UNIT 4 WASTES LANDFILL GAS

Structure

4.1 Introduction
  Objectives
4.2 Landfill Gas Basic
  4.2.1 Landfill gas composition
  4.2.2 Phases of Bacterial Decomposition of Landfill Waste
  4.2.3 Conditions affecting landfill gas production
  4.2.4 Conditions governing landfill gas migration
  4.2.5 Types of landfills found in communities
  4.2.6 Landfill gas emissions regulations
4.3 Landfill Gas Safety and Health Issues
  4.3.1 Landfill gas exposures
  4.3.2 Explosion Hazards
  4.3.3 Types of gases that can pose an explosion hazard
  4.3.4 Health Issues Associated with Landfill Gas Emissions
  4.3.5 Landfill gas odor and its trigger
4.4 Monitoring of Landfill Gases
  4.4.1 Landfill Gas Sampling Approaches: An Overview
  4.4.2 Soil Gas Monitoring
  4.4.3 Soil gas sample collection methods
  4.4.4 Surface Gas Monitoring
  4.4.5 Methods of near surface gas monitoring
  4.4.6 Near surface gas monitoring data
  4.4.7 Emissions Monitoring
4.5 Landfill Gas Control Measures
  4.5.1 Components of a landfill gas control plan
  4.5.2 Landfill gas collection
  4.5.3 Methods available for treatment of landfill gas
  4.5.4 Beneficial uses for collection of landfill gas
4.6 Landfill Gas collection system
  4.6.1 Gas Extraction and Transportation
  4.6.2 Design Aids for a Gas Collection System
  4.6.3 Gas Extraction and Faring
  4.6.4 Monitoring, Control, and Conclusions

4.1 Introduction

Disposal of household and light industrial and commercial wastes is a necessity. Although there are several technologies available to handle these wastes, the most common means of disposal remains the municipal solid waste (MSW) landfill. With thousands of MSW landfills across the nation, it is not surprising that over the past 15 years, the Agency for Toxic Substances and Disease Registry (ATSDR) has received many requests for technical assistance and consultation about landfill issues. One of the most common requests is to evaluate the public health implications of landfill gas releases.

Landfill gas releases may represent physical (explosion), chemical (substances in ambient or indoor air), and/or physiologic or quality of life (odor) public health concerns for those who live and work near (or on) a landfill. This primer is intended to provide the environmental health professional, as well as the interested community member, with a basic understanding of landfill gases and how they should be viewed and evaluated from a public health perspective. It provides answers to questions that ATSDR has received from federal agencies, tribes, state and local health departments, and communities. Generally, well-maintained and operated MSW landfills will not be of public health concern or a nuisance to nearby neighbors. However, because much is left to be learned about the health effects that may result from exposures to low levels of ambient air contaminants and mixtures of these contaminants, environmental health professionals should exert care when assessing landfill gas issues.

Objectives

After studying this unit, you should be able to

- Emission of Landfill gases
- Composition of landfill gases
- Monitoring of landfill gases
- Collection of landfill gases

4.2 Landfill Gas Basics

This chapter provides basic information about landfill gas—what it is composed of, how it is produced, and the conditions that affect its production. It also provides information about how landfill gas moves and travels away from the landfill site. Finally, the chapter presents an overview of the types of landfills that might be present in your community and the regulatory requirements that apply to each.

4.2.1 Landfill gas composition

Landfill gas is composed of a mixture of hundreds of different gases. By volume, landfill gas typically contains 45% to 60% methane and 40% to 60% carbon dioxide. Landfill gas also includes small amounts of nitrogen, oxygen, ammonia, sulfides, hydrogen, carbon monoxide, and nonmethane organic compounds (NMOCs) such as trichloroethylene, benzene, and vinyl chloride. Table 4.1 lists "typical" landfill gases, their percent by volume, and their characteristics.

How is landfill gas produced?

Three processes—bacterial decomposition, volatilization, and chemical reactions—form landfill gas.

Bacterial decomposition: Most landfill gas is produced by bacterial decomposition, which occurs when organic waste is broken down by bacteria naturally present in the waste and in the soil used to cover the landfill. Organic wastes include food, garden waste, street sweepings, textiles, and wood and paper products. Bacteria decompose organic waste in four phases, and the composition of the gas changes during each phase.

Volatilization: Landfill gases can be created when certain wastes, particularly organic compounds, change from a liquid or a solid into a vapor. This process is known as volatilization. NMOCs in landfill gas may be the result of volatilization of certain chemicals disposed of in the landfill.

Chemical reactions: Landfill gas, including NMOCs, can be created by the reactions of certain chemicals present in waste. For example, if chlorine bleach and ammonia come in contact with each other within the landfill, a harmful gas is produced.

Table 4-1: Typical Landfill Gas Components		
Component	Percent by Volume	Characteristics
Methane	45–60	Methane is a naturally occurring gas. It is colorless andodorless. Landfills are the single largest source of U.S. man-made methane emissions
carbon dioxide	40–60	Carbon dioxide is naturally found at small concentrations in the atmosphere (0.03%). It is colorless, odorless, and slightly acidic.
Nitrogen	2–5	Nitrogen comprises approximately 79% of the atmosphere. It is odorless, tasteless, and colorless.
Oxygen	0.1–1	Oxygen comprises approximately 21% of the atmosphere. It is odorless, tasteless, and colorless.
Ammonia	0.1–1	Ammonia is a colorless gas with a pungent odor.
NMOCs (non-methane organic compounds)	0.01–0.6	NMOCs are organic compounds (i.e., compounds that contain carbon). (Methane is an organic compound but is not considered an NMOC.) NMOCs may occur naturally or be formed by synthetic chemical processes. NMOCs most commonly found in landfills include acrylonitrile, benzene, 1,1-dichloroethane, 1,2-cis dichloroethylene, dichloromethane, carbonyl sulfide, ethyl-benzene, hexane, methyl ethyl ketone, tetrachloroethylene, toluene, trichloroethylene, vinyl chloride, and xylenes.
Sulfides	0–1	Sulfides are naturally occurring gases that give the landfill gas mixture its rotten-egg smell. Sulfides can cause unpleasant odors even at very low concentrations.
Hydrogen	0–0.2	Hydrogen is an odorless, colorless gas.
carbon monoxide	0–0.2	Carbon monoxide is an odorless, colorless gas.

4.2.2 Phases of Bacterial Decomposition of Landfill Waste

Bacteria decompose landfill waste in four phases. The composition of the gas produced changes with each of the four phases of decomposition. Landfills often accept waste over a 20- to 30-year period, so waste in a landfill may be undergoing several phases of decomposition at once. This means that older waste in one area might be in a different phase of decomposition than more recently buried waste in another area.

Phase I (Hydrolysis):

During the first phase of decomposition, aerobic bacteria—bacteria that live only in the presence of oxygen—consume oxygen while breaking down the long molecular chains of complex carbohydrates, proteins, and lipids that comprise organic waste. The primary byproduct of this process is carbon dioxide. Nitrogen content is high at the beginning of this phase, but declines as the landfill moves through the four phases. Phase I continues until available oxygen is depleted. Phase I decomposition can last for days or months, depending on how much oxygen is present when the waste is disposed of in the landfill. Oxygen levels will vary according to factors such as how loose or compressed the waste was when it was buried.

Phase II (Acidogenesis):

Phase II decomposition starts after the oxygen in the landfill has been used up. Using an anaerobic process (a process that does not require oxygen), bacteria convert compounds created by aerobic bacteria into acetic, lactic, and formic acids and alcohols such as methanol and ethanol. The landfill becomes highly acidic. As the acids mix with the moisture present in the land-fill, they cause certain nutrients to dissolve, making nitrogen and phosphorus available to the increasingly diverse species of bacteria in the landfill. The gaseous byproducts of these processes are carbon dioxide and hydrogen. If the landfill is disturbed or if oxygen is somehow introduced into the landfill, microbial processes will return to Phase I.

Phase III (Acetogenesis):

Phase III decomposition starts when certain kinds of anaerobic bacteria consume the organic acids produced in Phase II and form acetate, an organic acid. This process causes the landfill to become a more neutral environment in which methane-producing bacteria begin to establish themselves. Methane-and acid-producing bacteria have a symbiotic, or mutually beneficial, relationship. Acid-producing bacteria create compounds for the methanogenic bacteria to consume. Methanogenic bacteria consume the carbon dioxide and acetate, too much of which would be toxic to the acid-producing bacteria.

Phase IV (Methanogenesis):

Phase IV decomposition begins when both the composition and production rates of landfill gas remain relatively constant. Phase IV landfill gas usually contains approximately 45% to 60% methane by volume, 40% to 60% carbon dioxide, and 2% to 9% other gases, such as sulfides. Gas is produced at a stable rate in Phase IV, typically for about 20 years; however, gas will continue to be emitted for 50 or more years after the waste is placed in the landfill. Gas production might last longer, for example, if greater amounts of organics are present in the waste, such as at a landfill receiving higher than average amounts of domestic animal waste.

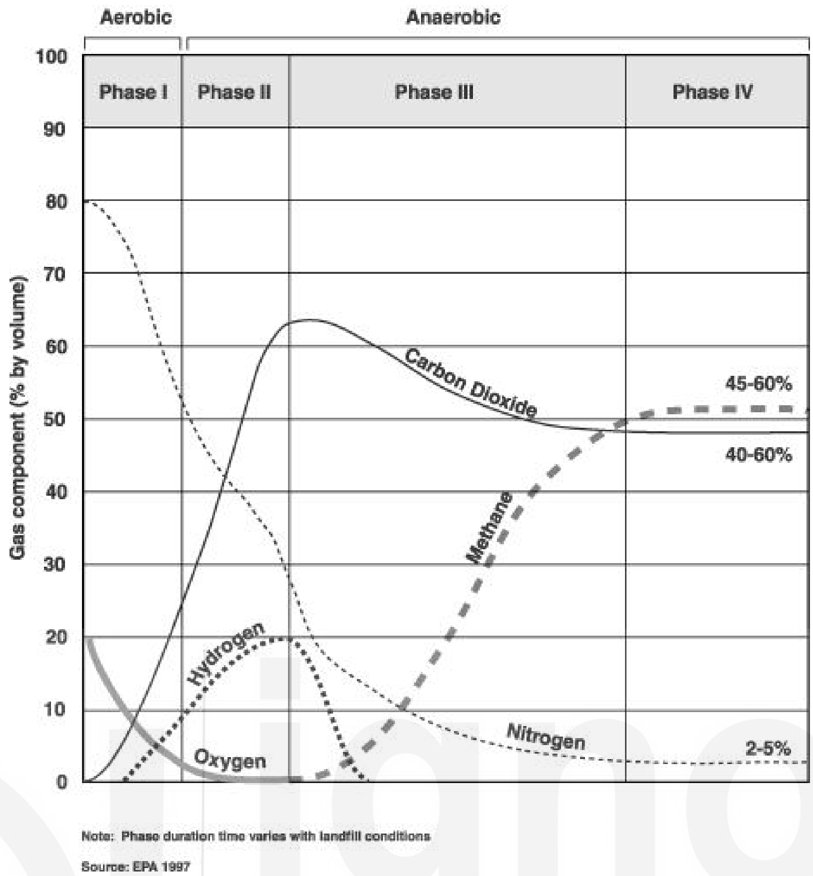

Figure 4.1: Production phases of typical landfill gas

4.2.3 Conditions affecting landfill gas production.

The rate and volume of landfill gas produced at a specific site depend on the characteristics of the waste (e.g., composition and age of the refuse) and a number of environmental factors (e.g., the presence of oxygen in the landfill, moisture content, and temperature).

Waste composition: The more organic waste present in a landfill, the more landfill gas (e.g., carbon dioxide, methane, nitrogen, and hydrogen sulfide) is produced by the bacteria during decomposition. The more chemicals disposed of in the landfill, the more likely NMOCs and other gases will be produced either through volatilization or chemical reactions.

Age of refuse: Generally, more recently buried waste (i.e., waste buried less than 10 years) produces more landfill gas through bacterial decomposition, volatilization, and chemical reactions than does older waste (buried more than 10 years). Peak gas production usually occurs from 5 to 7 years after the waste is buried.

Presence of oxygen in the landfill: Methane will be produced only when oxygen is no longer present in the landfill.

Moisture content: The presence of moisture (unsaturated conditions) in a landfill increases gas production because it encourages bacterial decomposition. Moisture may also promote chemical reactions that produce gases.

Temperature: As the landfill's temperature rises, bacterial activity increases, resulting in increased gas production. Increased temperature may also increase rates of volatilization and chemical reactions. The box on the following page provides more detailed information about how these variables affect the rate and volume of landfill gas production.

Waste Composition: The more organic waste present in a landfill, the more landfill gas is produced by bacterial decomposition. Some types of organic waste contain nutrients, such as sodium, potassium, calcium, and magnesium that help bacteria thrive. When these nutrients are present, landfill gas production increases. Alternatively, some wastes contain compounds that harm bacteria, causing less gas to be produced. For example, methane-producing bacteria can be inhibited when waste has high salt concentrations.

4.2.4 Conditions governing landfill gas migration

The direction, speed, and distance of landfill gas migration depend on a number of factors, described below.

- Landfill cover type: If the landfill cover consists of relatively permeable material, such as gravel or sand, then gas will likely migrate up through the landfill cover. If the landfill cover consists of silts and clays, it is not very permeable; gas will then tend to migrate horizontally underground. If one area of the landfill is more permeable than the rest, gas will migrate through that area.
- Natural and man-made pathways: Drains, trenches, and buried utility corridors (such as tunnels and pipelines) can act as conduits for gas movement. The natural geology often provides underground pathways, such as fractured rock, porous soil, and buried stream channels, where the gas can migrate.
- Wind speed and direction: Landfill gas naturally vented into the air at the landfill surface is carried by the wind. The wind dilutes the gas with fresh air as it moves it to areas beyond the landfill. Wind speed and direction determine the gas's concentration in the air, which can vary greatly from day to day, even hour by hour. In the early morning, for example, winds tend to be gentle and provide the least dilution and dispersion of the gas to other areas.
- Moisture: Wet surface soil conditions may prevent landfill gas from migrating through the top of the landfill into the air above. Rain and moisture may also seep into the pore spaces in the landfill and "push out" gases in these spaces.
- Groundwater levels: Gas movement is influenced by variations in the groundwater table. If the water table is rising into an area, it will force the landfill gas upward.
- Temperature: Increases in temperature stimulate gas particle movement, tending also to increase gas diffusion, so that landfill gas might spread more quickly in warmer conditions. Although the landfill itself generally maintains a stable temperature, freezing and thawing cycles can cause the soil's surface to crack, causing landfill gas to migrate upward or horizontally. Frozen soil over the landfill may provide a physical barrier to upward landfill gas migration, causing the gas to migrate further from the landfill horizontally through soil.
- Barometric and soil gas pressure: The difference between the soil gas pressure and barometric pressure allows gas to move either vertically or laterally, depending on whether the barometric pressure is higher or lower than the soil gas pressure. When barometric pressure is falling, landfill gas will tend to migrate out of the landfill into surrounding areas. As barometric pressure rises, gas may be retained in the landfill temporarily as new pressure balances are established.

4.2.5 Types of landfills found in communities

- Municipal solid waste (MSW) landfills are used to dispose of household wastes and non-hazardous commercial and industrial wastes. More than 6,000 MSW landfills exist across the United States, although fewer than 3,000 of these are currently active and accepting waste. Landfills constructed after 1979 are required, under Subtitle D of the Resource Conservation and Recovery Act (RCRA), to be designed and operated to prevent contaminant migration to the environment. This design may include liners or collection systems.
- Open dumps are waste disposal areas that were used before 1979 and constructed without any engineering design and siting criteria, and few, if any, regulatory controls. Open dumps do not meet the RCRA Subtitle D regulations. Open dumps may have accepted household wastes, similar to MSW landfills, as well as commercial and industrial wastes. These dumps did not have liners and rarely used daily cover for sanitary wastes. No precautions were taken to prevent contaminant migration to the environment.
- Construction and demolition (C&D) waste landfills are used for the disposal of construction and demolition waste such as wood, sheet rock, gypsum board, concrete, bricks, and paving materials. As with MSW landfills, C&D waste landfills containing nonhazardous materials are regulated under Subtitle D of RCRA.
- Hazardous waste landfills are used to dispose of wastes characterized under RCRA as "hazardous." These wastes include solvents, industrial wastes, and construction wastes such as asbestos.
- Vegetation waste disposal areas, also known as "yard waste and stump fill areas," are used to dispose of vegetation wastes. In areas where burning was prohibited, these areas were used by land developers to bury trees and brush cleared from land used for subdivisions and commercial developments.
- Animal waste landfills are areas where massive amounts of manure and, possibly, animal carcasses are disposed. There are no specific federal regulations for animal waste landfills. State regulations vary among the states that do regulate the animal waste landfills. As a result of the high organic content, methane production can be significant.

4.2.6 Landfill gas emissions regulations

Prior to 1979, landfills were often merely open dumps with few or no controls to prevent contaminant migration to the environment. Open dumps posed significant environmental and public health hazards. They attracted flies and vermin, and fires that could burn for days often broke out. These dumps had no gas collection systems, nor did they have liners to protect groundwater. Many state and local governments have regulated landfills since the middle of the twentieth century; however, before 1979, regulation and enforcement varied widely from site to site. In 1979, the federal government began regulating the siting, construction, operation, and closure requirements for landfills under RCRA. Subtitle D of RCRA addresses MSW and nonhazardous landfills and includes requirements for methane monitoring at the landfill perimeter. Subtitle C of RCRA addresses concerns associated with hazardous waste landfills. In 1996, EPA finalized regulations under the Clean Air Act (CAA)—the New Source Performance Standards and Emissions Guidelines (NSPS/EG)—that address methane and NMOC emissions from MSW landfills. These regulations are described in more detail below, according to the type of waste received by the landfill.

- Municipal solid wastes: Subtitle D of RCRA regulates the siting, design, construction, operation, monitoring, and closure of MSW landfills. RCRA establishes standards that MSW landfills must meet. These standards are enforced by the state solid waste authority. States may also develop additional standards that are more stringent than RCRA. RCRA requires that owners and operators of MSW landfills ensure that the concentration of methane gas generated by the facility does not exceed 25% of the lower explosive limit (LEL), the lowest percent by volume of an explosive gas in the air that will allow an explosion, for methane in facility structures and that the concentration of methane gas does not exceed the LEL for methane at the facility property boundary. If methane concentrations exceed the LEL at the property boundary, then RCRA requires the landfill owners/operators to notify the proper state authority and develop and implement a plan to correct the problem (see Chapter Three for more information about LELs). The state solid waste authority will determine whether the landfill has properly addressed the problem.

In 1996, EPA promulgated regulations under the CAA—NSPS/EG—that also address emissions from MSW landfills. The NSPS/EG require landfills that can hold 2.5 million megagrams (Mg) or more of waste and annually emit 50 Mg or more of NMOCs to install landfill gas collection systems and control landfill gas emissions. The collection systems must meet specific engineering design criteria. Control devices (usually a flare or some other combustion device) must reduce the NMOC emissions from the collected landfill gas by 98% or to a concentration of 20 ppm by volume. Those MSW landfills that are required to install controls based on their NMOC emission rate must also monitor surface methane emissions. If methane emissions are found at concentrations exceeding background levels by more than 500 parts per million (ppm) between 2 and 4 inches from the ground surface, the gas collection system must be adjusted or improved to achieve the 500 ppm level.

- Construction and demolition wastes: Most C&D waste is classified as nonhazardous and can be disposed of in an MSW landfill or in a C&D landfill (a landfill that accepts only C&D waste). The siting, design, construction, operation, monitoring, and closure of landfills containing nonhazardous C&D wastes are regulated under Subtitle D of RCRA. Air emissions from C&D landfills are not regulated and are not generally a concern, because C&D wastes do not contain much organic matter (which is necessary to produce landfill gas). However, if gypsum wallboard is present in C&D waste, hydrogen sulfide may be produced, particularly if moisture is introduced into the waste. Because of hydrogen sulfide's objectionable rotten-egg odor, C&D landfills that emit hydrogen sulfide often find themselves facing numerous complaints from the surrounding communities. Operators of these landfills often find that they must install gas control systems to reduce odors caused by the hydrogen sulfide gas.

- Hazardous wastes: The siting, design, construction, operation, monitoring, and closure of landfills containing hazardous wastes are regulated under Subtitle C of RCRA. Hazardous waste landfills are strictly regulated because they handle wastes that pose a greater risk to the public than nonhazardous household waste. Air emissions from hazardous waste landfills are not specifically regulated under RCRA Subtitle C. However, Subtitle C does address air emissions from the generation, storage, treatment, and trans-port of hazardous wastes.

4.3 Landfill Gas Safety and Health Issues

This chapter provides information about health and safety issues associated with landfill gas—specifically, possible explosion and asphyxiation hazards and issues related to odors emanating from the landfill and low-level chemical emissions. It also contains information about health and safety issues associated with landfill fires (which may or may not be the direct result of landfill gas). This chapter also describes the tools that can be used to help environmental professionals respond to community health concerns. It provides information about what is known and unknown about the short-term and long-term health effects associated with landfill gas emissions, which can be mixtures of hundreds of different gases.

4.3.1 Landfill gas exposures

People may be exposed to landfill gases either at the landfill or in their communities. As discussed in Chapter Two, landfill gases may migrate from the landfill either above or below ground. Gases can move through the landfill surface to the ambient air. Once in the air, the landfill gases can be carried to the community with the wind. Odors from day-to-day landfill activities are indicative of gases moving above ground. Gases may also move through the soil underground and enter homes or utility corridors on or adjacent to the landfill. Landfill gas collection and control systems have the greatest impact on gas migration and exposures.

4.3.2 Explosion Hazards:

Landfill gas may form an explosive mixture when it combines with air in certain proportions. This section provides information about:

- The conditions that must be met for landfill gas to pose an explosion hazard.
- The types of gases that may potentially pose explosion hazards.
- What can be done to assess whether a landfill is posing an explosion hazard.

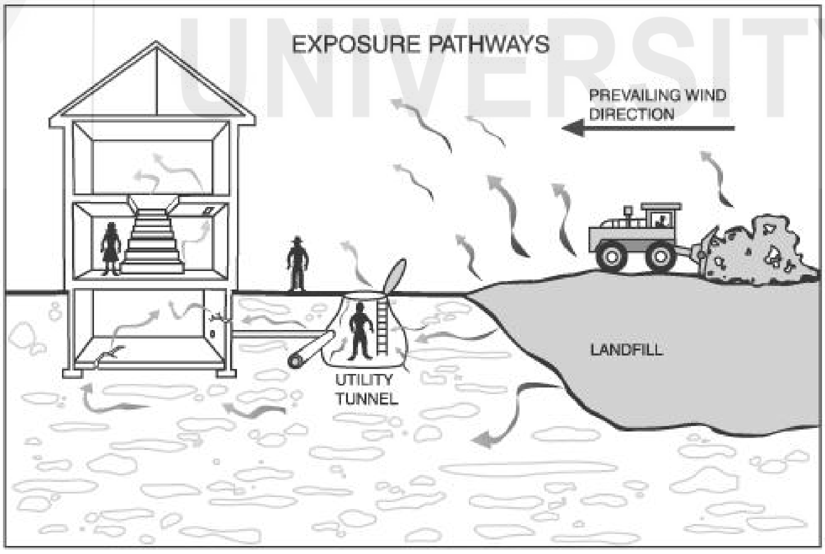

Figure 4-2: Potential Exposure Pathways to Landfill Gas

Landfill gas pose an explosion hazard

The following conditions must be met for landfill gas to pose an explosion hazard:

- Gas production: A landfill must be producing gas, and this gas must contain chemicals.

- Gas migration: The gas must be able to migrate from the landfill. Underground pipes or natural subsurface geology may provide migration pathways for landfill gas. Gas collection and treatment systems, if operating properly, reduce the amount of gas that is able to escape from the landfill.

- Gas collection in a confined space: The gas must collect in a confined space to a concentration at which it could potentially explode. A confined space might be a manhole, a subsurface space, a utility room in a home, or a basement. The concentration at which a gas has the potential to explode is defined in terms of its lower and upper explosive limits (LEL and UEL), as defined at right.

Lower and Upper Explosive Limits (LEL and UEL)

The concentration level at which gas has the potential to explode is called the explosive limit. The potential for a gas to explode is determined by its lower explosive limit (LEL) and upper explosive limit (UEL). The LEL and UEL are measures of the percent of a gas in the air by volume. At concentrations below its LEL and above its UEL, a gas is not explosive. However, an explosion hazard may exist if a gas is present in the air between the LEL and UEL and an ignition source is present.

4.3.3 Types of gases that can pose an explosion hazard

Methane: Methane is the constituent of landfill gas that is likely to pose the greatest explosion hazard. Methane is explosive between its LEL of 5% by volume and its UEL of 15% by volume. Because methane concentrations within the landfill are typically 50% (much higher than its UEL), methane is unlikely to explode within the landfill boundaries. As methane migrates and is diluted, however, the methane gas mixture may be at explosive levels. Also, oxygen is a key component for creating an explosion, but the biological processes that produce methane require an anaerobic, or oxygen-depleted, environment. At the surface of the landfill, enough oxygen is present to support an explosion, but the methane gas usually diffuses into the ambient air to concentrations below the 5% LEL. In order to pose an explosion hazard, methane must migrate from the landfill and be present between its LEL and UEL.

- Other landfill gases: Other landfill gas constituents (e.g., ammonia, hydrogen sulfide, and NMOCs) are flammable. However, because they are unlikely to be present at concentrations above their LELs, they rarely pose explosion hazards as individual gases. For example, benzene (an NMOC that may be found in landfill gas) is explosive between its LEL of 1.2% and its UEL of 7.8%. However, benzene concentrations in landfill gas are very unlikely to reach these levels. If benzene were detected in landfill gas at a concentration of 2 ppb (or 0.0000002% of the air by volume), then benzene would have to collect in a closed space at a concentration 6 million times greater than the concentration found in the landfill gas to cause an explosion hazard.

Table 4-2: Health Effects from Oxygen-deficient Environments	
Oxygen Concentration	Health Effects
21%	Normal ambient air oxygen concentration
17%	Deteriorated night vision (not noticeable until a normal oxygen concentration is restored), increased breathing volume, and accelerated heartbeat
14% to 16%	Increased breathing volume, accelerated heartbeat, very poor muscular coordination, rapid fatigue, and intermittent respiration
6% to 10%	Nausea, vomiting, inability to perform, and unconsciousness
Less than 6%	Spasmatic breathing, convulsive movements, and death in minutes

4.3.4 Health Issues Associated with Landfill Gas Emissions - Odors and Low-Level Chemical Exposures

Landfill odors often prompt complaints from community members. People may also have concerns about health effects associated with these odors and other emissions coming from the landfill. This section contains information about

- Symptoms possibly triggered by landfill gas odors.
- What scientists know about the potential health effects of exposures to landfill gas emissions.
- How environmental health professionals can assess whether landfill gas emissions may be posing a health threat.

4.3.5 Landfill gas odor and its trigger

People in communities near landfills are often concerned about odors emitted from landfills. They say that these odors are a source of undesirable health effects or symptoms, such as headaches and nausea. At low-level concentrations—typically associated with landfill gas— it is unclear whether it is the constituent itself or its odors that trigger a response. Typically, these effects fade when the odor can no longer be detected. Landfill gas odors are produced by bacterial or chemical processes and can emanate from both active or closed landfills. These odors can migrate to the surrounding community. Potential sources of landfill odors include sulfides, ammonia, and certain NMOCs, if present at concentrations that are high enough. Landfill odors may also be produced by the disposal of certain types of wastes, such as manures and fermented grains.

- Sulfides: Hydrogen sulfide, dimethyl sulfide, and mercaptans are the three most common sulfides responsible for landfill odors. These gases produce a very strong rotten-egg smell—even at very low concentrations. Of these three sulfides, hydrogen sulfide is emitted from landfills at the highest rates and concentrations.

- Humans are extremely sensitive to hydrogen sulfide odors and can smell such odors at concentrations as low as 0.5 to 1 part per billion (ppb). At levels approaching 50 ppb, people can find the odor offensive. Average concentrations in ambient air range from 0.11 to 0.33 ppb (ATSDR 1999a).
- Ammonia: Ammonia is another odorous landfill gas that is produced by the decomposition of organic matter in the landfill. Ammonia is common in the environment and an important compound for maintaining plant and animal life. People are exposed daily to low levels of ammonia in the environment from the natural breakdown of manure and dead plants and animals. Humans are much less sensitive to the odor of ammonia than they are to sulfide odors. The odor threshold for ammonia is between 28,000 and 50,000 ppb. Landfill gas has been reported to contain between 1,000,000 and 10,000,000 ppb of ammonia, or 0.1% to 1% ammonia by volume (Zero Waste America n.d.).
- NMOCs: Some NMOCs, such as vinyl chloride and hydrocarbons, may also cause odors. In general, however, NMOCs are emitted at very low (trace) concentrations and are unlikely to pose a severe odor problem.

Table 4-3: Common Landfill Gas Components and Their Odor Thresholds		
Component	Odor Description	Odor Threshold (parts per billion)
Hydrogen Sulfide	Strong rotten egg smell	0.5 to 1
Ammonia	Pungent acidic or suffocating odor	1,000 to 5,000
Benzene	Paint-thinner-like odor	840
Dichloroethylene	Sweet, ether-like, slightly acrid odor	85
Dichloromethane	Sweet,chloroform-like odor	205,000 to 307,000
Ethylbenzene	Aromatic odor like benzene	90 to 600
Toluene	Aromatic odor like benzene	10,000 to 15,000
Trichloroethylene	Sweet, chloroform-like odor	21,400
Tetrachloroethylene	Sweet, ether-or chloroform-like odor	50,000
Vinyl Chloride	Faintly sweet odor	10,000 to 20,000

The impact of landfill gas odors on sensitive populations such as people with pre-existing respiratory illnesses is not well documented or understood. A study conducted on Staten Island showed an increase in self-reported wheezing among asthmatics living near a landfill on days when they reported odors. Ambient air measurements, however, showed levels of hydrogen sulfide and other emissions much lower than levels known to be associated with adverse health effects (ATSDR 1999b). The box belowprovides more information about this study. The study suggests that odors in and of themselves may trigger respiratory effects among asthmatics. This preliminary conclusion may be confounded by other environmental triggers for respiratory response in asthmatics, such as dust mites, animal dander, tobacco smoke, and outdoor air pollution.

4.4 Monitoring of Landfill Gas

Environmental health professionals are rarely required to design and implement sampling and monitoring plans at landfills, but you might be asked to review and comment on such plans. In addition, you might need to review and interpret sampling and monitoring data, when available, to evaluate potential public health hazards. To make such tasks easier, this chapter provides basic information (e.g., monitoring program design, sampling and monitoring equipment, and data interpretation) about the different types of landfill gas sampling methods that you are most likely to encounter.

It is important to remember that monitoring data taken at landfills do not necessarily reflect the levels of contamination to which people may be exposed. However, these data usually offer some insight into either general air quality, landfill gas migration, or possible health hazards. In general, monitoring of gases that emanate from landfills falls into the following five categories:

1. Soil gas monitoring
2. Near surface gas monitoring
3. Emissions monitoring
4. Ambient air monitoring
5. Indoor air monitoring

4.4.1 Landfill Gas Sampling Approaches: An Overview

Many different types of landfill gas sampling approaches exist —too many to review in this manual. However, two important factors in selecting an appropriate landfill gas sampling approach include the sampling location and the sampling methods. The sampling location and sampling methods are selected according to the data uses and questions to be answered by the overall sampling program. Some examples of location, or placement, of gas monitors are described in the box below.

Table 4-4: Key Features of Different Types of Monitoring of Landfill Gases

Type of Monitoring	Description of Monitoring	Typical Parameters Reported	Relevance to Public Health
Soil Gas	Soil gas monitoring programs measure the concentrations of chemicals in the vapor space of soils. Measurements of soil gas levels are taken at depth with the use of probes or wells.	Most landfills are required by federal law to report levels of methane around the landfill perimeter. Oxygen, carbon dioxide, and nitrogen are frequently reported. Sometimes H 2S and other	Because soil gas monitoring data at many MSW landfills typically (though not always) characterize levels of only methane, the data are generally useful for evaluating risks of explosion and for getting a qualitative sense of whether landfill gases are migrating in the soils to off-site locations.

		specific NMOCs, such as vinyl chloride, might be reported if federal or state regulators suspect a significant problem. Pressure, in inches of water, is also frequently reported from permanent soil gas probes.	
Near Surface Gases	Measures the concentrations of gases at a point no higher than 4 inches above the ground surface.	Methane is the most common gas monitored but VOCs and H 2S are sometimes reported.	Outside air methane concentrations do NOT pose an inhalation or explosion hazard. Near surface monitoring of methane on the landfill does not provide useful information to determine impacts on the health of adjacent residents. Monitoring can qualitatively indicate whether high levels of landfill gas are escaping from the landfill surface or whether the landfill gas collection and control system is working well to minimize emissions.
Emissions	Emissions monitoring programs measure the rate at which chemicals are released from a particular source, such as landfill surfaces, flares, or stacks.	Landfill studies have measured emission rates for various pollutants, such as methane and NMOCs, from landfill surfaces and combustion by-products of flares and other treatment units.	Chemical-specific emissions data are useful for identifying potential contami- nants of concern at landfills, but they do not characterize the concentrations of chemicals that people actually breathe. Exposureconcentrations can be estimated from emissions data, but such estimates can be highly uncertain.

Ambient Air	Ambient air monitoring programs measure levels of pollution in outdoor ambient air, or the air that people breathe.	Ambient air monitoring can be conducted for a wide range of pollutants. Near landfills, air monitoring is most commonly conducted for EPA's criteria pollutants and NMOCs.	Because ambient air monitoring data characterize levels of pollution in the air that people breathe, they usually provide the best measure for air exposure concentrations in the vicinity of landfills. Of course, environmental health professionals still need to critically evaluate ambient air monitoring data to put them into proper perspective.
Indoor Air	Indoor air monitoring programs meas- ure levels of contamination in indoor air spaces.	Indoor air monitoring for methane is required at structures on many landfill properties. Methane monitoring at off-site locations and NMOC monitoring is usually only performed to address site-specific concerns. Oxygen levels in confined spaces, such as buried utilities, are measured to determine if carbon dioxide and/or methane gases have replaced sustainable oxygen.	Indoor air monitoring data are useful for evaluating risks of explosions and exposures to contaminants within homes. Emissions from household products and tasks might confound these measurements, and levels measured in one home generally are not representative of levels in other homes, even nearby residences.

Location of Landfill Gas Monitors

Landfill gas monitors are typically placed in three types of locations at or near landfills; these are subsurface, surface, or enclosed space. The three types of monitoring locations address different landfill gas concerns and can be used either alone or together in a sampling program. Note that these systems generally do not measure landfill gas levels at points of human exposure.

Subsurface Systems—Subsurface systems measure concentrations of contaminants in the soil gas at locations beneath the soil-air interface. The depth of sampling can range from a few inches to many feet below the surface.

Surface Systems—Surface systems measure concentrations of gas within a couple of inches above the soil-air interface.

Enclosed Space Systems—Enclosed space systems monitor gases in indoor air or confined areas overlying or adjacent to landfills, such as buildings, subsurface vaults, utilities, or any other spaces where the potential for gas buildup is of concern.

In addition to the sampling location, several methods of landfill gas collection can be used in a landfill gas sampling approach. Examples of these methods, and their implications, follow:

Portable vs. stationary sampling equipment: Some gas sampling can be performed with portable monitors, which typically are hand-held instruments that can be easily carried around a landfill. This type of device is useful for conducting an initial screening of landfill gas migration pathways or for identifying the source of methane leaks. Stationary monitors, on the other hand, usually are installed at fixed locations, where they remain for the duration of the intended monitoring. Stationary monitors are typically, though not always, capable of generating higher quality data than portable monitors.

Grab sampling vs. continuous monitoring: This distinction applies to most types of landfill gas monitoring (e.g., soil gas, emissions, ambient air, and indoor air). By definition, grab sampling is a one-time measurement of gas concentrations, thus providing a "snap-shot" of landfill gas composition at a given place and time. This type of sampling is generally not useful for evaluating changes in landfill gas composition over the long term, unless it is conducted at regular intervals according to a detailed plan. In contrast, continuous monitoring devices constantly sample and analyze gas concentrations. Some are capable of documenting fluctuations in concentrations over short intervals, while others can measure only average concentrations. All continuous monitors, however, provide insight into changes in gas composition over the long term.

Analysis of samples in the laboratory vs. analysis in the field: Depending on the data needs, gas samples are usually either collected and sent to a laboratory for analysis or analyzed directly in the field. Laboratory analysis may take days or weeks to perform and can be expensive, but this approach generates highly accurate and precise results and can measure concentrations of many different pollutants. Alternatively, real-time monitoring (or analysis in the field) reports concentrations as soon as they are measured; in some cases, these devices can measure changes in concentration from minute to minute. Most real-time monitors, however, measure concentrations of only one pollutant and are not as sensitive as laboratory analysis.

4.4.2 Soil Gas Monitoring

This section defines soil gas monitoring and how it relates to landfills, discusses why soil gas is often monitored at landfills, and presents information environmental health professionals should consider when reviewing soil gas monitoring data.

decomposing waste in landfills generates gases containing many chemicals that transport through soils and may eventually be released to the surface. While in the soils, the landfill gas is typically referred to as "soil gas." Soil gas monitoring, therefore, is the measurement of concentrations of gases in the subsurface.

There are many reasons for monitoring levels of contaminants in soil gas at or near landfills. The three main reasons that such monitoring is performed are reviewed below, though soil gas monitoring might be conducted for other reasons. Information about sampling methods and the relevance of the monitoring results to public health is presented later in this chapter.

To meet regulatory requirements: According to EPA regulations under RCRA (Subtitle D), MSW landfills must conduct soil gas monitoring for methane. Depending on the date of construction, some MSW landfills may be exempt from these RCRA regulations. EPA regulations provide flexibility for how states and Indian tribes implement these regulations. As a result, landfills operating in some states or tribal areas might be subject to different regulations than landfills operating in other areas. The data collected in fulfillment of these regulations serve two important purposes: they provide environmental regulators with information about the performance of landfill gas collection systems, and they characterize the extent to which accumulation and migration of landfill gas might pose an explosion hazard.

To characterize off-site fire or explosion hazards: At some landfills, soil gas monitoring for methane is performed at off-site locations to address concerns of landfill gas migration and potential explosion hazards.

To quantify off-site migration of chemicals: At some landfills, the landfill has been identified as a hazardous waste site under federal or state environmental regulations or residents are concerned about the trace amounts of chemicals (mostly NMOCs) that might migrate with the soil gas to residential areas. Migration of chemicals from these landfills cannot be directly addressed by methane monitoring data. Therefore, environmental agencies, or the residents themselves, might organize sampling efforts as part of site investigation efforts to identify the many contaminants in soil gases as well as their soil gas concentrations. Such chemical-specific soil gas monitoring provides the most detailed information about levels of contamination in landfill gas.

4.4.3 Soil gas sample collection methods

Soil gas samples are collected from temporary monitoring probes (often labeled punch probes or punchbars), permanent soil gas monitoring wells, and landfill gas collection wells and vents. Soil gas sample locations and sampling methods vary from landfill to landfill, depending on monitoring concerns or regulatory requirements. Soil gas monitoring results may provide a great deal of information about landfill gases and how they are moving through the landfill. Soil gas monitoring can characterize methane and other gases, such as NMOCs, in concentrations within the landfill and around its perimeter. Important factors to consider when interpreting results include the sample location, frequency, and data quality. Based on the location of soil gas monitoring wells or probes, data can identify off-site subsurface pathways and on-site or off-site buildings that may be endangered by migrating methane and other gases. This information may be used by decision makers to determine if and what soil gas collection and treatment is needed to protect public safety and health.

In addition, environmental regulations may require only methane monitoring. Other gases, such as NMOCs, may be present in the subsurface. When reviewing soil gas data, environmental health professionals should be careful to consider the sampling locations in relation to potentially exposed populations and sample analyses conducted in relation to the gases, especially NMOCs, that may be present.

4.4.4 Surface Gas Monitoring

This section defines near surface gas monitoring and how it relates to landfills. This section also discusses why near surface gases might be monitored at landfills, and presents information that environmental health professionals should consider when reviewing the resulting data sets.

Reason why near surface monitoring performed at landfills

Near surface monitoring of landfill gases may be performed to determine the need for, and the design of, a LFG control system. The near surface monitoring is also used to determine if a LFG control system is adequately preventing methane and other landfill gases from escaping in high quantities through the landfill cover. Under the Clean Air Act, large landfills that are required to install landfill gas collection and control systems by the NSPS/EG must perform near surface methane monitoring quarterly to show that the system is operating properly. Corrective action must be taken if methane readings are more than 500 ppm above background.

4.4.5 Methods of near surface gas monitoring

A common method of near surface gas monitoring is the use of a portable instrument such as a organic vapor analyzer-flame ionization detector (OVA/FID). Normally, the instrument is calibrated for methane but it can be calibrated for other gases commonly found in landfills. The OVA may be fitted with a funnel over the monitoring probe inlet. The probe inlet and funnel are then held within 2 to 3 inches of the ground surface and the measurement of gas is recorded by the sampling technician.

Using a method known as landfill gas sweeping or emissions screening, the sampling technician walks over the surface of the landfill in either a random method or over a pre-defined grid. The sampling technician records the instrument readings, making careful note of the geographic location of each measurement and the surface conditions. The measurements may be recorded as parts per million, percent by volume, or percent of lower explosive limit, depending upon the type of portable instrument used.

A grab sample may also be taken using a sampling device fitted with a Tedlar® bag or with a SUMMA®- polished canister. In both cases the samples are taken to a laboratory for analysis. The laboratory analysis may yield results for many more specifically identified constituents of landfill gas than use of portable instruments.

4.4.6 Near surface gas monitoring data

Near surface gas data provide the concentrations of gases, usually just methane that are moving through the cover of the landfill into the atmosphere. If laboratory analysis of samples is used, the results may help characterize the NMOCs being emitted by the landfill into the atmosphere.

Near surface gas data may indicate the location of point sources of relatively high concentrations of landfill gases such as cracks in the landfill cover. Such information may be useful in locating permanent soil gas probes for long term monitoring or gas recovery wells to control the release of landfill gases. Near surface gas monitoring is also useful inside buildings to locate sources of landfill gas movement into the building. Cracks and openings into the buildings may then be sealed to reduce the amount and concentrations of infiltrating gases.

However, near surface gas data do not indicate the concentrations of gases that people may be breathing because of the effects of rapid dilution that is normally expected of gases traveling from the surface of the landfill to the 3- to 5-foot height that may be considered the breathing zone for many people.

Near surface gas data may be used in computer air models that estimate the level of contamination in ambient air in adjacent communities. The quality and validity of such models for public health purposes will greatly depend on the quality and validity of the gas data and site specific meteorologic measurements, as well as the validity of the assumptions and defaults values used in the computer model. Air models and estimates that substitute too many default values for site specific measurements have very limited value for public health conclusions about breathing zone concentrations.

4.4.7 Emissions Monitoring

This section defines emissions monitoring and how it relates to landfills, discusses why emissions might be monitored at landfills, and presents information that environmental health professionals should consider when reviewing emissions monitoring data. Unlike soil gas and near surface gas monitoring, which measure the concentrations of chemicals in landfill gas, emissions monitoring measures the rates at which chemicals in landfill gases are released from landfills. Emissions sources at landfills that are most frequently monitored are the landfill surface itself and landfill gas combustion units (e.g., flares or other combustion devices).

4.5 Landfill Gas Control Measures

This chapter presents an overview of common landfill gas control technologies. These technologies include means to collect gases, control and treat gases, and use gases to benefit the community (e.g., to generate electricity or heat buildings). A landfill might need gas control measures for several reasons, including government regulations, odor problems, or uncontrolled releases of gases that could pose safety and health concerns. As an environmental health professional, you are not expected to be able to design and implement a landfill gas control plan. However, you should have a basic understanding of the control options that are available to help prevent or control exposures to landfill gas.

Reasons for implementing control measures at a landfill.

Many landfills install gas control measures because of regulatory requirements. The federal government has developed laws and regulations that govern the operation and maintenance of landfills. These regulations have been developed to reduce health and environmental impacts from landfill gas emissions through the reduction of ozone precursors (volatile organic compounds and nitrogen oxides), methane, NMOCs, and odorous compounds. States may also have statespecific landfill regulations, which must be as strict or more strict than the federal regulations. The boxes on the next page review some of the applicable regulations.

4.5.1 Components of a landfill gas control plan

The goal of a landfill gas control plan is to prevent people from being exposed to landfill gas emissions. This goal can be achieved by either collecting and treating landfill gas at the landfill or by preventing landfill gas from entering buildings and homes in the community. Technologies used to control landfill gas at the landfill or in the community can be applied separately or in combination. Note that the NSPS/ EG requires a gas collection and control system design plan for landfills that meet the criteria presented on the next page. The NSPS rule specifies the type of information that must be included and the criteria the collection and control systems must meet.

4.5.2 Landfill gas collection

Landfill gas can be collected by either a passive or an active collection system. A typical collection system, either passive or active, is composed of a series of gas collection wells placed throughout the landfill. The number and spacing of the wells depend on landfill-specific characteristics, such as waste volume, density, depth, and area. Most collection systems are designed with a degree of redundancy to ensure continued operation and protect against system failure. Redundancy in a system may include extra gas collection wells in case one well fails. The system-specific components for passive and active gas collection systems are discussed below.

- **Passive Gas Collection System:** Passive gas collection systems use existing variations in landfill pressure and gas concentrations to vent landfill gas into the atmosphere or a control system. Passive collection systems can be installed during active operation of a landfill or after closure. Passive systems use collection wells, also referred to as extraction wells, to collect landfill gas. The collection wells are typically constructed of perforated or slotted plastic and are installed vertically throughout the landfill to depths ranging from 50% to 90% of the waste thickness. If groundwater is encountered within the waste, wells end at the groundwater table. Vertical wells are typically installed after the landfill, or a portion of a landfill, has been closed. A passive collection system may also include horizontal wells located below the ground surface to serve as conduits for gas movement within the landfill. Horizontal wells may be appropriate for landfills that need to recover gas promptly (e.g, landfills with subsurface gas migration problems), for deep landfills, or for active landfills. Sometimes, the collection wells vent directly to the atmosphere. Often, the collection wells convey the gas to treatment or control systems (e.g., flares).

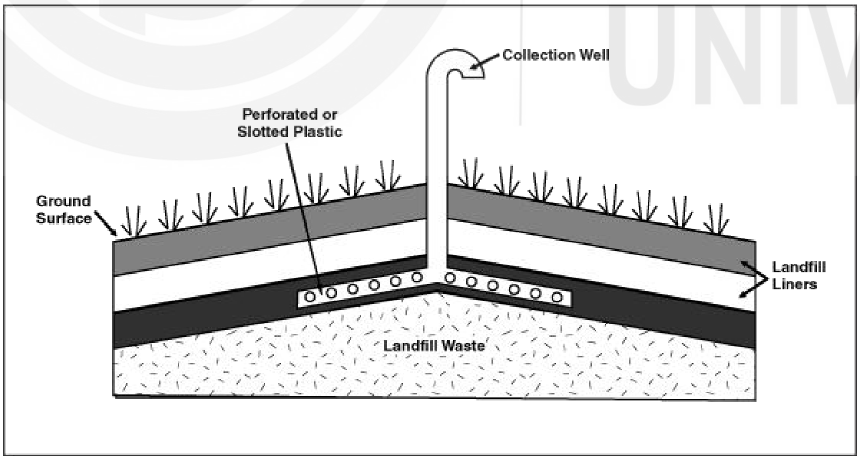

Figure 4.3: Passive Gas Collection System

- **Active Gas Collection:** Well-designed active collection systems are considered the most effective means of landfill gas collection (EPA 1991). Active gas collection systems include vertical and horizontal gas collection wells similar to passive collection systems. Unlike the gas collection wells in a passive system, however, wells in the active system should have valves to regulate gas flow and to serve as a sampling port. Sampling allows the system operator to measure gas generation, composition, and pressure.

- Active gas collection systems include vacuums or pumps to move gas out of the landfill and piping that connects the collection wells to the vacuum. Vacuums or pumps pull gas from the landfill by creating low pressure within the gas collection wells. The low pressure in the wells creates a preferred migration pathway for the landfill gas. The size, type, and number of vacuums required in an active system to pull the gas from the landfill depend on the amount of gas being produced. With information about landfill gas generation, composition, and pressure, a landfill operator can assess gas production and distribution changes and modify the pumping system and collection well valves to most efficiently run an active gas collection system. The system design should account for future gas management needs, such as those associated with landfill expansion.

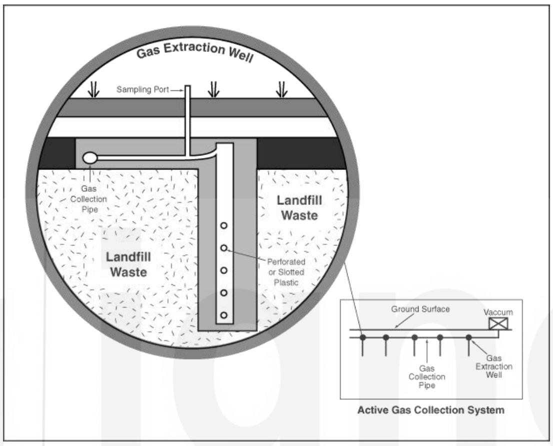

Figure 4.4: Active Gas Collection System

4.5.3 Methods available for treatment of landfill gas after collection

Some passive gas collection systems simply vent landfill gas to the atmosphere without any treatment before release. This may be appropriate if only a small quantity of gas is produced and no people live or work nearby. More commonly, however, the collected landfill gas is controlled and treated to reduce potential safety and health hazards. Common methods to treat landfill gas include combustion and noncombustion technologies, as well as odor control technologies.

- **Combustion:** Combustion is the most common technique for controlling and treating landfill gas. Combustion technologies such as flares, incinerators, boilers, gas turbines, and internal combustion engines thermally destroy the compounds in landfill gas. Over 98% destruction of organic compounds is typically achieved. Methane is converted to carbon dioxide, resulting in a large greenhouse gas impact reduction. Combustion or flaring is most efficient when the landfill gas contains at least 20% methane by volume. At this methane concentration, the landfill gas will readily form a combustible mixture with ambient air, so that only an ignition source is needed for operation. At landfills with less than 20% methane by volume, supplemental fuel (e. g., natural gas) is required to operate flares, greatly increasing operating costs. When combustion is used, two different types of flares can be chosen: open or enclosed flares.
- *Open flame flares* (e. g., candle or pipe flares), the simplest flaring technology, consist of a pipe through which the gas is pumped, a pilot light to spark the gas, and a means to regulate the gas flow. The simplicity of the design and operation of an open flame flare is an advantage of this technology. Disadvantages include inefficient combustion, aesthetic

complaints, and monitoring difficulties. Sometimes, open flame flares are partially covered to hide the flame from view and improve monitoring accuracy.

- *Enclosed flame flares* are more complex and expensive than open flame flares. Nevertheless, most flares designed today are enclosed, because this design eliminates some of the disadvantages associated with open flame flares. Enclosed flame flares consist of multiple burners enclosed within fire-resistant walls that extend above the flame. Unlike open flame flares, the amount of gas and air entering an enclosed flame flare can be controlled, making combustion more reliable and more efficient.
- *Noncombustion.* Noncombustion technologies were developed in the 1990s as an alternative to combustion, which produces compounds that contribute to smog, including nitrogen oxides, sulfur oxides, carbon monoxide, and particulate matter. Noncombustion technologies fall into two groups: energy recovery technologies and gas-to-product conversion technologies. Regardless of which noncombustion technology is used, the landfill gas must first undergo pretreatment to remove impurities such as water, NMOCs, and carbon dioxide. Numerous pretreatment methods are available to address the impurities of concern for a specific landfill. After pretreatment, the purified landfill gas is treated by noncombustion technology options.
- *Energy recovery technologies* use landfill gas to produce energy directly. Currently, the phosphoric acid fuel cell (PAFC) is the only commercially available noncombustion energy recovery technology. Other types of fuel cells (molten carbonate, solid oxide, and solid polymer) are still under development. The PAFC system consists of landfill gas collection and pretreatment, a fuel cell processing system, fuel cell stacks, and a power conditioning system. Several chemical reactions occur within this system to create water, electricity, heat, and waste gases.
- *Odor Control Technologies:* Odor control technologies prevent odor-causing gases from leaving the landfill. Installing a landfill cover will prevent odors from newly deposited waste or from gases produced during bacterial decomposition. Covering a landfill daily with soil can help reduce odors from newly deposited wastes. More extensive covers are installed at landfill closure to prevent moisture from infiltrating the refuse and encouraging bacterial growth and decomposition. Vegetative growth on the landfill cover also reduces odors. Flaring is another technique that can eliminate landfill gas odors by thermally destroying the odor-causing gases. Venting landfill gas through a filter is another technology used to reduce odors. Landfill gas is collected and vented through a filter of bacterial slime. As long as oxygen is present, bacteria will decompose landfill gas under aerobic conditions, producing carbon dioxide and water.

What Are the Limitations of the Landfill Gas Control Options?

Landfill Gas Collection Technologies

Active venting

Effectiveness depends on proper placement of system to gas source.

Improper operation and monitoring potentially creates aerobic conditions that may lead to piping deformation and subsurface fires.

Requires monitoring and maintenance.

Passive venting

Most effective using shallow trenches.

Not completely effective for petroleum-based vapors.

Community Control Technologies

Gas Pressure Controls

Crawl space venting requires maintenance, and performance data are limited.

Passive venting is effective only with low underground gas concentrations.

Active venting may require maintenance.

Leakage Area Controls

Plumbing corrections may only partially remedy the problem.

Use of sealing, caulking, and liners has had limited success gas migration. Another control option is to install a low-permeability liner around the basement or underground portion of the building.4.5.4 Beneficial uses for collection of landfill gas

Landfill gas is the single largest source of man-made methane emissions in the United States, contributing to almost 40% of methane emissions each year (EPA 1996). Consequently, a growing trend at landfills across the country is to use recovered methane gas from landfills as an energy source. Collecting landfill gas for energy use greatly reduces the risk of explosions, provides financial benefits for the community, conserves other energy resources, and potentially reduces the risk of global climate change.

Some examples of successful landfill gas to energy projects are presented in the box below.

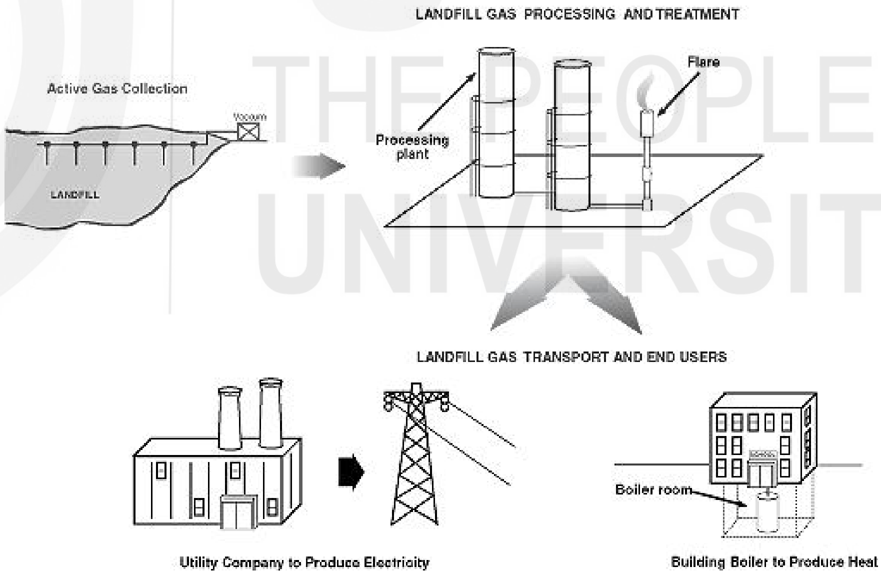

Figure 4.5: Landfill Gas Recovery System

4.6 Landfill Gas collection system

4.6.1 GAS EXTRACTION AND TRANSPORTATION

The gas is extracted by a blower, which can be to a high degree adjusted to different flow rates. It should provide vacuum pressures between 1 and 50 (100) hPa. The vacuum pressure should be distributed into the landfill body as homogeneous as possible. To reach this aim, a certain number of vertical or horizontal gas wells have to be installed in the landfill body.

There should be nearly no pressure loss inside the well, which can be achieved by choosing adequate gas pipe diameters (typical diameter ≤ 100 mm). If the landfill has a depth >25e30 m, two gas extraction pipes of different length (with a gas seal underneath the shorter pipe) may be installed that may be operated with different vacuum pressures (lower and higher level). It is standard in Germany that each well is connected via a pipe to a distribution station, where the transportation pipe of several wells is connected to a main header pipe that transports the gas to the blower station. In the distribution station a valve can adjust the flow rate. In the pipe just in front the valve technical facilities for measuring in the pipe pressure, flow rate, gas composition, and temperature should be installed. In the gas distribution station, it may make sense to distinguish between lean gas and "normal" gas as it may, e.g., occur in landfill, which consist of an older and a younger part. In this case, the distribution station may be connected to two header pipes; as a result two separate gas collection systems exist. In most cases this is not necessary as long as the gas collection system can be adjusted in a way that high methane concentrations can be reached.

4.6.2 DESIGN AIDS FOR A GAS COLLECTION SYSTEM

Gas wells

For the design of gas wells, the following aspects should be considered:

- Inside the wells almost no pressure loss should occur.
- Landfill settlements should not cause pipe damages.
- Pipe stability should be proven.
- High temperatures (50e60○C) should not influence the pipe stability.
- Wells should be constructed in a way that air is not sucked in through the landfill surface, i.e., gas wells should be gas tight against air intrusion especially at the well head and the upper part of the well.

In case of typical vertical gas well with a flexible pipe in a pipe system for compensating settling, this is not used in any cases. A vertical gas well is in most cases drilled into the landfill by using an auger. The well should have the following characteristics:

- The diameter should be between 1.0 and 1.2 m, dependent on the (expected) water level in the landfill.
- They should be filled with lime-deficient course gravel (e.g., 16/32 mm).
- The perforation should cover not more then 5% of the pipe surface. The openings can either be slots or holes. Slots and holes should be large enough to avoid clogging but smaller than the diameter of the gravel.

It should also to be considered that:

- To compensate settling the connection between the gas, extraction pipe and the horizontal pipe should be flexible.

The upper part of the well has to be sealed (e.g., using low permeable clay) dependent of the height of the landfill at length from the landfill surface of at least 3 m. The gas extraction piped where it is slotted should be surrounded by course gravel to avoid clogging. For keeping the temperature high, the combustion chamber has to be insulated. To meet safety prescriptions, the flare has to be equipped with a flame control and an electronic ignition system.

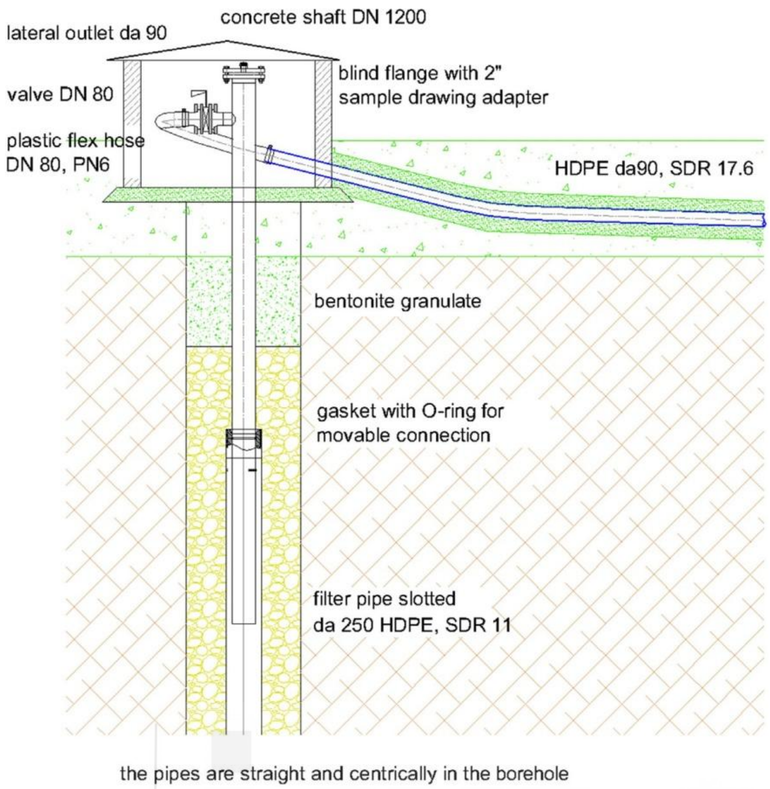

Figure 4.6: Typical vertical gas well

4.6.4 MONITORING, CONTROL, AND CONCLUSIONS

Owing to varying conditions in the landfill body, atmospheric pressure fluctuations, increasing landfill height and age, and changing operation modes, the LFG collection system has to be permanently adjusted. Automatically operating monitoring systems may be helpful.

As an example, the following monitoring program may be followed: Once a week:

- Measuring gas composition at each well (e.g., in the distribution station), if methane concentrations divert from the set value 50%, the extracted flow rate should be adjusted (preferably continuous gas quality monitoring at least before the blower).
- Gas flow rate at the blower station (preferably continuous flow monitoring). Two times a year:
- Measuring the water level in the wells, if the water level is too high and affects gas extraction, water has to be pumped out.
- Measuring the temperature in the wells.
- Analyzing the gas flow rate and gas composition including trace gases at the central blower. If the concentrations of trace gases are too high, additional gas treatment measures may be necessary; if the gas composition shows air intrusion leaks, it should be identified and repaired; if the gas flow is less then 5e7 times lower than the original flow rate, the installation has to be investigated, repaired, and if not feasible diminished and redesigned.
- If there is a certain tendency to lean gases, the gas collection concept has to be revised. In this case aerobization of the landfill, passive gas venting, or lean gas treatment may be the options.
- Detecting gas emissions at the surface of a lined landfill (FID monitoring would help to identify leaks). If emissions are detected the operation mode and the gas collection system should be investigated and appropriate measures have to be taken.

Every 15 years:

- Controlling gas wells and pipes using camera systems, if failures are determined, actions such as cleaning or repairing have to be started.

Safety control installations: maintenance and repairing may be necessary.

SAQ 1

a) What are the gases components that emerge from a typical landfill and the factors that affects its production?

SAQ 2

a) Discuss the several hazards and health issues created by landfill gases.

SAQ 3

a) Explain the various methods for the treatment of landfill gases.

4.7 SUMMARY

Several gases are generated from waste landfill sites. It has several components and effects on man and his environment. It is therefore very essential to manage the evolve gases through monitoring and treatment of the gases. To understand the management of these gases, few points to understand includes – the biological degradation of solid waste comprising four steps (hydrolysis, acidification, acetic acid production and methane production), hazardous effects of these gases and their treatment. If not monitored and manage effectively, the effects of these gases will have huge impact to the ecosystem. It is necessary to arrange the final gases extraction, faring, transportation and aids for the gas collection system.

4.8 KEY WORDS

Anaerobic: Reaction in the absence of oxygen

Hydrolysis: The chemical breakdown of a compound due to reaction with water.

Acetogenesis: Acetogenesis refers to the synthesis of acetate, which includes the formation of acetate by the reduction of CO_2 and the formation of acetate from organic acids.

Methanogenesis: Methanogenesis is the process of generation of methane by methanogens, which are strictly anaerobic microorganisms or archaeons.

4.9 ANSWERS TO SAQS

SAQ 1

Please refer Table 4.1 and section 4.2.3.

SAQ 2

Please refer section 4.3.

SAQ 3

Please refer section 4.5.3.

4.10 FURTHER READINGS

1. Mitigation of Landfill Gas Emissions, By Malgorzata Pawlowska, ISBN 9780415630771, Published April 22, 2014 by CRC Press.
2. Handbook of Solid Waste Management and Waste Minimization Technologies, by Nicholas P. Cheremisinoff, ISBN 978-0-7506-7507-9
3. Handbook of Environmental Engineering, by Rao Y. Surampalli, Tian C. Zhang, Satinder Kaur Brar, Krishnamoorthy Hegde, Rama Pulicharla, Mausam Verma, ISBN: 978125986022, McGraw-Hill Education.
4. Landfill Gas to Energy: Technologies and Challenges, by Vasudevan Rajaram, Faisal Zia Siddiqui, Mohd Emran Khan, Publisher CRC Press, ISBN-10 : 0415664748.