Trace constituents</td>
<td>0.01-0.6</td>
</tr>
</tbody>
</table>

**Characteristics**

- **Temperature, °C**: 38-76
- **Specific gravity**: 1.02-1.06
- **Moisture content**: Saturated
- **High heating values, MJ/m³**: 15-20

**CH₄ and CO₂ are the principle gases produced from anaerobic decomposition of biodegradable organic waste components in MSW**
Anaerobic decomposition in landfill

Complex Organics
(Carbohydrates, proteins, lipids)

→

Mono and Oligomers
(sugars, amino acids, long-chained fatty acids)

→

Intermediates
(Propionate, butyrate, alcohols)

→

H₂ + CO₂

→

Acetate

→

CH₄ + CO₂

1. Hydrolysis
2. Fermentation
3. Acetogenesis
4. Methanogenesis

Generalized Phases of A Landfill:
I. Initial adjustment phase

- Biological decomposition occurs under aerobic conditions, because a certain amount of air is trapped within the landfill.
- The principle source of aerobic and anaerobic m.o.’s responsible for waste decompostion is the soil material used as intermediate cover.
- Wastewater treatment plant sludges disposed of to landfills and recycled leachate are other sources of m.o.’s.
II. Transition phase

- Oxygen is depleted and anaerobic conditions begin to develop.
- As landfill becomes anaerobic, nitrate and sulfate (e- acceptors) are often reduced to $N_2$ and $H_2S$ gases.
- Reduction of nitrate and sulfate occur at -50 to -100 mV (ORP).
- pH of leachate starts to drop due to the presence of VFAs and effects of elevated $CO_2$ concentrations within the landfill.

III. Acid formation phase

- Complex organics (lipids, proteins, carbohydrates) are first hydrolyzed to simpler compounds (long-chain fatty acids, amino acids, and sugars) and then fermented to intermediate products (VFAs, alcohols).
- Significant amounts of VFAs and small amount of $H_2$ are produced.
- $CO_2$ is the principle gas generated.
- M.o.’s are facultative and anaerobic acidogens (fermentative bacteria).
III. Acid formation phase

- pH of leachate often drops to 5 or below because of high concentrations of VFAs and CO$_2$.
- Due to the dissolution of VFAs in leachate BOD$_5$, COD and conductivity increase significantly.
- Because of low pH values, heavy metals are solubilized.
- If leachate is not recycled, essential nutrients are lost from the system.

IV. Methane formation phase

- Acetic acid and H$_2$ formed by acidogens are converted to CH$_4$ and CO$_2$ by strict anaerobes called methanogens.
- Because the acetic acid (VFAs) are consumed, pH rises to 6.8-8.
- Concentration of COD and BOD$_5$ and conductivity are reduced.
- With higher pH values, fewer inorganic constituents (heavy metals) remain in leachate.
V. Maturation phase

- Occurs after the readily available biodegradable organic material has been converted to CO\textsubscript{2} and CH\textsubscript{4}.
- Landfill gas generation diminished significantly. Small amounts of O\textsubscript{2} and N\textsubscript{2} may found in landfill gas as well as CO\textsubscript{2} and CH\textsubscript{4}.
- Leachate often contains humic and fulvic acids, which are difficult to process further.

### Variation in gas production with time

Figure 11-12

Graphical representation of gas production over a five-year period from the rapidly and slowly decomposable organic materials placed in landfill.
Movement of Landfill Gas

- In an active landfill, the internal pressure is usually greater than atmospheric pressure and landfill gas is released by:
  - Convection (pressure-driven)
  - Diffusion
- Sorption of the gasses into liquid or solid components and
- Generation or consumption of a gas component through chemical reactions or biological activity influence the movement of landfill gas.

Control of Landfill Gases

- The movement of landfill gases is controlled:
  - to reduce atmospheric emissions,
  - to minimize the release of odorous emissions,
  - to minimize subsurface gas migrations and
  - to allow the recovery of energy from methane.
- In **passive control** systems, the pressure of the gas that is generated within landfill serves as the driving force for the movement of the gas.
- In **active control** systems, energy in the form of an induced vacuum is used to control the flow of gas.
Perimeter interceptor trench filled with gravel and horizontal perforated pipes are used to intercept the lateral movement of landfill gases. Perforated pipe is connected to vertical risers through which the landfill gas that collects in the trench backfill can be vented to atmosphere without a liner.

Passive control of landfill gasses

Perimeter barrier trenches (or slurry walls), usually filled with impermeable materials such as bentonite or clay slurries, are used to prevent the lateral subsurface gas movement. Landfill gas is removed from the inside face of the barrier with gas vents.
Impermeable liners (compacted clay and geomembranes) are used in modern landfills to control the movement of gases as well as leachate. Single and multilayer configurations are applicable.

Passive control of landfill gasses

Lateral migration of landfill gas can be reduced by relieving gas pressure with gas vents installed through the final cover.

Landfill gas vents and flares

Gas vents can be connected together and equipped with a gas burner/flare
Active control of landfill gasses

- Both vertical and horizontal gas wells are used for extraction of landfill gas from within landfill.
- The wells are spaced so that their radii of influence overlap.
- For deep landfills with a composite cover containing a geomembrane a 50-60 m spacing is common for landfill gas extraction wells.
- In landfills with clay and soil covers, a closer spacing (30 m) may be required to avoid pulling atmospheric gases in.
- Vertical gas extraction wells are usually installed after the landfill or portion of the landfill have been completed.
Active control of landfill gasses

Equilateral triangular distribution for vertical gas extraction wells

Management of Landfill Gas

- **Flaring (thermal destruction)**
  - CH$_4$ and VOCs in landfill gas are combusted in the presence of oxygen contained in air to CO$_2$, SO$_2$, NO$_x$ and other related gases.

- **Energy recovery**
  - Landfill gas is usually converted to electricity using internal combustion engines, gas or steam turbines.

- **Gas purification and recovery**
  - Separation of CO$_2$ from CH$_4$ can be accomplished by physical/chemical adsorption and membrane separation.
Composition, Formation and Control of Landfill Leachate

Leachate is the liquid that percolates through solid waste and extracts dissolved and suspended materials.

### Table 11.19
Typical data on the composition of leachate from new and mature landfills

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Value, mg/L*</th>
<th>Range</th>
<th>Typical</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>4.5–7.5</td>
<td>6</td>
<td>6.0–7.5</td>
</tr>
<tr>
<td>Total hardness as CaCO₃</td>
<td>300–10,000</td>
<td>3,500</td>
<td>200–500</td>
</tr>
<tr>
<td>Calcium</td>
<td>500–3,000</td>
<td>1,000</td>
<td>100–400</td>
</tr>
<tr>
<td>Magnesium</td>
<td>50–1,500</td>
<td>250</td>
<td>50–200</td>
</tr>
<tr>
<td>Potassium</td>
<td>200–1,000</td>
<td>500</td>
<td>300–400</td>
</tr>
<tr>
<td>Sodium</td>
<td>200–2,500</td>
<td>500</td>
<td>100–200</td>
</tr>
<tr>
<td>Chloride</td>
<td>200–3,000</td>
<td>500</td>
<td>100–400</td>
</tr>
<tr>
<td>Sulfate</td>
<td>50–1,200</td>
<td>60</td>
<td>30–200</td>
</tr>
</tbody>
</table>

* Concentrations may vary with storage conditions.

### Water balance and leachate generation in landfills

**Water (vapour) out in the landfill gas**

**Water in repacked landfill**

**Water in the control volume**

**Water in leachate generation**

**Water in liquid waste**

**Water from in situ leachate**

**Water in cover material**

**Water in from above**

**Intermediate cover material**

**Unit area**

**Control volume**

**Water out from below**

*Definition sketch for water balance used to assess leachate formation in a landfill.*
Control of leachate in landfills

**Single-composite barrier types**

Double-composite barrier types: The first liner is the primary liner or the leachate collection system. The second liner is leachate detection layer. Leachate detection probes are placed between the first and second liner.

Leachate collection systems

Leachate collection system with graded terraces
Leachate collection systems

Leachate collection system using multiple leachate collection pipes

Leachate management options

- **Leachate recycling**
  - An effective method for the treatment of leachate is to collect and recirculate the leachate through the landfill.

- **Leachate evaporation**
  - One of the simplest leachate management systems involves the use of lined leachate evaporation ponds.

- **Leachate treatment**
  - Where leachate recycling and evaporation is not used and the direct disposal of leachate to a WWTP is not possible, some form of pretreatment or complete treatment will be required.

- **Discharge to municipal wastewater collection system**
Treatment of leachate: Chemical & physical operations Table 11-18

<table>
<thead>
<tr>
<th>Treatment process</th>
<th>Application</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical processes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neutralization</td>
<td>pH control</td>
<td>Of limited applicability to most leachates</td>
</tr>
<tr>
<td>Precipitation</td>
<td>Removal of metals and some anions</td>
<td>Produces a sludge, possibly requiring disposal as a hazardous waste</td>
</tr>
<tr>
<td>Oxidation</td>
<td>Removal of organics; denitrification of some inorganic species</td>
<td>Works best on dilute waste streams; use of chlorine can result in formation of chlorinated hydrocarbons</td>
</tr>
<tr>
<td>Wet air oxidation</td>
<td>Removal of organics</td>
<td>Costly; works well on refractory organics</td>
</tr>
<tr>
<td>Physical operations</td>
<td>Removal of suspended matter</td>
<td>Of limited applicability alone; may be used in conjunction with other treatment processes</td>
</tr>
<tr>
<td>Filtration</td>
<td>Removal of suspended matter</td>
<td>Useful only as a polishing step</td>
</tr>
<tr>
<td>Air stripping</td>
<td>Removal of ammonia or volatile organics</td>
<td>May require air pollution control equipment</td>
</tr>
<tr>
<td>Steam stripping</td>
<td>Removal of volatile organics</td>
<td>High energy costs; condensate steam requires further treatment</td>
</tr>
<tr>
<td>Adsorption</td>
<td>Removal of organics</td>
<td>Proven technology; variable costs depending on leachate</td>
</tr>
<tr>
<td>Ion exchange</td>
<td>Removal of dissolved inorganics</td>
<td>Useful only as a polishing step</td>
</tr>
<tr>
<td>Ultrafiltration</td>
<td>Removal of bacteria and high molecular weight organics</td>
<td>Subject to fouling; of limited applicability to leachate</td>
</tr>
<tr>
<td>Reverse osmosis</td>
<td>Dilute solutions of inorganics</td>
<td>Costly; extensive pretreatment necessary</td>
</tr>
<tr>
<td>Evaporation</td>
<td>Where leachate discharge is not permissible</td>
<td>Resulting sludge may be hazardous; can be costly except in and around urban areas</td>
</tr>
</tbody>
</table>

Treatment of leachate: Biological processes Table 11-18

<table>
<thead>
<tr>
<th>Treatment process</th>
<th>Application</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biological processes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activated sludge</td>
<td>Removal of organics</td>
<td>Defoaming additives may be necessary; separate clarifier needed</td>
</tr>
<tr>
<td>Sequencing batch reactors</td>
<td>Removal of organics</td>
<td>Similar to activated sludge, but no separate clarifier needed; only applicable to relatively low flow rates</td>
</tr>
<tr>
<td>Aerated stabilization basins</td>
<td>Removal of organics</td>
<td>Requires large land area</td>
</tr>
<tr>
<td>Fixed film processes (trickling filters, rotating biological contactors)</td>
<td>Removal of organics</td>
<td>Commonly used on industrial effluents similar to leachates, but not tested on actual landfill leachates</td>
</tr>
<tr>
<td>Anaerobic lagoons and contactors</td>
<td>Removal of organics</td>
<td>Lower power requirements and sludge production than aerobic systems; requires heating; greater potential for process instability, slower than aerobic systems</td>
</tr>
<tr>
<td>Nitrification/denitrification</td>
<td>Removal of nitrogen</td>
<td>Nitrification/denitrification can be accomplished simultaneously with the removal of organics</td>
</tr>
</tbody>
</table>
Treatment of leachate

- Anaerobic leachate treatment processes
- Aerobic leachate treatment processes
- Chemical treatment process for removal of heavy metals and organics
Surface Water Management

- Equally important in controlling the movement of leachate is the management of all surface waters including rainfall, stormwater runoff, intermittent streams and artesian springs.

- Surface water control systems:
  - Surface water drainage facilities
  - Stormwater storage basins
  - Intermediate cover layers
  - Final cover layers

Intermediate cover layers

- They are used to cover the wastes placed each day to eliminate harboring disease, to enhance aesthetic appearance of landfill site and to limit the amount of surface infiltration.

- The greatest amount of water that enters a landfill and becomes leachate enters during the period when the landfill is being filled.

- Materials and method of placement of the intermediate cover can limit the amount of surface water that enters the landfill.
Intermediate cover layers

- If the amount of native soil available for use as intermediate cover is limited, alternative materials can be used.
- Compost produced from yard waste and MSW, geosynthetic clay liner and clay are the alternative materials effective in limiting the surface water into the landfill.
- Composted MSW need not be cured fully before being used as intermediate cover.
- Use of composted MSW increases the capacity of landfill.

Final cover layers

Typical landfill final cover configurations

<table>
<thead>
<tr>
<th>Surface layer</th>
<th>Protective layer</th>
<th>Drainage layer</th>
<th>Barrier layer</th>
<th>Subbase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cover soil, available locally or imported</td>
<td>Sand, gravel or geonet and geotextile separator</td>
<td>Geomembrane</td>
<td>Compacted and graded native soil</td>
<td>Typical components that constitute a landfill cover</td>
</tr>
</tbody>
</table>
Important topics that must be considered in a landfill design
- Layout of landfill site
- Types of wastes that must be handled
- The need for a convenience transfer station
- Estimation of landfill capacity
- Evaluation of the geology and hydrology of the site
- Selection of landfill gas and leachate control facilities
- Layout of surface drainage facilities
- Aesthetic design considerations
- Monitoring facilities
- Determination of equipment requirements
- Development of an operations plan

In planning the layout of a landfill site, the location of the following must be determined:
- Access roads, office space and plantings
- Equipment shelters and (if used) scales
- Storage and/or disposal sites for special wastes
- Areas to be used for waste processing
- Areas for stockpiling cover material
- Drainage facilities
- Location of landfill gas management facilities
- Location of leachate treatment facilities
- Location of monitoring wells
**Layout of Landfill Sites**

- Site Management Office
- Control and Reception of Waste
- Water Quality Monitoring Boreholes
- Landfill Gas Monitoring Boreholes
- Landfill Gas Control System
- Working Area
- Basal Engineering
- Restoration
- Landfill Gas Extraction System
- Power Generation Plant
- Visual Intrusion
- Leachate Control
- Landfill Gas Flare
- Waste Degradation and Stabilisation

**Design of Landfills**

- Important factors to consider in the design of landfills
  - Access (roads to landfill site, temporary roads to unloading area)
  - Land area (large enough for 10-25 years)
  - Landfilling method (excavated cell/trench, area, canyon)
  - Completed landfill characteristics (slope of final cover: 3-6%)
  - Surface drainage (to divert surface water runoff)
  - Intermediate cover material (waste to cover ratio: 5-10 to 1)
  - Final cover (multilayer design)
  - Landfill liner (multilayer design, leachate collection system)
  - Cell design and construction
Design of Landfills

- Important factors to consider in the design of landfills
  - Groundwater protection (divert any underground springs)
  - Landfill gas management (passive and active control)
  - Leachate collection (determine $Q_{\text{max}}$ and size of collection pipes)
  - Leachate treatment (Based on expected leachate flow rate and discharge standards select the appropriate treatment process)
  - Environmental requirements (gas and liquid monitoring facilities)
  - Equipment requirements
  - Fire prevention

Typical equipment used at landfills

![Typical equipment used at landfills](image)

*Figure 11-68* Typical equipment used at landfills for the placement and covering of solid waste.
Landfill Closure and Postclosure Care

- They are the terms used to describe what is to happen to a completed landfill in the future.
- Development of Long-Term Closure Plan
  - Cover and landscape design
  - Control of landfill gases
  - Collection and treatment of leachate
  - Environmental monitoring systems
- Postclosure Care
  - Routine inspections
  - Infrastructure maintenance
  - Environmental monitoring systems

TEKNİK GEZİ İLANI

22 Mayıs 2012 Salı;
- Göktürk-Odayeri Düzenli Katı Atık Depolama Sahası
- Sızıntı Suyu Arıtma Tesisi
- Tibbi Atık Yakma Tesisi ve
- Kemerburgaz Kompost ve Geri Kazanım Tesisi’ne teknik gezi düzenlenecektir.

Hareket saati : 09:00
Toplanma yeri : MB-Binası giriş
Hareket yeri : Göztepe Kampüsü büyük otopark
Gezi sorumlusu : Esin Bozkurt

Katılım zorunludur, katılamayanlar sebebini resmi olarak belirlemelidir.