



# Landfill Off-Gas Collection and Treatment Systems

An Online Continuing Education Course for Engineers

**Course Number: EN-8021**

**Credit: 8 Hours / 8 PDH / 8 CPD**

## CHAPTER 1

### Introduction

**1.1. Background.** This course provides information about the design of systems to monitor, collect, transport, and treat off-gas from municipal, industrial and hazardous waste landfills. The course describes various landfill gas (LFG) emission control techniques and presents design procedures relative to each. The following topics are discussed in this course:

- Reasons for LFG control.
- Theory of LFG emissions.
- LFG and condensate characteristics.
- Estimation of LFG production.
- LFG collection and treatment design considerations.
- Operation and maintenance requirements.
- Regulatory requirements.

1.1.1. *Reasons for Landfill Gas Control.* The following is a list of common reasons for controlling the gas produced by a landfill:

- Prevent air pollution and comply with regulatory air emission criteria.
- Reduce hazards due to off-site migration.
- Prevent damage to the landfill cover slope stability.
- Odor control.
- Energy recovery.
- Prevent vegetation distress.

1.1.2. *Gas Generation Mechanisms.* LFG emissions are governed by gas-generation mechanisms and gas-transport mechanisms. The following paragraphs describe these mechanisms and the major factors influencing gas generation and transport. The three primary causes of LFG generation are volatilization, biological decomposition, and chemical reactions.

1.1.2.1. *Volatilization.* Volatilization is due to the change of chemical phase equilibrium that exists within the landfill. Organic compounds in the landfill volatilize until the equilibrium vapor concentration is reached. This process is accelerated when biological activity increases the temperature of the waste mass. The rate at which compounds volatilize depends on their physical and chemical properties. Some of these properties are discussed in the following paragraphs.

1.1.2.2. *Vapor Pressure.* Vapor pressure quantifies the tendency of a pure liquid compound to partition to the vapor phase. Liquid molecules that possess sufficient kinetic energy are projected out of the main body of a liquid at its free surface and pass into vapor. The pressure exerted by this vapor is known as the vapor pressure. The vapor pressure of water at 20° C (68° F) is 2.34 kN/m<sup>2</sup> (0.339 psi). Pressure conversion factors are given in Table 1-1.

**Table 1-1.  
Pressure Conversion Factors.**

10 <sup>3</sup> N/m <sup>2</sup>	=	1 kPa
1 psi	=	6.895 kPa
12 inches of water (at 4°C)	=	0.433 psi
1 inches of water (at 4°C)	=	1.87 mm Hg
29.92 inches of Hg	=	1 Atmosphere

1.1.2.3. *Henry's Law Constant.* Henry's Law determines the extent of volatilization of a contaminant dissolved in water. Henry's Law states: The amount of any gas that will dissolve in a given volume of liquid, at constant temperature, is directly proportional to the pressure that the gas exerts above the liquid. Henry's Law is presented in the formula:

$$P_A = H_A \times X_A$$

where

$P_A$  = partial pressure of compound A in the gas phase

$H_A$  = Henry's constant of compound A

$X_A$  = mole fraction of compound A in liquid phase in equilibrium with the gas phase.

Henry's constant quantifies the tendency for a volatile in landfill leachate to partition to the vapor phase. This constant is temperature-dependent, increasing with increasing temperature.

1.1.3. *Biological Decomposition.* Sanitary landfills produce large quantities of gas, with the major components being methane (CH<sub>4</sub>) and carbon dioxide (CO<sub>2</sub>). LFG generation occurs as a result of two conditions, aerobic and anaerobic decomposition and can be divided into three distinct phases, however, it is important to understand that there will be both aerobic and anaerobic degradation occurring at the same time.

1.1.3.1. *Phase 1—Aerobic Decomposition.* During the aerobic decomposition phase, microorganisms slowly degrade the complex organic portions of the waste using the O<sub>2</sub> trapped during the landfilling process to form simpler organic compounds, CO<sub>2</sub>, and water. Aerobic decomposition begins shortly after the waste is placed in the landfill and continues until all of the entrained O<sub>2</sub> is depleted from the voids and from within the organic waste. Aerobic bacteria produce a gas characterized by high temperatures, high CO<sub>2</sub> content (30 percent), and low CH<sub>4</sub> content (2 to 5 percent).

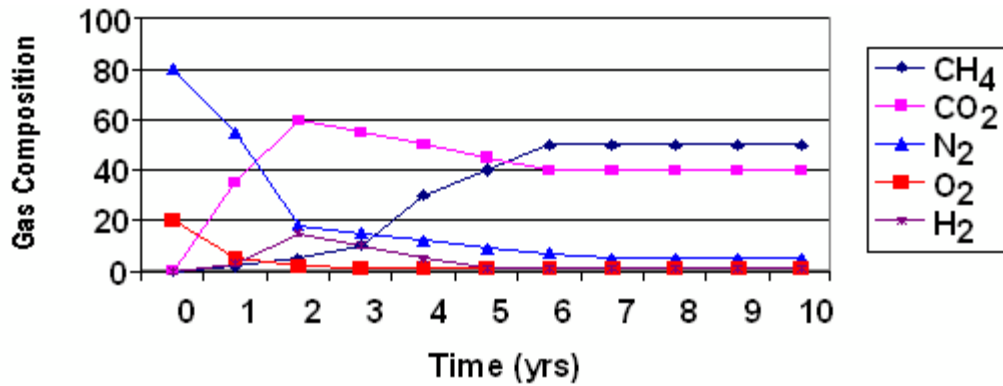
Aerobic decomposition within the landfill typically lasts for several months, however, due to air exchange between the atmosphere and the landfill, there may always be some aerobic degradation

occurring at the edges of the waste. Aerobic degradation generally degrades many of the larger polymers such as starches, cellulose, lignins, proteins, and fats into smaller, more available oligomers (polymer consisting of 2 to 4 monomers). These oligomers can then be further degraded into dimers (molecules consisting of two identical simpler molecules) and monomers such as sugars, peptides, amino acids, long-chain fatty acids, glycerol and eventually organic acids. These less complex products of aerobic degradation are more readily degraded anaerobically than the larger polymers.

1.1.3.2. *Phase 2—Anaerobic Decomposition.* Anaerobic decomposition occurs in two distinct phases. When all of the entrained  $O_2$  is depleted from the waste, the waste decomposition changes from aerobic to anaerobic and two new groups of bacteria emerge which thrive in anaerobic environments. Facultative microbes convert the simple monomers into mixed acid products along with hydrogen and  $CO_2$ . Anaerobic bacteria convert the mixed volatile organic acids (e.g., formic, acetic, propionic and butyric acids), aldehydes and ketones into primarily acetic acid and hydrogen. These organic acids reduce the pH, which increases the solubility of some organics and inorganics, increasing the concentration of dissolved solids in the leachate.  $CH_4$  production can be limited during this stage since the low pH (5 to 6) is somewhat toxic to methanogenic (methane-producing) bacteria.

1.1.3.3. *Phase 3—Anaerobic Decomposition.* In the next phase of decomposition,  $CH_4$  forming bacteria utilize  $CO_2$ , hydrogen, and inorganic acids to form  $CH_4$  gas and other products. During this stage of anaerobic decomposition, the methanogenic bacteria become more prominent. These methanogens degrade the volatile acids, primarily acetic acid and use hydrogen to generate  $CH_4$  and  $CO_2$ . This degradation results in a more neutral pH (7 to 8) as the organic acids are consumed. A decrease in chemical oxygen demand (COD) and dissolved solids concentration within the leachate also occurs.

Phase 3 of the decomposition process is characterized by lower temperatures, high  $CO_2$  concentrations (40 to 48 percent), and significantly higher  $CH_4$  concentrations (45 to 57 percent). Anaerobic decomposition will continue until all of the volatile organic acids are depleted or until  $O_2$  is reintroduced into the waste. Figure 1.1 shows landfill gas composition trends versus time for the aerobic and anaerobic decomposition of landfill refuse.



**Figure 1.1. Landfill Gas Composition.**

1.1.4. *Chemical Reactions.* Chemical reactions between materials in the waste can release gases. Most of these potential reactions are buffered by the presence of water. However, unpredictable reactions are possible with so many compounds potentially present. The heat generated from biological processes also tends to accelerate the release rate of compounds produced by chemical reactions.

**1.2. Factors Affecting LFG Generation.** Gas generation in landfills is affected by several factors:

- Waste composition.
- Temperature.
- Moisture.
- pH.
- Atmospheric conditions.
- Landfill cover.
- Waste density.
- Waste age.

1.2.1. *Waste Composition.* The primary nutrients (macronutrients) required for bacterial growth in a landfill are carbon, hydrogen, oxygen, nitrogen, and phosphorus. Small amounts of other elements (micronutrients) such as sodium, potassium, sulfur, calcium, and magnesium are also required for bacterial growth. The availability of macronutrients in the landfill mass has an affect on both the volume of leachate generated from microbial processes and the composition of the generated gases. Landfills that accept municipal wastes generally have an adequate nutrient supply for most microbial processes to proceed. Specialized landfills that handle hazardous materials or munitions wastes only, may not have sufficient nutrients in the waste to sustain a large microbial population. The primary sources of macronutrients are yard wastes and food wastes. Micronutrient requirements are very small and can usually be met by the trace amounts found in wastes and/or leached from cover soils.

1.2.2. *Temperature.* The optimum temperature range for aerobic decomposition is 54 to 71°C (130 to 160°F), while the optimum temperature range for anaerobic bacteria is 30 to 41°C (85 to 105°F). A dramatic drop in activity of anaerobic bacteria has been noted at temperatures below 10°C (50°F).

1.2.3. *Moisture.* Moisture is needed for biological decomposition of waste. The moisture content of MSW as received typically ranges from 15 to 40 percent with an average of 25 percent. The moisture content can vary greatly in different zones of the landfill. Very low moisture content may prevent decomposition of waste and thus limit gas production. The optimum moisture content to maximize gas production is in the 50 to 60 percent range.

1.2.4. *pH.* The materials placed in a landfill can cause the pH of leachate within the landfill to vary widely. However, leachate is typically expected to be in the pH range of 5 to 9. The pH during CH<sub>4</sub> formation is generally in the range of 6.5 to 8.0. One concern during the acidic stages of the biological process (or any other time leachate within the landfill exhibits a low pH) is that the reduced pH will mobilize metals that may leach out of the landfill, or become toxic to the bacteria generating the gas.

1.2.5. *Atmospheric Conditions.* Atmospheric conditions affect the temperature, pressure, and moisture content within a landfill. Landfill covers and liners help to isolate waste from atmospheric conditions by limiting oxygen intrusion, limiting infiltration of precipitation, and buffering the effects of temperature changes.

1.2.5.1. *Temperature.* Cold climates will reduce biological activity in the surface layers, reducing the volume of gas generated. Deeper in the waste, the surface temperature affects are usually overcome by the heat generated by biological activity. The primary factors that affect temperature are waste depth, compacted density, microbial activity, chemical reactions, water content, and climate.

1.2.5.2. *Pressure.* Atmospheric pressure can have a minor affect on the rate at which landfill gas is released to the atmosphere. It can also influence the operation of gas extraction systems. A decrease in barometric pressure results in a temporary increase in LFG flow and an increase in barometric pressure will cause LFG flow to temporarily decrease. This is because the pressure within the landfill changes at a slower rate than the atmosphere and a pressure gradient temporarily develops between the inside and outside of the landfill until these pressures equalize.

1.2.5.3. *Precipitation.* Precipitation dramatically affects the gas generation process by supplying water to the process and by carrying dissolved O<sub>2</sub> into the waste with the water. High rates of precipitation may also flood sections of the landfill, which will obstruct gas flow. The amount of precipitation that reaches the waste is highly dependent on the type of landfill cover system.

