A COMPILATION OF LANDFILL GAS FIELD PRACTICES AND PROCEDURES

PREPARED BY:
SWANA®'S LANDFILL GAS MANAGEMENT DIVISION

MARCH 1992

SWANA

SOLID WASTE
ASSOCIATION OF
NORTH AMERICA

PUBLICATION #GR-LG 0101

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Landfill Gas Division of
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of North America
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FOREWORD

This document was prepared by the SWANA Landfill Gas Division and is based on its professional assessment of current practices and procedures relating to the control, recovery and utilization of landfill gas. The observations and suggestions in this document should serve as a starting point for readers who are interested in furthering their own knowledge of the subject matter.

After carefully considering the wisdom and feasibility of issuing recommended standards and guidelines, the Division concluded that such a step would be premature. As the patterns and practices associated with landfill gas control, recovery and utilization are still emerging, it made no sense for the Division to attempt to fashion durable and realistic criteria and norms. Nevertheless, the Division has successfully delineated workable approaches that will benefit both experienced persons and firms, as well as newcomers to the field.

SWANA plans to supplement the materials in this report from time to time as warranted by significant breakthroughs in technology or technique. This edition is an update to the original 1985 edition. Meanwhile, the Division invites interested persons to submit their comments or opinions.

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SWANA would like to acknowledge the following individuals for their hard work and dedication toward the publication of this document:

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A COMPILATION OF LANDFILL GAS FIELD PRACTICES AND PROCEDURES

HEALTH AND SAFETY SECTION

PREPARED BY:

SWANA LANDFILL GAS DIVISION
HEALTH & SAFETY TASK FORCE

August 1991

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HEALTH AND SAFETY SECTION

A. PURPOSE AND GENERAL INTRODUCTION

The purpose of this section is to provide information on health and safety practices for use in working with landfill gas (LFG) at municipal solid waste (MSW) landfills. This document is based on a consensus of practices developed based on specific experience with LFG. This document is not intended to apply to hazardous waste sites, however certain special circumstances which may be encountered at MSW landfills are addressed.

The Occupational Safety and Health Act (OSHA) of 1970 requires employers to furnish a place of employment which is free of recognized hazards that cause or are likely to cause death or serious physical harm to employees. Employers have the obligation to eliminate recognized hazards, to comply with safety and health standards, and to provide the necessary information and training to the employee.

Landfill safety requires more than the common sense safety procedures common to all industries. Bacterial decomposition of trash results in the formation of methane, a colorless, odorless, potentially explosive gas that together with other volatile materials is emitted into the atmosphere and migrates through the soil into surrounding areas. Air quality studies consistently show that concentrations of most potentially hazardous substances in the ambient air on and in the vicinity of solid waste landfills are well below threshold limits. Threshold limits are those limits above which chemical substances may cause harm. Various standards for threshold limits are discussed later in this text. However, in the presence of confined or enclosed areas and venting sources of gas on or adjacent to landfills, dangerous concentrations of combustible and possibly toxic gases may accumulate. LFG is chiefly composed of four common gases: methane, carbon dioxide, nitrogen and oxygen. The first three are simple asphyxiants; hence, oxygen depletion may also occur in these areas of confinement. Therefore, safety procedures should be followed at all times (e.g., monitoring for adequate levels of oxygen and for explosivity in vaults or excavations, etc.).

When conducting certain special activities such as drilling and trenching in refuse, or entering confined spaces such as vaults and excavations, toxic and odorous gases can be present. Odorous gases cause nausea in some persons. Toxic gases may also be present at concentrations above or below the levels deemed safe for human exposure; there is always a potential for levels to be sufficient to cause permanent and irreversible damage and even death. Monitoring of site conditions during these special activities is therefore recommended even where not specifically required by law.

Work activities which place employees in direct contact with LFG will most likely require the use of respiratory protection equipment. This is often advisable as a

Work activities which place employees in direct contact with LFG will most likely require the use of respiratory protection equipment. This is often advisable as a precautionary measure, even if regulatory action levels have not been exceeded. Such a policy demonstrates prudence by limiting exposure. The law requires that when working with carcinogens all possible exposure must be limited to the maximum extent feasible.

Where appropriate, Federal OSHA and other regulations have been cited to assist the reader in locating specific information on standards and requirements. More stringent local standards have been cited as examples where Federal OSHA guidance is lacking.

B. PLANNING

Employees are required to comply with safety rules and regulations applicable to their activities and conduct. Personnel must be physically able and mentally willing to comply with safety requirements. Managers should organize and plan for both the most likely and least likely contingencies. Planning should include the following:

1. Designate responsibility outlined as follows:

    a. Principal in charge. (Engineering company principal, Public Works Director, etc.)

    b. Technical/Project Director. (Project Principal/Associate/Director, etc.)

    c. Safety Officer/Manager (office). (Project Manager/Company Safety Manager, Landfill Operations Manager, etc.)

    d. Site Safety Coordinator (field). (Project Engineer, LF Operations Supervisor, etc.)

2. Physical health examination reports, certified by a qualified occupational health physician, should state that the worker is fit to wear the personal protective equipment required.

3. Identify the nearest hospital and emergency notification phone numbers.

4. Prepare admissions information before time of need for each employee, as appropriate.

The following admissions information is often required:

a. Name, address, telephone.

c. Social Security Number, date of birth, age.

d. Employer - address, telephone.

e. Responsible party - Social Security Number.

f. Insurance company - name, address, telephone, policy holder, policy number.

g. Personal medical data - tetanus history, general history, present medications, personal physician.

h. Allergic reactions or allergies.

C. SAFETY PLANS AND PROGRAMS

It is common for a company or a work location such as a landfill to have a general health and safety plan or program. General health and safety program components should address the following as necessary/appropriate depending on conditions and state and local laws:

1. Accident Prevention Program (General Safety).
2. Hazard Communication and "Right-to-Know".
3. Noise Control.
4. Dust Control.
5. Respiratory Protection Program.
6. Medical Surveillance (mandatory under certain circumstance, optional in others).
7. Safety training program (including hazardous materials and hazardous waste site training).
8. Personnel and Work Environment Monitoring.
9. Records Maintenance (all of the above).

1. Accident Prevention Program

A written accident prevention program covering general safety issues is the first basic building block of an overall health and safety program. The program should cover company policy, objectives of the program, and assignments of responsibility for the health and safety function. Availability of resources should also be addressed.

Employee training sessions and routine "tailgate" safety meetings are advisable and in some instances required.

2. Hazard Communication and "Right-to-Know" Standards

Typically, requirements for hazard communication and "right-to-know" programs do not apply to waste sites. However, future incorporation of such programs may be mandatory or at least in the best interest of the landfill owner/operator, LFG developer, or consultant. Such programs provide a good start for properly informing personnel of the hazards to which they may be exposed. These programs are necessary in any event if such hazards are known or suspected to exist. The Hazard Communication Standard does apply to construction, and recovery system operation and maintenance activities. The Federal Hazard Communication Standard is covered in 29 CFR Part 1910.1200.

For example, if personnel perform such tasks as constructing or repairing and maintaining PVC LFG collection systems, and therefore work with PVC cement and primer, then the personnel who work with those materials are covered under requirements of Hazard Communication and "Right-to-Know" statutes. Material Safety Data Sheets (MSDSs) must be maintained, and personnel must be trained in their understanding and use. MSDSs may also be required at LFG recovery plants where water treatment or other types of chemicals are used. Information on constituents found in LFG (vinyl chloride, methylene chloride, benzene, or toluene, for example) could be included in such a program, if concentrations are significant. It may be impractical to attempt to identify all chemicals; only those chemicals of special significance or when found in a high enough concentration in raw LFG to be of concern should be addressed in detail, however. For municipal sites, such an approach may not be mandatory, but may be prudent both from a common sense standpoint as well as from a liability perspective.

3. Noise Control

Where high levels of noise may be present for prolonged periods, a noise control program is typically required. Appropriate use of hearing protection, (e.g., ear plugs, ear muffs, etc.,) should be enforced. The Noise Control Standard is covered in 29 CFR Part 1910.95.

4. Dust Control

Typical dust control mitigation practices require the regular use of a water truck. Where high levels of dust and particulates may be generated from excavation, drilling or earth moving operations, a dust control program, sometimes including fugitive dust monitoring and sampling, is typically required.

5. Respiratory Protection Program

A written respiratory protection program is a legal requirement where it is necessary to employ the use of respiratory protection equipment. Requirements for a minimal acceptable program can be found at 29 CFR 1910.134 (b). The elements of a good program are:

1. Use of engineering controls wherever possible.
2. Hazard identification and assessment.
3. Written standard operating procedures.
4. Employee training.
5. Periodic medical assessment of employees and approval for respirator fitting and use.
6. Appropriate respirator selection for a specific job.
7. Proper qualitative fitting of respirators to personnel.
8. Maintenance and storage of respiratory protection equipment.
9. Periodic reevaluation of the program.

Persons involved in the administration of a program should be thoroughly familiar with such concepts as the protection factor (PF) of the air purifying respirators (APRs) used, the Maximum Use Concentration (MUC) of the APRs, determination of the Maximum Use Limitation (MUL) of a respirator, Permissible Exposure Limits (PELs), Threshold Limit Values (TLVs), and the levels Immediately Dangerous to Life and Health (IDLHs), as well as other concepts such as warning properties and respirator filter breakthrough.

Specific regulatory requirements for respiratory protection are delineated in CFR 29, Part 1910.134, for general industry and 29 CFR 1926.103 for the construction industry. Federal OSHA PELs are found in 29 CFR 1910.1000 Subpart Z. The PELs are legal standards. Note, that many states publish their own PELs and often adopt the American Conference of Governmental Industrial Hygienists (ACGIH) TLVs. Additional guidance may be found in the current annual edition of "Threshold Limit Values and Biological Exposure Indices" published by the ACGIH. This document contains the often cited Threshold Limit Value/Time-Weighted-Average (TLV-TWA), Threshold Limit Value/Short-Term Exposure Limit (TLV-STEL) and Ceiling (C) exposure limits. Also providing relevant guidance are the National Institute of Occupational Safety and Health (NIOSH) Recommended Exposure Limits (RELs) found in "NIOSH Pocket Guide to Chemical Hazards" (1990) available from the U.S. Government Printing Office. Note that there are some differences between these standards. TLVs are not intended to be applied by untrained persons.

Engineering Controls

It is a basic tenet of respiratory protection that an employer must first employ whatever engineering controls are available to reduce the hazard. If, after instituting such controls, conditions still warrant the use of respiratory protection, then such use must be implemented. An example of an engineering control would be an exhaust hood to control venting vapors while drilling.

Medical Assessment for Respirator Use

Prior to distribution of respirators to individuals and their fit testing, individuals must see a qualified physician to undergo an occupational physical assessment for proposed respirator use. This is a strict legal requirement. A physician who is Board-certified in Occupational Health is recommended. There are numerous medical issues which must be addressed by a qualified medical professional, such as diabetes, cardiovascular problems, and the like, which are not readily apparent to the untrained individual.

Respirator Fit Testing

As previously stated, respirator fit testing is performed only after approval by a qualified physician. Fit testing is intended to verify the fit of a particular brand of respirator to a specific individual, demonstrate effectiveness and instill confidence in respiratory performance, and allow the tested individual to determine and experience the physical limitations of respirator use.

6. Medical Surveillance

In addition to medical approval and surveillance for use of respiratory protection equipment, baseline physicals and medical surveillance may be required for certain work under special circumstances. If exposure to concentrations of toxic chemicals, such as benzene, vinyl chloride, and asbestos for example, is above action levels, then medical surveillance is warranted; otherwise, it probably is not. Constructor, consultant and LFG developer staff who routinely work directly with LFG at municipal landfills, as well as with other issues such as at hazardous waste sites, would fall into this category; most others would not. 29 CFR Part 1910.20 governs access to employee exposure medical records.

7. Safety Training Program

A basic safety training program, is usually provided to serve the following functions:

1. Teach and inform employees about basic safety concerns.
2. Address job-specific hazards likely to be encountered.
3. Fulfill certain legal notification and training requirements.
4. Heighten employee awareness.

8. Personnel and Work Environment Monitoring

Consistent with any applicable "general health and safety clause," an employer must monitor employees and/or the work environment whenever a risk for employee exposure is known or can be suspected. Requirements for personnel or work environment monitoring are dependent on the type of work being performed and specific site conditions. Therefore, monitoring may or may not be appropriate, depending on the situation and whether or not specifically required by federal, state, or local regulations. The employer will determine when, and at what frequency, such monitoring should be performed.

Typically in industrial processes, the contaminants or substances which may cause a health threat are known and monitoring is straightforward. For certain specific substances of great concern, action levels, at and above which monitoring must take place, are specified by regulation (e.g., the action level for vinyl chloride is 0.5 parts-per-million or ppm). The action level for a given substance is typically set at one-half of the TLV or OSHA PEL, but may be specified otherwise by regulation. When it is necessary to monitor work on waste sites, more complex issues are encountered. A thorough site characterization is necessary at the outset of site work for the safety of personnel who will engage in field monitoring, construction, engineering, or LFG recovery activities. The monitoring or sampling plan may need to be modified or adjusted based on findings.

Monitoring or sampling techniques could involve the use of a combustible gas analyzer (CGA) or an organic vapor analyzer-flame ionization detector (OVA-FID) to monitor total raw gas concentration in air and estimate the percentage of trace contaminants based on analytical data. Alternately, continuous use of more sophisticated personnel or area sampling could be required. Any monitoring or sampling plan should be able to demonstrate an approach with a justifiable rationale, and should be scrutinized for statistical validity. The necessity for such monitoring or additional sampling should be determined by an experienced and qualified professional based on the types of hazards and risks present and the extent of exposure for the work to be performed.

9. Records Maintenance

Accurate, reproducible, and verifiable records are essential for an effective overall health and safety program. They also provide protection against liability and preclude situations where compliance cannot be demonstrated. Records should include medical assessment and respirator use approvals, certification of fit test, respirator eyeglass insert information, respirator maintenance records, and gas characterization information.

D. HAZARD ASSESSMENT AND IDENTIFICATION

A necessary step in the implementation of respiratory and bodily protection is the identification of the hazards to be protected against. Extreme caution is warranted in dealing with situations where LFG is detected within the explosive range. Other kinds of special hazards are listed under the section of this document titled "Safety Procedures for Well Drilling and Construction".

In the case of LFG, hazard assessment and identification should include a complete site-specific characterization of the gas. Initial characterization may be performed by gas chromatograph/mass spectrometer. Once chemicals are tentatively identified qualitatively, more specific quantitative data can be obtained using a more specific analytical detector for the classes of chemicals in question. The analytical method selected should be capable, at a minimum, of identifying those compounds of concern at concentration levels at or below any action levels set for those compounds (i.e., one half the TLV or PEL).

Identification is difficult due to the heterogeneous nature of landfills and the dynamic nature of the biological decomposition process occurring within the landfill. Hence LFG composition varies from site to site, as well as throughout any site. An appropriate initial characterization, however, can serve to generally predict chemicals that are present and their relative concentrations. When characterization is performed, care must be exercised in interpreting results, taking into consideration the specific limitations of the analytical methods and hardware used.

In addition to the fixed gases (CH_4, O_2, N_2, and CO_2), trace contaminants are present in LFG. There are literally hundreds to thousands of chemicals in LFG, most of which are at such low levels that it is impractical to identify all of them. Accuracy and sensitivity to a given class of chemicals will vary, depending upon the analytical procedures and equipment used. The chemicals which have received the most regulatory scrutiny are the volatile priority pollutants. These are generally aliphatic, aromatic, cyclical, and chlorinated hydrocarbons. Other classes of chemicals may also be present in LFG, gas condensate from various phases in a recovery process, and leachate. These may also include organic and inorganic acids and bases, sulfur compounds, metals, and metal hydrides.

The following is a brief (but incomplete) list of some of the priority pollutant chemicals of chief regulatory concern which may be found in LFG:

CHEMICAL	FORMULA
Benzene	C_6H_6
Chloroethene (Vinyl Chloride)	CH_2:CHCl
1,2-Dibromoethane (Ethylene Dibromide)	$BrCH_2CH_2Br$
1,2-Dichloroethane (Ethylene Dichloride)	$ClCH_2CH_2Cl$
Dichloromethane (Methylene Chloride)	CH_2Cl
Tetrachloroethylene (Perchloroethylene)	Cl_2C:CCl_2
Tetrachloromethane (Carbon Tetrachloride)	CCl_4
1,1,1-Trichloroethane (Methyl Chloroform)	CH_3CCl_3
Trichloroethylene	HClC:CCl_2
Trichloromethane (Chloroform)	$CHCl_3$
Hydrogen Sulfide	H_2S

E. SITE-SPECIFIC SAFETY PLANS

For special activities such as those mentioned above, a safety plan should be developed. This plan should be as site- and situation-specific as possible.

F. SAFETY MANAGEMENT

The following checklist comprises items that would be part of a minimum safety plan:

1. Designated safety persons shall be qualified to insure compliance with requirements and safety concerns.

2. Safety procedures shall be documented and reviewed with all workers prior to the start of work. A safety plan should be maintained at the job site.

3. Scheduled meetings should be held to review the safety program.

4. Unsafe acts should be stopped if discovered.

5. Required safety equipment shall be on site, and shall be checked for completeness and function.

6. If Air Purifying Respirators (APRs) are used, a written document should be prepared by each employer which describes the standard operating procedures governing selection and use of respirators, medical examination and approval, fit testing, respirator inspection, cleaning and disinfecting, repair, and storage.

7. All employees who may be required to wear respirators should be fit-tested and trained in the proper use of respirators.

8. Appropriate local authorities (fire department, air quality, etc.) should be notified prior to drilling, trenching, or flaring, etc.

9. Contracts for LFG testing, construction, or operation should include a safety procedures clause.

G. SAFETY EQUIPMENT

Workers engaged in construction or maintenance of LFG facilities should wear protective safety equipment as follows:

1. Hard hats, if near moving or mechanical equipment, or if working in confined spaces or where overhead hazards may exist (e.g., in excavations or around scaffolding).

2. Steel-toed, shoes or rubber boots.

3. Safety glasses and/or face shields, as appropriate.

4. Protective gloves if working with wet solid waste or where exposure to leachate or condensate is expected. Selection of protective materials is dependent on the potential hazards present and should be based on performance data and recommendations provided by material manufacturers.

5. Hearing protection, depending on noise level of work environment.

Other protective equipment may include:

1. Chemically protective overalls (e.g., Saranex, Tyvek, etc.)

2. Steel-toed steel shank neoprene boots.

3. Chemically protective gloves (e.g., Viton, neoprene, nitrile).

4. Respiratory protection as appropriate for the level of hazard, e.g., half-face and/or full-face APRs with NIOSH-approved organic vapor/acid gas (OV/AG) cartridges or canisters and appropriate dust/mist/fume capability.

5. A pressure demand self-contained breathing apparatus (SCBA), fitted with a pressure-demand type regulator and 30-minute (minimum) bottle or a supplied air system.

The following safety equipment should be available at the job site in quantities sufficient to cover the construction/testing crew:

1. Clean water, soap, and paper towels.

2. First aid kit, eye wash station, stretcher, and blanket.

3. Two Fire extinguishers - 20:A-80:BC.

4. "No Smoking" signs and/or barrier tape.

5. Two parachute-type harnesses and safety lines (for use in excavations, manholes, trenches and vaults, etc.)

6. CGA/oxygen indicator.

7. Hydrogen sulfide indicator (direct reading instrument or Dräger-type diffusion tubes).

8. Additional monitoring equipment for toxic vapors and aerosols.

9. Barricades and/or barrier tape.

10. Covers for excavations that will remain open at the end of the day.

11. Air-moving equipment that can provide ventilation if working in substandard air environments (trenches, condensate drain pits, etc.).

12. Fire-resistant blanket suitable for extinguishing a small fire or to provide heat to personnel in shock.

13. Construction equipment equipped with vertical exhaust or spark arrestors if within 2 feet of grade.

14. Flagging, traffic markers, and fluorescent orange safety vests for use when working around operating equipment or near public roadways.

H. PERSONAL HEALTH AND HYGIENE

1. Personal safety and the safety of fellow workers require that all employees arrive at the job and remain mentally alert. No alcohol or drugs are permitted. Smoking should be prohibited or limited on the landfill site. No worker should handle excavated solid waste without wearing gloves. Parts of the body accidentally exposed to waste, leachate, or condensate should be washed immediately with soap and water. Eating meals on the landfill should be discouraged.

2. Any cut or abrasion shall be treated immediately by a qualified professional health practitioner, as the chance of infection is high when working on a landfill. A tetanus shot is recommended at specified intervals for all personnel involved in site construction/testing activities.

3. Workers should avoid contact with hazardous plants, or those known or suspected to be hazardous, growing on the landfill.

4. Animals, snakes, spiders, and other insects should be avoided, especially around vaults and vault boxes. First aid supplies should include a snake bite kit. If unusual flora or fauna are expected, they should be identified as potential hazards in the site safety plan. Antidotes and/or medication should be maintained for persons with severe allergies.

5. The address, telephone number, and location map of the nearest hospital and medical emergency room should be prominently posted. In addition, the

telephone number of an the ambulance and fire department/rescue unit should be prominently posted.

6. Workers should wash hands prior to eating, drinking, smoking, or changing clothes.

I. LANDFILL SAFETY PROCEDURES

1. As a general safety rule, LFG work should be performed by a team composed of a minimum of two people. In situations where hazards are minimal, and where it is necessary to allow an individual to work alone, another responsible individual must be aware of the lone workers task and scheduled time of completion/return, and if possible should monitor the individuals progress.

2. When working on (or within 1,000 feet of) an active or completed solid waste landfilled area, workers should be alert to the existence of (or potential for) hazardous conditions, e.g., the presence of LFG. A distance of 1,000 feet is used by some authorities as the maximum distance that LFG will migrate under average conditions. Migration distance, however, may be greater through underground conduits, in favorable subsurface soil conditions, or where surface conditions interfere with normal surface venting.

   Hazards that might occur could be one or more of the following:

   a. Fires may start spontaneously from exposed and/or decomposing waste.

   b. Fires and explosions in confined or enclosed spaces from the presence of methane gas.

   c. Landfill gases may cause oxygen deficiency in underground trenches, vaults, conduits, and structures.

   d. Hydrogen sulfide (H_2S) may be present. H_2S is a colorless, toxic, very flammable gas which, in low concentrations, has an offensive odor described as that of rotten eggs. H_2S, however, quickly numbs the olfactory senses so that reliance upon the sense of smell can lead to a very dangerous condition and even cause virtually instant death.

   e. Sudden subsidence or collapse of the landfill surface during activities such as drilling.

3. A *confined space* is defined as a space where existing ventilation is insufficient to remove dangerous air contamination and/or where there is an oxygen deficiency, and where ready access/egress to escape, provide aid, or to remove

a disabled employee is difficult. Work in confined spaces is normally governed by strict procedural regulations, so check local codes.

4. In the case of flammable gases such as methane, a *dangerous air contamination due to flammability of a gas or vapor* is defined, (in California, Title 8, Article 108, Confined Spaces, Section 5156,) as any concentration greater than 20 percent of the lower explosive limit (LEL) for any substance. There is no equivalent Federal OSHA standard, so check local and state codes. An atmosphere considered to be an *immediately dangerous to life and health* (IDLH) atmosphere is one containing less than 19.5 percent oxygen by volume or one containing a concentration of another hazardous or toxic chemical at or above the limits set by NIOSH.

5. Note that while the Resource Conservation and Recovery Act (RCRA) (40 CFR, Part 257.3-8 Safety) places limits on the maximum allowable methane concentration in landfill facility structures, on or near landfills, at not to exceed 25 percent of the LEL or 1.25 percent methane gas in air (by volume), local OSHA regulations on flammable or combustible environments may place a more stringent requirement on the maximum concentration allowed in a working environment (i.e., an occupied structure which is not private and residential).

6. The flammable range for methane is approximately 5 to 15 percent in air at sea level at 25 Degrees C. As little as 0.3 millijoule of static electricity is sufficient to cause a methane ignition. This has been equated to 1/50 the amount of static electricity accumulated by a person walking across a carpeted floor on a dry day. The autoignition temperature of methane is 1004 Degrees F. The specific (vapor) density of methane is 0.6 that of air while the specific density of undiluted LFG is normally about 1.0 (close to that of air, depending on constituent concentrations). Therefore it should not be automatically assumed that because LFG contains methane the mixture is lighter than air and will rise. Behavior of LFG will vary with its constituent makeup which also varies.

7. Prior to the entry of workers into an excavation, vault, or ditch deeper than 3 feet, and routinely during construction, the atmosphere in the excavation should be tested for explosive concentrations, oxygen deficiency and H_2S levels. Air blowers or fans should be available for positive ventilation. A pressure-demand SCBA or supplied air respirator must be used when entering areas containing hazardous and/or oxygen-deficient atmospheres. APRs with chemical cartridges can be used for gaseous contaminants (but not H_2S) if all of the following conditions are met: if the oxygen concentration is satisfactory, if the chemical contaminants have been identified, the concentrations have been monitored, the cartridges are effective in removing the contaminants, and all the contaminants have good warning properties. Mechanical filter respirators should be used only for protection against appropriate particulate matter for which they are rated.

8. Fires and explosions in confined spaces require a source of ignition. Smoking is strictly forbidden except in well-ventilated areas. Nonsparking and/or explosion-proof tools should be used in vaults, trenches, and other enclosed areas. Positive ventilation is required in construction shacks or other structures on or near a landfill. Temporary structures on the landfill surface should be constructed on blocks or other supports, with a ventilated area under the main floor. Construction equipment should be equipped with a vertical exhaust at least 5 feet above grade and/or with spark arrestors.

9. H_2S gas is usually always present at some concentration, generally below 100 ppm, in LFG. It is unlikely that hazardous concentrations of H_2S will build up (see Table 1) except in vaults or other confined spaces where oxygen deficiency may be a hazard. However, in special circumstances, where there is an natural or manmade presence of gypsum along with high moisture, for example, very high (lethal) concentration levels of H_2S may be produced at landfills. A large amount of construction debris containing wallboard concentrated in one location at a landfill would be another potential example. Thus, dangerous and unexpected pockets of H_2S gas could be encountered under certain circumstances. Personnel must be trained for, and alert to, these possibilities.

   One must always remain alert to observe such conditions. Air-purifying respirators are not normally effective against H_2S unless specifically rated for such use, and then only for a limited concentration and duration of use. In situations when high concentrations of H_2S are known or suspected pressure-demand SCBA or supplied air respirators should be used.

10. Employees with beards should not work in areas where snugly fitted air masks or respirators may be necessary. All employees should be fit-tested on the respirator that they will wear in order to assure a proper facepiece seal against the face. Fit-testing should reoccur at least annually.

11. For employees who wear glasses, respirator eyeglass inserts should be provided if full-face masks are used. The wearing of contact lenses with any type of respirator shall be prohibited.

TABLE 1

Physiological Response to Various Concentrations of Hydrogen Sulfide

Response	H_2S Concentration (ppm)
Maximum allowable concentration for prolonged exposure,8 hours (1,2)	10
Slight symptoms after several hours	70-150
IDLH - level at which exposure is immediately dangerous to life and health (3)	300
Death possible/probable. Permanent nervous system damage.	400-700
Immediate death	1000

Note: Laboratories are often not able to properly analyze for H_2S due to its reactivity. Dräger diffusion type tube monitoring may be generally adequate, however other interferants, (e.g., SO_2,) are certain to be present and likely will render a falsely high reading, and therefore cannot be relied upon for accurate measurement. Note that when using Dräger diffusion type tubes, some interferants may mask detection of the chemical of interest.

References:

1. American Council of Governmental Industrial Hygienists Threshold Limit Value.

2. State of California Division of Safety, General Industry Safety Orders #5155,

3. National Institute for Occupational Safety and Health (NIOSH), Pocket Guide to Chemical Hazards, September 1985.

4. Chemical Hazards in the Workplace, Procter, N. and Hughes, J.; J.B. Lippencott Co., Philadelphia, Pennsylvania; 1978

J. SAFETY PROCEDURES FOR WELL DRILLING AND CONSTRUCTION

1. One person should be present at all times during construction. This person shall have the sole responsibility of assuring the observance of all safety procedures, and will be trained in the use of all recommended safety equipment.

2. Smoking shall not be permitted within 50 feet of a boring. No smoking on the landfill is preferred.

3. Fire extinguishers should be on hand during drilling (two 20:A-80:BC extinguishers are recommended). The drilling crew should be alert for the potential for the drill auger to spark against rock or metal causing a serious fire in the boring. LFG will typically burn almost invisibly under such circumstances. Fires should be extinguished by covering the boring with earth materials by using earth moving equipment. As a contingency before drilling, arrangements should be made to have a loader or equivalent equipment available or on call in case of a boring fire.

4. Any personnel working near the edge of a well (greater than 12 inches in diameter) under construction shall wear a parachute-type harness and safety line tied to an immobilized drill rig or some other safe immobilized structure, and/or shall work with a drilling platform in place. Due to the typically oxygen deficient environment "down hole," an individual who fell "down hole," even a short distance, would likely not survive until recovered. For this reason, it is preferable that all individuals working in the vicinity of drilling activities be tethered.

5. No worker shall be allowed to work alone at any time near the edge of the well under construction. At least one other worker shall be present, beyond the areas considered to be subject to the possible effects of LFG or cave-in. The number of persons working near the boring should also be limited to only the number necessary to accomplish the task, however there should always be sufficient workers present nearby to remove an injured worker or summon help.

6. During drilling, special consideration must be given to the less stable conditions represented by refuse, vis-à-vis compacted soil. Refuse must be considered more prone to instability that may cause side wall failure of the boring at any time. If this were to occur, the magnitude of the failure could be substantial. Individuals present at the time of failure could be buried in an oxygen deficient environment.

   It is imperative that the personnel performing drilling work remain alert at all times to changing subsurface conditions and signs of impending physical failure such as fissures, etc. It is not uncommon to experience a "hollowing out" effect creating a cavity at depth much larger than the boring due to side wall failure "down hole". This could cause a sudden collapse to occur at the surface. It should be remembered that the drill rig usually exerts a large and vibratory force at the surface in the vicinity of the boring.

7. Drilling personnel must be alert to the potential for encountering subsurface hazards, particularly in older landfills where screening of disposal materials may have been less controlled. Although rare, a variety of hazardous situations have been encountered while drilling in landfills especially near military or chemical processing facilities. These potential hazards include:

    - Unknown hazardous chemicals in drums or containers. These could include combustible or explosive, reactive, toxic or corrosive materials.
    - Military munitions.
    - Asbestos.
    - Compressed gas cylinders (CGCs).
    - Biomedical waste.
    - Radioactive waste.

8. Periodically during the well construction, the work area should be monitored for levels of methane, H_2S, vinyl chloride, benzene and/or other volatile organic chemicals.

9. If the well construction is not completed by the end of the working day, the hole shall be covered with a plate of sufficient overlap to prevent access to the hole and sufficient thickness and structural strength to support expected loads and the plate shall be weighted down to discourage removal. The edges of the plate shall be covered with a sufficient quantity of wet dirt to prevent gas from escaping. Barricades shall be placed around the covered hole outside the range of possible cave-ins.

10. All pipes shall be capped at the end of each working day.

11. An exhaust hood can be used to control venting LFG vapors while drilling to reduce personnel and environmental exposure. This is mandatory in some locales.

K. SAFETY PROCEDURES FOR EXCAVATION, TRENCHING AND PIPE INSTALLATION

1. Excavation permits and shoring may be required for excavations deeper than 4 to 5 feet (into which workers will enter). Check state regulations as standards and requirements vary.

2. One person should be present at all times during construction with the sole responsibility to observe all safety procedures. This person shall be trained in the use of all recommended safety equipment.

3. Smoking shall be prohibited within 50 feet of trenching and piping. No smoking on the landfill is preferred.

4. Prior to the entry of workers into an excavation deeper than 3 feet, and periodically during their work, the atmosphere in the excavation should be tested. If there are any doubts regarding safety, no worker shall be allowed to enter the excavation without at least a half-face or full-face OV/AG mask. If there is an oxygen deficiency, a concentration of any constituent with poor warning properties at a level greater than its TLV, or a concentration of hydrogen sulfide greater then 10 ppm, a pressure-demand SCBA or supplied air respirator with 5 minute emergency escape bottle should be used. If a combustible mixture of methane is present, further precautionary measures shall be taken; entry should be forbidden until the methane concentration is acceptable and at least below 1.0 percent by volume in air, or 20 percent of the LEL. If workers are not equipped with supplied air or pressure-demand SCBAs, then entry should be forbidden until the methane concentration is below 0.1 percent by volume in air, unless the Maximum Use Limitation (MUL) of the APR is greater. Workers required to work on an emergency basis, in any environment at or above the IDLH (the level immediately dangerous to life and health as declared and published by NIOSH) for any constituent component in the working environment, should be outfitted in pressure-demand SCBAs.

5. No worker should be allowed to work alone at any time in or near the excavation. Another worker shall be stationed, beyond the area considered to be subject to the possible effects of LFG. There should always be a sufficient number of workers present to remove an injured or endangered worker and to summon help.

6. Periodically during construction, the work area should be monitored for levels of methane, H_2S, vinyl chloride, benzene, and other volatile organic chemicals.

7. No worker may handle excavated solid waste without wearing appropriate work gloves and clothing, which will provide an adequate barrier to the waste.

8. Construction equipment should be equipped with a vertical exhaust at least 5 feet above grade and/or with spark arrestors.

9. Electrical motors, if used in the excavation area, shall be explosion-proof or non-sparking, totally enclosed fan cooled (TEFC); and electrical controls should be explosion-proof or intrinsically safe and meet the requirements for Class I, Division 2, Group D, (Methane), rated equipment in accordance with the National Electric Code (NEC).

10. No welding should be permitted in, on, or immediately near the excavation area, unless previously and continuously monitored for methane and other combustible gases.

11. Soil should be stockpiled near the excavation or well for use in smothering any combustion, should it occur.

12. Solvent cleaning, gluing, or bonding of pipe should be performed, to the extent possible, outside the trench. An organic vapor respirator shall be worn by persons using PVC solvents or glues. Personnel using solvent and cement shall be familiar with the appropriate materials safety data sheets for those products.

13. Forced ventilation may be required for workers who must work in trenches deeper than 3 feet. Air blowers and fans may be used for positive ventilation. Dilution ventilation may address either an explosive gas hazard or a hazardous chemical health hazard. The amount of air required for ventilation must be determined based on the concentrations of explosive LFG or hazardous chemical constituents, the LEL for methane or the TLVs for the hazardous chemical constituents in question, the volume to be protected, ambient conditions, and an appropriate safety factor. These calculations should be performed by a qualified individual.

14. During piping assembly, all valves should be closed immediately after installation.

15. As construction progresses, all valves should be closed as installed to prevent the migration of gases through the pipeline and gas collection system.

16. All piping shall be capped at the end of each working day.

L. GENERAL CONSTRUCTION/MAINTENANCE

1. When drilling on LFG collection system piping containing LFG, only explosion-proof electric or hand-powered drills should be used.

2. When using alternating-current powered power tools, a portable ground-fault current interrupter (GFCI) should be used.

3. When welding near gas recovery process equipment, suitable procedures and precautions should be employed including:

    - Processing a "hot work" permit. (A self-issued serial numbered permit is required in many states.)

    - Designate a specific, dedicated individual, by name, as a fire watch.

    - Verify that explosive concentrations are not present using an explosimeter.

    - Have adequate fire extinguishers (20:A-80:BC) and fire blankets on hand.

    - Sandbag all drains.

    - Provide the appropriate purge and inert blanket on process equipment and piping.

    Procedures for safe welding and purging of process equipment are available from the American Petroleum Institute (API).

M. SHORING AND BRACING

1. No person shall enter any trench deeper than 4 to 5 feet unless the trench has been shored, braced, sloped, or other provisions made to prevent cave-in. Shoring shall be engineered by a qualified and licensed civil or structural engineer or engineering geologist. Drawings, specifications, and calculations shall be signed by the engineer.

2. Special consideration must be given to the less stable conditions represented by refuse vis-à-vis compacted soil. Refuse must be considered more prone to instability that may cause slope or side wall failure. This is due to the high void ratio, irregularity of material composing the refuse, and a typically lesser degree of compaction than soil.

N. FIELD SAMPLING FOR HEALTH AND SAFETY

1. The following instruments will remain at the job and be continuously employed by a qualified person:

   - H_2S chemical reagent diffusion tube indicator or direct reading instrument.
   - Oxygen analyzer.
   - CGA (methane analyzer).

2. CGAs and other electronic portable monitoring instruments should be rated explosion-proof or intrinsically safe. It is also recommended that they be Factory Mutual rated.

3. It is important that any site always be initially characterized so that correct information can be available to make appropriate decisions about personnel exposure safety.

4. To accomplish Item 3, a gas sample should be collected prior to the beginning of work or as soon as possible, and should be analyzed for volatile organic chemicals. If historical information or preliminary field screening indicate a need, the sample should also be analyzed for heavy metals capable of volatilizing, acid gases, and other inorganic compounds. Proper instructions and close coordination with the laboratory are important to properly characterize the gas. Several composite samples will provide a more uniform representation of LFG at the site. Several non-composited samples, may however, provide a better indication of peak concentrations and show chemicals which would not be indicated in the composite samples.

5. Monitoring for vinyl chloride, benzene, or other constituent chemicals may also need to be conducted during drilling operations. A written record of monitoring should be maintained daily.

O. RESPIRATORY PROTECTION

1. All employees who may be required to wear respirators shall be trained in the proper use of respirators. Such individuals will have an appropriate physical examination for use of respirators. Each individual will be approved by a qualified physician for such respirator use. All personnel who wear respirators shall come under the jurisdiction of their employer's written respiratory protection program, and will follow and be knowledgeable about the program. Personnel will be individually fit-tested wearing their assigned respirator. Fit-

testing will be conducted with isoamyl acetate for organic vapor cartridges and irritant smoke (stannic chloride) for particulate filter cartridges prior to respirator use on site. The above notwithstanding, these provisions should not be intended to preclude otherwise unauthorized personnel from emergency use of respirators or voluntary upgrading. Documentation for compliance with these provisions should be maintained.

2. Persons with interfering facial hair shall not be permitted in areas where respiratory protection equipment is required; i.e., beards are prohibited.

3. Permanent damage to the eyes (cornea) from acid gases and particulates may result if contact lenses are worn. Therefore, wearing contact lenses on site shall be prohibited. Those persons shall have prescription spectacle inserts installed in their respiratory protective equipment.

4. All NIOSH procedures and guidelines for respirator selection and use should be adhered to. Only equipment certified by NIOSH in its most recent certified equipment list will be used. APRs with chemical cartridges can only be used for acid gas/organic solvent vapors under the following conditions:

    - If the oxygen concentration is satisfactory.
    - If the chemical contaminants have been identified.
    - The concentrations are monitored.
    - The chemical filter cartridges are effective in removing the contaminants.
    - The cartridges are approved for such use (by NIOSH).
    - The contaminants have good warning properties.

    If all of the above conditions cannot be satisfied, then Level B protection using pressure-demand SCBAs or supplied air is required. APRs with chemical cartridges/canisters will not be used for protection in environments containing constituents which have poor warning properties, and which are at or above, or can reasonably be expected to be near, at, and/or above the limitation of the protection factor (PF) for the respirator. The maximum working environment shall be determined by multiplying the PF for the type of respirator by the TLV for the chemical substance under consideration, (MUC = PF X TLV). A list of PFs is shown in **TABLE 2.**

TABLE 2

Table of Respiratory Protection Equipment Protection Factors

Type of Air Purifying Respirator	Protection Factor
Half-face APR	10
Full-face APR	100
When employed for protection from benzene. See Note 1.	50
When employed for protection from vinyl chloride using vinyl chloride rated specific canister with a 4 hour service life. See Notes 2 and 3.	25
Pressure-Demand SCBA or supplied air-line respirators	10,000

NOTE 1: See the Benzene Standard, 29 CFR 1910.1028.

NOTE 2: See the Vinyl Chlorine Standard, 29 CFR 1910.1017.

NOTE 3: Because respirator cartridges/canisters meeting the service life requirements listed in 29 CFR 1910.1017 (g) are not normally available, work involving vinyl chloride concentrations above the action level of 0.5 ppm will require use of pressure-demand SCBAs.

5. Pressure demand SCBA or pressure demand supplied-air full-face masks shall be used when entering areas containing oxygen-deficient atmospheres, unknown atmospheres, or atmospheres considered to be at or above IDLH levels. Personnel (with appropriate SCBA apparatus) will not enter IDLH environments without emergency justification by and approval of a site safety manager or responsible project manager. An emergency is constituted by an already existing life threatening situation.

6. The length of time an APR canister or cartridge is effective in removing hazardous material from the ambient air will depend on the type and concentration of hazardous material in the air and the level of effort required for a worker to accomplish his assigned tasks. The higher the breathing rate, the more frequently canisters will need to be replaced. These maximum operating periods vary according to manufacturer, so it will be necessary to monitor the total usage of cartridges and canisters during all work requiring a respirator.

P. SPECIAL CONDITIONS

Certain types of work may present unusual problems at certain sites with special conditions. Examples include the following:

1. For protection against infectious waste, a Tyvek suit, appropriate gloves and boots, and a NIOSH-approved respirator with a high-efficiency particulate filter (HEPA) incorporated in the mask canister or cartridge, are suggested. Personnel should avoid or minimize contact with any waste, and be cautioned about possible contact with sharp objects such as needles. The HEPA filter may be combined with an OV/AG cartridge or canister.

2. For protection against gas vapors while drilling or while working around an open well casing, a NIOSH-approved full-face air-purifying respirator with an OV/AG canister including a HEPA filter may be necessary. The Saranex or Tyvek suit are also required. Also, appropriate gloves and boots. Appropriate measures must be taken to prevent heat stress.

3. For protection from asbestos fibers, the minimum required includes a respirator with a HEPA filter and a Tyvek suit. The Tyvek suit may either be coated or uncoated. Special regulations exist for asbestos, for complete requirements see the Asbestos Standard, 29 CFR 1910.1001.

4. A determination may need to be made regarding whether additional protection will be required, if significant levels of vinyl chloride or benzene (or other more toxic chemicals) are found during characterization. The action levels for vinyl chloride and benzene are one-half of 1 ppm. The maximum threshold limit value

of benzene or vinyl chloride to which workers may be exposed over an 8-hour period is 1 ppm. The maximum concentration of vinyl chloride to which workers may be exposed in any given period is 5 ppm. If higher levels of vinyl chloride are found, respiratory protection levels may need to be adjusted to Level B (SCBA or supplied air) if engineering controls cannot reduce these levels. Because vinyl chloride and benzene are both regulated carcinogens, it is imperative and required that exposure be limited where at all possible; if not, then exposure must be reduced to the minimum possible extent through appropriate respiratory protection (i.e., vinyl chloride and benzene exposure should be held to zero whenever possible). For the Vinyl Chloride Standard, see 29 CFR 1910.1017. For the Benzene Standard, see 29 CFR 1910.1028.

5. Special compliance requirements apply for personnel who must work with potential exposure to certain chemicals including vinyl chloride, benzene, and asbestos above action levels. Compliance requirements may vary with each compound and by state, but will likely include:

- Mandatory training.
- Medical record keeping.
- Exposure monitoring, and record keeping.
- Certifications.
- Specific protective equipment requirements.

GLOSSARY OF HEALTH AND SAFETY ACRONYMS

ACGIH - American Conference of Governmental Industrial Hygienists

API - American Petroleum Institute

APRs - Air purifying respirators

C - Ceiling exposure limit

CO_2 - Carbon dioxide

CGA - Combustible gas analyzer

CGCs - Compressed gas cylinders

CH_4 - Methane

GFCI - Ground-fault current interrupter

H_2S - Hydrogen sulfide

HEPA - High-efficiency particulate filter

IDLH - Immediately Dangerous to Life and Health

LEL - Lower explosive limit

LFG - Landfill gas

MSDSs - Material Safety Data Sheets

MUC - Maximum Use Concentration

MUL - Maximum Use Limitation

N_2 - Nitrogen

NEC - National Electric Code

NIOSH - National Institute of Occupational Safety and Health

O_2 - Oxygen

OSHA - Occupational Safety and Health Act

OVA-FID - Organic vapor analyzer-flame ionization detector

OV/AG - Organic vapor/acid gas

PEL - Permissible Exposure Limit

PF - Protection factor

PPM - Parts-per-million

RCRA - Resource Conservation and Recovery Act

REL - Recommended Exposure Limit

SCBA - Self-contained breathing apparatus (pressure demand type)

SO_2 - Sulfur dioxide

TLV - Threshold Limit Value

TLV-STEL - Threshold Limit Value/Short-Term Exposure Limit

TLV-TWA - Threshold Limit Value/Time-Weighted-Average

REFERENCES

1. American Conference of Governmental Industrial Hygienists. Threshold Limit Values and Biological Exposure Indices for 1990-1991.

2. California Administrative Code, Title 8, General Industry Safety Orders, State of California Department of Industrial Relations.

3. California Administrative Code, Title 8, Section 5155, (General Industry Safety Order 5155), Airborne Contaminants. State of California Department of Industrial Relations. November 1986. (Reprint).

4. California Administrative Code, Title 8, General Industry Safety Orders Article 108, Confined Spaces. March 1990. (Reprint)

5. California Administrative Code, Title 8, General Industry Safety Orders Section 5144, Respiratory Protective Equipment. September 1985. (Reprint)

6. CHRIS Hazardous Chemical Data, U. S. Department of Transportation, United States Coast Guard, November 1984. Commandant Instruction M.16465.12A, November 1984.

7. Code of Federal Regulations, Title 29, Labor, Part 1910, Occupational Safety and Health Standards, 1990.

8. Code of Federal Regulations, Title 29, Labor, Part 1926, Safety and Health Regulations for Construction, Occupational Safety and Health Administration, 1990.

9. Code of Federal Regulations, Title 29, Labor, Part 1910.95, Occupational noise exposure, Occupational Safety and Health Standards, Occupational Safety and Health Administration, 1990.

10. Code of Federal Regulations, Title 29, Labor, Subpart I-Personal Protective Equipment, Occupational Safety and Health Standards, Occupational Safety and Health Administration, 1990.

11. Code of Federal Regulations, Title 29, Labor, Part 1910.134, Respiratory Protection, Occupational Safety and Health Standards, Occupational Safety and Health Administration, 1990.

12. Code of Federal Regulations, Title 29, Labor, Part 1910.1000, Subpart Z-Toxic and Hazardous Substances, Occupational Safety and Health Standards, Occupational Safety and Health Administration, 1990.

13. Code of Federal Regulations, Title 29, Labor, Part 1910.1200, Hazard Communication, Occupational Safety and Health Standards, Occupational Safety and Health Administration, 1990.

14. National Fire Protection Association, Fire Protection Guide, 16th Edition, National Fire Protection Association, Batterymarch Park, Quincy, MA 02269, 1986.

15. U.S. Department of Health and Human Services, NIOSH Guide to Industrial Respiratory Protection, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication Number 87-116, September 1987.

16. U.S. Department of Health and Human Services, NIOSH Pocket Guide to Chemical Hazards, DHHS (NIOSH) publication no. 90-117, National Institute for Occupational Safety and Health, Cincinnati, Ohio, June 1990.

A COMPILATION OF LANDFILL GAS

FIELD PRACTICES AND PROCEDURES

LANDFILL GAS MONITORING, SAMPLING, AND ANALYSIS SECTION

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SAMPLING AND ANALYSIS TASK FORCE

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LANDFILL GAS MONITORING, SAMPLING, AND ANALYSIS

A. INTRODUCTION

The purpose of this section is to provide information on the current array of accepted procedures and instruments used for field monitoring, field sampling, and laboratory analysis of landfill gas (LFG) generated at municipal solid waste (MSW) landfills. This document is based on a consensus of practices employed by researchers, scientists, engineers, and regulatory agencies at various waste sites nationwide.

The monitoring and sampling techniques presented in this section focus on commonly used portable devices and instruments. Stationary instruments generally are not considered here; however, several types of apparatuses are available. Stationary instruments and continuous monitors are likely to grow in importance as improvements are made in equipment durability, detection technology, and data storage.

Monitoring and sampling of landfill gas components can be conducted at wells, within landfill gas collection system piping, at the landfill surface, within buildings and structures, in soils adjacent to the landfill, and in air quality studies. LFG is chiefly composed of four major gases: methane, carbon dioxide, nitrogen, and oxygen.

Because these gases generally are present in large quantities, they are measured in terms of the percent volume occupied in the air. Other volatile organic gases also are found in LFG in trace concentrations, usually at the part-per-million or part-per-billion level. The equipment that is used to monitor and sample the trace gases requires more sensitivity and more sophistication than that used to measure the four major gases. Table 1 summarizes the gas parameters discussed in this section and lists the field monitoring or sampling equipment associated with each gas parameter.

The remainder of this section is organized as follows: field monitoring procedures and equipment are discussed as they pertain to measurement of the principal and trace gas components of LFG. Additional information is provided for measurement of gas-related variables, such as gas pressure, gas flow, and water levels. Next, field sampling procedures are presented for the collection and transportation of representative gas samples for subsequent instrument quantification at a laboratory. General procedures and techniques for LFG sample analysis are described last in this section, with an emphasis on the measurement of trace gases (VOCs). References for this section are presented at the end.

How an investigation is planned and implemented can affect the type of monitoring and sampling instruments used, the sampling collection equipment, and the approach for laboratory analysis. Careful planning should be accomplished prior to conducting field work.

LFG investigations may be designed according to the geology of the site, the type and age of the waste, any existing gas control measures, the potential for off-site gas excursions (both for explosion and odor concerns), and data from past monitoring rounds.

- To evaluate the potential for LFG migration, either in buildings or confined spaces, on- or off-site.
- To protect workers in areas where LFG may collect by determining whether breathable and non-explosive atmospheres are present.
- To test the effectiveness of LFG protection or recovery systems.
- To identify the quality and/or quantity of LFG component gases, particularly methane, for potential use as an energy source.
- To identify the trace volatile component present in LFG that can be associated with corrosion or odors (e.g., hydrogen sulfide), human health effects (e.g., vinyl chloride, benzene, etc.), or other problematic conditions.
- To determine success in meeting state or federal air quality standards associated with air (or LFG) emissions from MSW landfills.
- To record and evaluate parameters related to LFG collection or migration, such as: water table depth, condensate formation, gas velocity or flow, and gas pressure in a controlled system or within a landfill.

TABLE 1
LANDFILL GAS
FIELD INVESTIGATION EQUIPMENT

	PARAMETER	DEVICE
GAS SAMPLING	Methane (CH_4)	Infrared Detector Catalytic Oxidation Detector Thermal Conductivity Meter Flame Ionization Detector
	Carbon Dioxide (CO_2)	Infrared Detector Fyrite Indicator Chemical Tube Detector
	Oxygen (O_2)	Electrochemical Cell Fyrite Indicator
	Hydrogen Sulfide (H_2S)	Electrochemical Cell Chemical Tube Indicator
	Volatile Organic Compounds (VOCs)	Sampling Bags (pump/aspirator) Evacuated Canisters (pump) Adsorbent Traps (pump/aspirator)
FORCE	Gas Pressure	Magnehelic Gauge Digital Manometer U Tube Manometer
	Gas Flow	Pitot Tube (with chart) Hot-wire Anemometer (calculation)
WATER	Water (H_2O)	Water Level Indicator Chalk and Line
	Condensate	VOA Vials Bottles (plastic or glass)

B. FIELD MONITORING

1. General

LFG investigations generally include monitoring for methane, carbon dioxide, and oxygen. With the use of portable field instruments, field monitoring can establish concentrations of these gases quickly and accurately. Similarly, field instruments can be used to determine values for other gas-related parameters.

Field monitoring instruments generally require the gas sample to be drawn into a detector chamber under a steady flow condition, either by hand aspiration or by an electric pump. Care should be taken when using such instruments for sampling from small void spaces. If a sample is drawn too rapidly, the concentration detected on the instrument may appear lower than the value actual through dilution. A steady and accurate reading will be obtained when the aspiration rate is less than or equal to the rate of replenishment. Portable instruments that are used in the detection of flammable or other gases operate using various thermal chemical principles; each principle of measurement and associated instrument has related advantages and disadvantages, as discussed below.

2. Water Levels

Liquid levels (e.g., water, leachate, LFG condensate) can be determined within wells or holding tanks with a water level measuring device available from several suppliers. These devices have short probes attached to 100 to 300 feet of insulated wire, usually marked at 1-ft. or metric intervals. Upon contact with water, a light or an alarm (or both) is activated, and the depth reading can be made and recorded. Typically, these water level indicators are battery-powered, light-weight, and easy to use.

3. Gas Pressure

Gas pressure (and vacuum) measurements can be taken at points along the gas collection system piping, and at other monitoring points such as off-site wells and probes. For gas probes, pressure readings are obtained to determine whether subsurface soils (or waste materials) are under pressure or vacuum conditions relative to atmospheric conditions. If subsurface pressures are positive, then methane readings can be obtained readily with an aspirator. If pressure is negative, then readings should be taken with an electric pump capable of pulling a vacuum greater than that found within the probe or well.

Gas pressures associated with landfill gas systems can be measured readily with a water-filled U-tube manometer. Alternatively, readings generally can be taken with a Magnahelic pressure gauge, or an electronic pressure gauge.

Magnahelic --

A Magnahelic (trade name) pressure guage is a small, hand-held device which senses changes in gas pressure through the use of an internal diaphragm. When connected to a port of a monitoring well, subsurface gas pressures are indicated in inches of water with a pointer on the face of the Magnahelic gauge. This gauge is capable of reading both positive and negative pressure conditions in LFG collection system piping, gas monitoring wells, or probes. Separate Magnahelic gauges are available to accommodate varying ranges of gas pressure (e.g., zero to 0.5 inches of water, zero to 5 inches, and zero to 80 inches).

<u>Advantages</u>

- Highly responsive (accuracy within 2 percent of full scale).
- Resistant to shock and vibration.
- No liquids involved.
- Small and portable.

<u>Disadvantages</u>

- Separate gauges needed to accommodate a wide range of pressures.
- Each port measures only positive or negative.
- Gauges must be held vertical for accurate measurement.

U-Tube Manometers --

A U-tube manometer is used to measure positive, negative, or differential pressures in a monitoring well or LFG collection system piping in inches of water or mercury (as the displaced fluid). A U-shaped tube is filled about half-way with fluid (to the zero point) with both ends open to the atmosphere, and the fluid at the same height in both tubes. Application of a positive or negative pressure (when connected to a monitoring well or probe) at one end of the tube will result in a change in the fluid level; the total difference in fluid level represents the pressure. Manometers can be made of glass, of rigid, shatterproof tubing mounted on durable backings, or of flexible plastic tubing which can be rolled for transport.

Advantages

- High accuracy.
- No batteries or power source needed.
- One port measures both positive and negative pressures.
- Provides direct measurement of pressure.
- Device is capable of measurements over the full range of pressures expected.

Disadvantages

- Potential to lose fluid (e.g., water or mercury) during transport.
- Must be held vertical and secured when in use.
- Must have a scale that covers needed range.

Digital Manometer/Pressure Indicator --

A battery-powered, hand-held digital pressure indicator is available for measurement of positive, negative, or differential pressure. The instrument uses a pressure transducer to measure the pressure at the inlet port, and uses a digital readout that displays the measurement up to two decimal places. This type of device is accurate to within 2 percent of the full scale. Available in ranges up from zero to 1,000 inches of water.

Advantages

- No leveling of the instrument is required.
- High accuracy.
- Small, hand-held instrument.
- No potential of toxic fluid loss.
- One unit is appropriate for all pressure ranges encountered.

Disadvantages

- Requires power source (battery).
- LCD readout can be problematic in extreme cold.

4. <u>Gas Flow</u>

Gas flow measurements are required for operation of LFG collection systems and for gas sampling. There are several techniques for measuring flow; accordingly, the equipment can be stationary (as with installed orifice plates, venturi meters, mass flow samplers, turbine-type air velocity meters, etc.) or portable, as in case of pitot tubes or hot-wire anemometers. A few common devices are discussed below:

Pitot Tube --

Total pressure (P+) minus static pressure (Ps) in a header line equals the velocity pressure. The pitot tube is a stainless steel, L-shaped probe attached by tubing to a meter which measures the differential of P+ and Ps.

Essentially, a pitot tube consists of an impact tube (which receives total pressure input) fastened concentrically inside a second tube of slightly larger diameter which receives static pressure input from radial sensing holes around the tip. The air space between inner and outer tubes permits transfer of pressure from the sensing holes to the static pressure connection at the opposite end of the pitot and then, through connecting tubing, to the low or negative pressure side of a manometer. When the total pressure tube is connected to the high pressure side of the manometer, the velocity pressure is indicated directly.

Gas flow is determined from the velocity present reading and associated charts related to gas velocities within pipes of known diameters. To use the pitot tube, a sampling port hole of appropriate diameter must be drilled into the gas collection system piping.

<u>Advantages</u>

- Portable, few parts.
- Sturdy, not easily damaged or corroded.
- With correct operation, accuracy is within 2 percent.
- Inexpensive.

<u>Disadvantages</u>

- Dirtied easily by condensate and particulates. Cleaning required after each use.
- Accurate in straight ducts only. Elbows or other obstructions in the line will cause turbulence; should have at least four pipe diameters on either side of measuring port.

- Need to take traverse readings (sectional and cross-sectional) and average these results.

Orifice plates are widely used in fluid and gas-flow systems for flow measurement and as flow limiters. As defined, they are relatively small, thin, metal plates inserted cross-sectionally into the gas header line between two bolted flanges. The plate has a reduced diameter (in relation to the header pipe) which relates by formula to the diameter of the pipe and the differential pressures taken at the adjacent measuring points across the orifice. The two ports may be located within the flange bodies or may be built into the header. To calculate gas flow at the orifice, a pressure measurement is taken at each port to determine the pressure differential; other variables in the gas equation are either known or estimated.

Advantages

- Relatively inexpensive, readily available.
- Provides accurate readings.
- Readily installed.
- Permanent fixture, repetitive readings can be taken.

Disadvantages

- Orifice plates can block gas condensate drainage.
- In-line installation creates greater system head loss.

Hot-Wire Anemometers --

As with the pitot tube, a port hole must be made in the gas collection system piping for insertion of the hot-wire anemometer. These devices have a temperature probe heated to a standard temperature which responds to the cooling effect of the gas as it passes over the probe.

The temperature differential is translated into air velocity units (feet per minute) on an LED screen or to a deflecting vane meter, depending on the model. While accurate for the purpose of some investigations, hot-wire anemometers, like pitot tubes, need to be used in a program where traverse readings are taken and averaged to obtain readings of greater accuracy.

Advantages

- Quick to set up.
- Portable and lightweight.
- New models measure other temperature directly.

- Easy to read.

Disadvantages

- Traverse readings should be taken.
- Turbulence may affect readings.
- Not particularly sturdy.
- Expensive to repair.

5. Methane

Methane content is the most significant parameter for LFG investigations. Oxygen and gas pressure readings are parameters that are recorded primarily as supportive information for the methane content readings. The measurement of methane content can be accomplished either by using a portable meter in the field or by collecting samples in the field and analyzing them for methane concentrations in the laboratory. Field sample collection and laboratory analysis are discussed later in this section.

Methane content measured in the field is generally expressed as percent methane by volume in air. Alternatively, methane concentration may be expressed as a percent of the lower explosive limit (LEL) of methane in air. Methane is combustible and ignitable in concentrations ranging between 5 and 15 percent in air; thus, 100 percent of the LEL equals 5 percent methane in air. For lower concentrations of methane, often the percent LEL is reported, since monitoring often is mandated based on concentrations at or below the LEL.

Catalytic oxidation detectors are commonly used to measure the percent LEL of methane or other flammable gases. These types of detectors are useful in measuring relatively low concentrations of flammable gas in air. However, they will respond to any flammable gas, and therefore must be calibrated for the specific gas under investigation. For example, a detector calibrated for methane in air will indicate a positive reading for combustible gas if hydrogen gas (in air) is passed through the detector (when no other flammable gas is present).

The accuracy of readings also may be affected within oxygen-deficient atmospheres. Readings are suspect unless sufficient oxygen is available to assure complete oxidation of the gas. Some LEL-scale only instruments may not respond at all to flammable gas at such low oxygen levels. Thus, a "zero" reading could be misinterpreted as meaning that methane is not present. To overcome this problem, field meters are usually equipped with a second detector that measures the methane gas concentration in a different manner.

The thermal conductivity detector measures the total concentration of all flammable gases in the sample by comparing its thermal conductivity against an internal electronic standard representing normal air. These detectors can measure the full zero to 100 percent range of gas concentrations. Thermal conductivity detectors measure a physical property, and therefore are not affected by variations in oxygen levels. They can be affected, however, by mixtures of methane and carbon dioxide. Such mixtures can cause inaccuracies in the instruments because each gas affects the thermal conductivity of the cell in a different manner. Manufacturers have recognized this problem, and will calibrate their instruments using mixtures of the two gases in air. Therefore, it is essential that this type of instrument be properly calibrated in relation to the appropriate gas mixture.

A third type of detector is the flame ionization detector. This instrument can detect the majority of organic materials drawn through a hydrogen flame. The portable versions of this detector are sensitive, and operate typically in the 1 to 10,000 parts per million (ppm) by volume range. Generally, these instruments are used for detecting low concentrations of flammable gas present at soil surfaces and in soil gas, and in buildings/structures and confined spaces.

Combustible Gas Indicators --

Commonly used for methane detection in the field, combustible gas indicators are battery-powered, hand-held meters which have both catalytic oxidation and thermal conductivity devices (for LEL and volume gas measurements, respectively) that share a common display. Operators should avoid assuming that one display is simply a more sensitive scale than the other. In some models, however, the two detectors are linked in such a way that if the gas concentration is above the LEL value, the LEL reading goes off the scale when the instrument is switched to the LEL gauge. This feature averts ambiguous readings caused by low oxygen levels.

These combustible gas indicators can be "poisoned" by various gases, such as hydrogen sulfide and organic lead compounds. Because the detector can fail, recalibration and detection replacement should be performed regularly. In addition, some manufacturers supply "poison resistant" detectors that require less frequent replacement.

<u>Advantages</u>

- Small, portable, and self-contained for field use.
- Internal battery.
- Simple to operate.

Disadvantages

- Thermal conductivity instruments can be damaged by other gases, requiring calibration or parts replacement.
- Low oxygen content can give inaccurate zero percent LEL readings.
- Non-selective; limited to combustible fraction of gas.
- Chlorinated vapors may cause a catalytic reaction, indicating a flammable condition which does not actually exist, thereby requiring frequent calibration of the instrument.

Infrared Gas Analyzer --

Infrared equipment can be used to measure specific gases and gas mixtures. Typically, this equipment consists of an infrared source and an infrared detector. As an infrared beam is projected through a gas sample, the amount of light absorbed at various wave lengths correlates to the concentration of methane and carbon dioxide present. Such meters are capable of measuring methane and carbon dioxide over a range of 0.5 ppm to 100 ppm. Percent methane and LEL readings are shown on a digital readout; readings can be stored, and some optional equipment is available to take readings at multiple locations over time, unattended. The wavelength of the analyzer must be selected to reduce interference or false positive readings.

Most models on the market are stationary versions, but portable meters are being developed. Infrared analyzers are also available for detection of gases in large void spaces, such as buildings, under floors, manholes and other confined spaces. Such a device can be used to detect the presence of gas along paths of up to 700 yards, so as to provide an average concentration over an area (also known as the flux rate). However, use of this equipment is limited currently.

Advantages

- Infrared sensor will not be poisoned by typical LFG.
- High accuracy.
- Low oxygen levels will not affect LEL readings.
- Self-calibrating.
- Can store field data for subsequent dowloading.
- Can be set to select the most appropriate range to measure gas levels (zero to 10 percent and zero to 100 percent).

Disadvantages

- Greater power requirements (reduced battery life) when compared to combustible gas indicators.
- Interference can result in fault positive detections.
- Few portable models available; mostly stationary models.
- Expensive.

6. Carbon Dioxide

Carbon dioxide, a major component of LFG, can be detected using chemical detector tubes (as in the Draeger-type tube), fyrite indicators, or portable electronic meters with built-in pumps. In the case of chemical detector tubes, a sample is drawn over a specially-formulated chemical and produces a color change. Detector tubes can be used only once and are subject to interference by other gases and chemical vapors. Using this colorimetric method, the range of detection with these tubes is commonly between 0.15 to 7 percent by volume.

Fyrite indicators use a liquid absorbed that changes the volume of liquid with respect to the concentration of carbon dioxide present in the gas sample. These indicators are discussed below for oxygen measurements.

Portable meters are also available for measuring carbon dioxide concentrations using infrared technology; the operative ranges are zero to 5 percent and zero to 100 percent. These instruments may be coupled with an oxygen and combustible gas meter to give an analysis of the three major component gases.

7. Oxygen

Oxygen content often is measured in conjunction with LFG investigations, either in the raw gas, in monitoring wells, or in confined spaces. Oxygen meters are available in various forms, and are sometimes built into the housing of combustible gas indicators. Generally, oxygen meters employ an electrochemical cell as the sensor. Oxygen meters may incorporate either an alarm, an LED indicator, or a combination of the two. Alarm levels are adjustable over a limited range.

Electrochemical Cell Detectors --

Oxygen from a sample is drawn into the instrument by an internal pump and is passed over the electrochemical cell where an electrochemical reaction occurs. The rate of the reaction is proportional to the concentration of oxygen in the sample. The percent of oxygen by volume in air is displayed on the face of the meter. Various models measure ranges from zero to 25 percent and zero to 100 percent oxygen in air.

Advantages

- Typically included as part of another meter.
- Easy to use.
- Portable, operates on batteries.
- Accurate readings.

Disadvantages

- Loss of sensitivity due to moisture.
- Corrosion and chemical poisoning are problems.
- Electrochemical cell has limited shelf life.
- Instrument requires frequent calibration.

Fyrite Indicator --

This method uses a liquid absorbent that changes the volume of liquid with respect to the concentration of oxygen in the gas sample. The gas sample is obtained with an aspirator. Fyrite indicators can also be used for measurement of carbon dioxide.

Advantages

- Easy to use; requires no power source.
- Provides fast analysis.
- Portable, few parts.
- Low cost.
- No significant interference from background gases.

Disadvantages

- Limited accuracy.
- Each instrument is limited to one gas.
- Fyrite solutions degrade over time and with repeated use.

8. Hydrogen Sulfide

The measurement of hydrogen sulfide in landfill gas can be accomplished either directly with a portable gas meter in the field or through sampling and subsequent laboratory analysis. Hydrogen sulfide may be present at low levels in landfill gas, usually less than 1 percent by volume in air.

Electrochemical Cell Indicators --

Portable hydrogen sulfide meters are available which use an electrochemical cell consisting of two precious-metal electrodes with an acid electrolyte. A current is generated by the electrochemical reaction of hydrogen sulfide gas which diffuses into the reaction chamber. The current produced is directly proportional to the hydrogen sulfide concentration, and the reading is displayed on the screen. Various hydrogen sulfide meters are available, with operating ranges commonly from 1 to 2000 ppm. Some meters are available with a lower detection limit (0.003 ppm) and an operation range of 0.001 ppm to 50 ppm. Some meters are available equipped with oxygen and combustible gas sensors and alarms.

<u>Advantages</u>

- Easy to use.
- Portable.
- Often exists as part of combustible gas meter.

<u>Disadvantages</u>

- Most hydrogen sulfide gas meters do not have operational ranges less than 1 ppm.
- Other gases may interfere with accurate hydrogen sulfide readings (i.e., produce positive concentrations). Frequent calibration checks are required.

Chemical Tube Detectors --

As in the detection of carbon dioxide, chemical detection tubes are made for the detection of hydrogen sulfide gas. These chemical detection tubes contain a specific chemical that reacts with hydrogen sulfide to produce a color change. The aspirator hand pump is used to obtain a constant sample volume of gas.

<u>Advantages</u>

- Portable
- Easy to use.
- Relatively inexpensive.

<u>Disadvantages</u>

- Limited accuracy.
- Interference from other gases may occur.

- Single use only.
- Highly susceptible to operator error.

9. Other Trace Gases

Identification and monitoring of trace gases, commonly termed volatile organic compounds (VOCs), generally require collection of a gas sample and subsequent analysis in a laboratory. Several methods are available for both sampling and analyzing the organic compounds.

C. FIELD SAMPLING

1. General

This section discusses various means of performing field sampling of landfill gas. The general purpose of field sampling is to collect and transport a representative gas sample for subsequent laboratory analysis and quantification of results. While specific techniques for field sampling may differ, the general techniques involve delivery devices (such as vacuum pumps) and sample containers (such as bags).

2. Sample Delivery Devices

Three basic delivery systems are available for use in transporting LFG from its source (landfill probe, well, or extraction system header) to a sample container: hand aspirator, electric hand-held personal pump, and portable vacuum pumps.

Hand Aspirator --

This device is inexpensive and practical for obtaining small gas volumes. Typically, hand aspirators are used with portable combustible gas indicators or for delivery of a small gas volume to a colorimetric detector tube or a sample bag. Drawbacks of aspirators include lack of flow control, contamination from outside air sources, and small sample volumes.

Personal Pumps --

Several manufacturers supply portable, hand-held pumps for gas sample collection. These personal pumps can be clipped to the operator's belt, and have optional flow regulators and timers which allow the operator to perform other tasks while the pump is sampling. Typically, these pumps are sturdy and can operate for several hours on rechargeable batteries. These pumps are suitable for bag sampling, as well as for combustible gas meters and colorimetric detector tubes.

Vacuum Pumps --

Other vacuum pumps are available for field sampling with a greater vacuum is required to obtain a sample. Typically, electric vacuum pumps can be employed to operate either from a permanent power source or from a 12-volt DC battery.

The advantages of vacuum pumps include large sample flow rates, sturdy construction, and a low potential for air contamination. These pumps can be used to deliver LFG to canister-type samplers so as to provide a pressurized sample for subsequent laboratory analysis.

3. Sample Containers

Adsorbent Traps --

These devices are generally glass or stainless steel tubes filled with a collection medium (such as Tenax, activated charcoal, or silica gel), which serves as an adsorbent for constituents found in LFG. The gas stream to be sampled is passed through the tube and the adsorbents at a recorded flow rate and volume. The purpose of this sampling technique is to selectively adsorb and concentrate specific classes of trace compounds onto the media for later desorption and analysis in the laboratory. Generally, each tube is equipped with pressure/vacuum type seals at each end. The inlet end of the tube is connected directly to the gas stream, while the outlet is connected to either a vacuum pump or pressure regulator for sampling from sources under either a negative or positive pressure. Desorption at the laboratory is by use of liquid, solvents, or through applying a heat source to the tube.

Advantages

- Easy to transport compared to whole air samples on sampling bags.
- Adsorbents can be selected based on the specific VOCs to be sampled.
- Most trace LFG components can be quantitatively adsorbed.
- Concentration of the target analyses in the field with proper sampling train.

Disadvantages

- Adsorbents have limited adsorbative capacity and may become saturated.
- Sample delivery system capable of providing precise flows is required.
- Adsorbent capacity may be affected by the temperature and pressure of the system.
- Proper laboratory handling is required to desorb gases, introducing additional sources of potential error.

- Compounds with a low molecular weight may not be trapped effectively.
- Multiple analyses cannot be performed on a single tube.
- Sampler should be present during sample collection.

Canisters --

These sample containers can be made of stainless steel, glass, or aluminum and can be used for both quantitative and qualitative analysis of gas samples. Due to their sturdy construction and ability to hold a large volume of gas in a compressed state, repeated gas analyses can be performed. Sizes for canisters range from small "bombs" (250, 500, and 1,000 cc) to 6-liter canisters. Aluminum bombs may be adequate for principal LFG components (methane, carbon dioxide, oxygen, nitrogen, hydrogen, and carbon monoxide). However, canisters constructed of stainless steel are preferable due to their relatively inert nature. The inside of these canisters usually is treated with the patented SUMMA polishing process. This treatment coats the inside of the canister with a chrome-nickel oxide.

The size of the canister used is dependent on whether pre-concentration of the sample is needed (in a case of low concentrations, as in ambient air samples), the length of sample time (grab versus integrated over time) and the actual sample volume desired. Samples are obtained generally by utilizing a pump and flow regulator or rotameter. Gas samples can be pressurized within the canister to obtain actual sample volumes that are greater than the size of the canister. Alternatively, a vacuum may be applied to the canister prior to sample collection, so that samples may be obtained directly without the use of a pump.

<u>Advantages</u>

- Pressurized canisters can be leak tested to check integrity of sample train.
- Multiple analyses can be performed from a canister.
- Operator need not be present during the sampling run.
- Sample volumes do not need to be measured and recorded.
- When sampling using the canister vacuum, no power source is required.
- Durable and easy to transport.
- Canisters can be reused with proper cleaning.

<u>Disadvantages</u>

- Large canisters may be inconvenient to transport if large numbers of samples can only be reached by foot.
- Each component of the sample train must be cleaned prior to additional sampling.

- Air leaks in system elements upstream of the canister are a potential source of error.
- Power source is needed for positive pressure sampling.

Sampling Bags --

Sampling bags generally are manufactured from one of several layered synthetic materials such as teflon, rubber, tedlar, or mylar, or a combination of layered materials such as polyester, vinyl, and aluminum. Bag sizes generally vary from less than 1 liter up to 180 liters. Bags are equipped with one or two sample inlet/outlet valves, for connection to the sampling train or for extraction of the sample for laboratory analysis.

Samples can be collected by one of two methods. In one method, a pump is placed between the bag and the sample source to obtain a grab or time integrated sample. Otherwise, the bag is attached to the inlet inside of a tightly sealed container or drum and the vacuum pump is connected to the outlet port. The vacuum formed inside the drum allows the bag to fill to obtain a grab sample.

Advantages

- Capable of obtaining large sample volumes.
- Purging of container is not required.
- When a sample is collected in a vacuum container, decontamination of the pump and components is not necessary.
- Multiple analyses may be performed from a single sample.

Disadvantages

- Sample storage within bags is a limitation; some compounds may pass through bag sidewalls. Analysis should be conducted within 24 hours.
- Bags have potential to leak or puncture.
- They are bulky when filled and awkward for transport.
- Translucent bags may allow photo-degredation of certain LFG components prior to analysis.
- Water vapor and LFG may condense inside the bag.
- Polyester, vinyl, aluminum, and rubber bags are reactive to certain LFG components.

D. SAMPLE ANALYSIS

1. General

Analysis for the major and trace components in landfill gas can be conducted either in the field or in the laboratory, depending on the accuracy and time frame desired for analysis. Several manufacturers now supply portable gas chromatographs (GC) which can be used readily in the field for "real time" analysis. Alternatiively, GC and GC/MS (mass spectrometer) systems can be mounted on a more permanent basis in trailers or vans where continued field analysis is desired. The advantages of GC and GC/MS instruments for analysis of LFG samples include reliability, accuracy, repeatability, quality assurance documentation, quality control, deffendability, low detection limit, and automation of analysis and data storage. A brief discussion of GC and GC/MS detection systems is given below.

2. GC Multi-Detector Systems

The gas chromatograph utilizes a separation technology to identify and quantify specific gases present in the sample when compared to known standards. A GC equipped with a fused silica capillary column is frequently used for the separation of LFG trace compounds.

GC technology greatly includes the introduction or insectiion of a gas sample into the instrument port via a valve. The sample is transported by a carrier gas (e.g., helium) through a column specific to the separation required for identification/quantification of the target analyte(s). Separation of the analytes is achieved by repeated sorption and desorption as the sample progresses through the column. Effectiveness of the separation depends on the temperature of the column, the flow rate of the carrier gas and the physical or chemical interaction between the sample mixture and the column. On leaving the column, the gas is passed through a detector, and the response is recorded electronically or on a chart recorder.

The GC is used in conjunction with the detector appropriate for the specificity and sensitivity of the analysis performed. The following is a summary of the detectors frequently used with the GC for LFG analyses.

Non-Specific Detectors --

a. Electron capture detector (ECD) - A highly sensitive and selective detector. This method is capable of determining subpicogram quantities of halogenated compounds. This system is able to capture electronegative atoms from the chromatographic column and record their peaks at a linear response up to 4 orders of magnitude above baseline.

b. Electrolytic conductivity detector (EICD) - This system has been found useful in assessing the quality of LFG allowing detection of halogenated, sulfonated, and nitrogen-containing compounds. Without a GC separation, this system can be used to determine the total levels of the three above-mentioned families.

c. Photoionization detector (PID) - The PID is most utilized for analyzing aromatic species of organic and some inorganic gases in the picogram to microgram range. This system utilizes an ionization process which occurs as a result of adsorption of a photon by a molecule. The PID is a non-destructive method, so it may be used in series with other detectors so that simultaneous and selective analyses of two separate analyte groups may be tested.

d. Lead acetate detectors - This method can be used either with a GC, or the gas sample can be directly injected into the detector. This system is used for determining the presence of sulfur-containing compounds through pyrolizing the sample, which results in the conversion of sulfur-containing compounds to hydrogen sulfide. This system can be used for continuous monitoring in the field.

e. Flame photometric detector (GC/FPD) - This system is used for the detection of sulfur compounds in LFG in the ppm and ppb range, and does not require preconcentration. This method may be used to determine individually specified sulfur components or total sulfur concentration.

Advantages

- Less expensive than GC/MS.
- Less sample volume is required for analysis.
- Is more sensitive than GC/MS (ECD may be 1,000 times more sensitive).

Disadvantages

- Multiple detectors must be calibrated.
- Compound identification may not be definite.
- Data interpretation similar to GC/MS.
- Potential interference from co-eluting compound(s).
- Cannot identify unknown compound outside range of calibration or without standards.
- Does not differentiate targeted compounds from interfering compounds.

The type of standard (i.e., standard gas mixture) with which sample gases are compared during chromatography is important for determining the accuracy of results. Standards are available from a number of commercial sources, either as single components or as a mixture within an inert gas. Standards that are suitable both in terms of component and concentration should be used. Calibration standards are injected both before and after sample analysis as a quality check of the accuracy and reproducibility of the resulting data.

3. GC/MS Systems

The detector systems are used with GC/MS instruments for identification and quantitation of trace compounds in LFG. Generally, GC/MS is listed for analysis of gas compounds present at ppm or ppb levels.

The MS/SCAN detector system is used to identify qualitatively all compounds present in a sample. This system provides positive identification (not quantitation) of compounds detected when compared against an initial compound library.

The MS/SIM (Select Ion Mode) detector system is used to identify and quantify a target list of compounds. Compound quantification is accurate and detection limits for trace compounds in LFG can approach 1 ppb.

Advantages

- Conclusive compound identification.
- Less operator interpretation is necessary than for multi-detector GC.
- Little interference from co-eluting peaks.

Disadvantages

- Greater cost than a multi-detector GC systems.
- Greater sample volume is required than for a multi-detector GC.

E. APPLICABLE REFERENCES AND ANALYTICAL METHODS

A listing of references and technical documents applicable to the sampling and analysis of landfill gas is given below. While this listing is not exhaustive, it provides guidance to the reader to plan and conduct sampling programs, to determine proper analytical methods.

1. Pollack, A.J.; Holdren, M.W., McClenny, W.A. "Multi-Absorbent Preconcentration and Gas Chromatographic Analysis of Air Toxics with an Automated Collection/Analytical System", JAWMA, 41:1217 (1991).

2. McClenny, W.A.; Pleil, J.D., Evans, G.F. "Canister-Based Method For Monitoring Toxic VOCs in Ambient Air", JAWMA, 41:1308 (1991).

3. Holdren, M.W.; Smith, D.L. "Stability of Volatile Organic Compounds While Stored In SUMMA - Polished Stainless Steel Canisters", Final Report, EPA Contract 68-02-4127, WA-13, 1987.

4. Hsu, J.P.; Miller, G; Moran, V. "Analytical Method For Determination of Trace Organics in Gas Samples Collected By Canister", J. Chrom. Sc. 29:83 (1991).

5. Winberry, W.T. Jr.; Murphy, N.T.; Riggan, R.M. "Method TO-14" in Compendium of Methods For The Determination of Toxic Organic Compounds In Ambient Air, EPA-600/ 4-89-017, June 1988.

6. Pau, J.C.; Knoll, J.E., Midgett, M.R. "A Tedlar Bag Sampling System For Toxic Organic Compounds in Source Emission Sampling and Analysis", JAWMA, 41:1095 (1991).

7. Kerfoot, H.B.; et al. "Analytical Performance of Four Portable Gas Chromatographs Under Field Conditions", JAWMA, 40:1106 (1990).

8. Barbola, M.J.; Shen, T.T. "Planning Air Monitoring for LDLs at Waste Sites", in Measurement of Toxic and Related Air Pollutants, Proceedings of 1988 EPA/APCA Symposium.

9. Test Methods for Evaluating Solid Waste, U.S. Environmental Protection Agency, SW-846, November 1986.

10. Test Methods for Evaluating Solid Waste, Physical/Chemical Methods: Update Package, U.S. Environmental Protection Agency, A389-148076, 1989.

A COMPILATION OF LANDFILL GAS

FIELD PRACTICES AND PROCEDURES

MATERIALS AND EQUIPMENT SECTION

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MATERIALS AND EQUIPMENT TASK FORCE

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MATERIALS AND EQUIPMENT

A. INTRODUCTION

This section will present an overview of the materials and equipment available and used to handle landfill gas (LFG). The handling of landfill gas comes about for two reasons: one is the control of the landfill gas at site where migrating gas creates a potentially hazardous environment (control); the second is where the gas is being recovered as an energy source (recovery).

All landfill gas control systems shall meet all existing and future regulating agency requirements. Systems must meet requirements of EPA, DNR, air emission standards, water quality standards, and any other state or federal regulating agency.

Materials and equipment used to handle landfill gas will be subjected to certain conditions that should be considered during system design. Materials that come in contact with the gas should be corrosion resistant due to the high moisture content of the gas and certain acids that may be present. Another consideration resulting from the moisture content of landfill gas is the need for removal of condensate that accumulates at various points in the system. There should also be special design features to minimize the chance of fire or explosion due to the flammability of some gas-air mixtures. While pressure differentials in landfill gas collection systems are relatively low (under 1 psi), certain types of processing require high pressures (up to 500 psig). Temperature of the gas varies greatly depending on the landfill and climate, but is usually well within the capabilities of commonly available materials (65°F to 120°F).

Additional design factors resulting from constructing a system in and on a landfill will also affect the materials and equipment selected. Among these are:

- exposure to waste or leachate
- differential settlement
- site maintenance and closure.
- proximity to heavy equipment work or travel areas

B. GAS CONTROL

Production of LFG creates a positive pressure within the landfill; this pressure acts as a driving force (convection), causing LFG migration into surrounding soils and through surface soils. In addition, a concentration gradient causes diffusive flow of LFG away from the landfill (i.e., LFG flows from areas of high concentration into areas of lower concentration). Most of the LFG will vent to the atmosphere through the surface of the fill; however, under certain soil conditions and landfill configurations, the driving forces described can result in off-site subsurface migration of LFG.

LFG migration can create a hazard, since the methane present in LFG is combustible. Methane is a colorless, odorless gas that is potentially explosive at concentrations between 5 and 15 percent by volume in air (the explosive limits for methane) and when in the presence of oxygen and a source of ignition. At higher concentrations, methane is flammable. Subsurface LFG migration is considered controlled when the concentration of methane at the landfill boundary is maintained below 5 percent and preferably at zero.

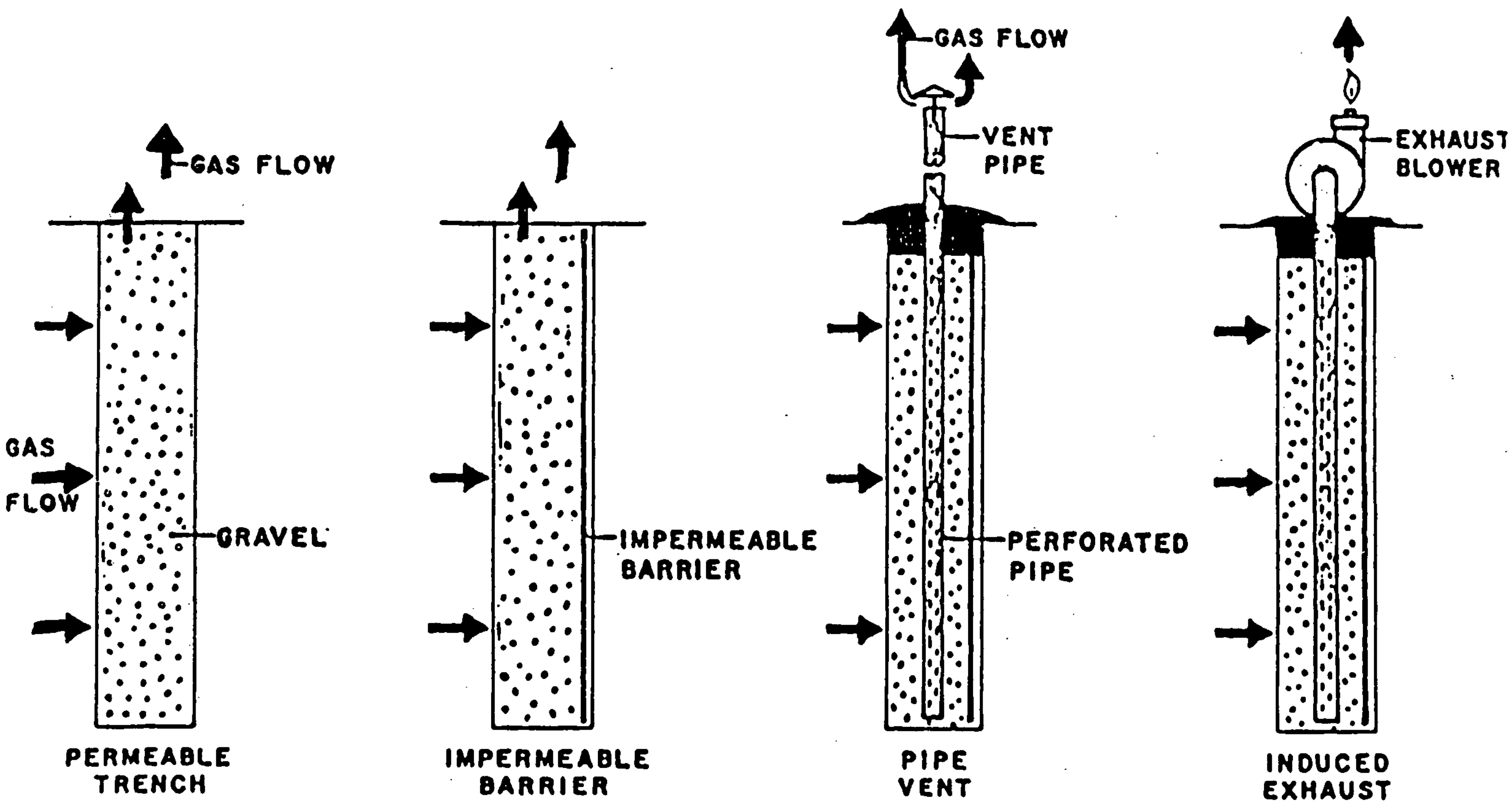
Alternative methods for controlling LFG migration are: (1) interceptor trenches; (2) barrier walls; (3) combination interceptor/barrier trenches; (4) vacuum extraction systems; and (5) pressure air injection systems. Variations of these can also be applied to building protection systems for buildings that are located on or near waste fill areas. Passive methods of building protection include: 1) sub-slab geomembranes; and 2) lateral vent systems. Active methods include: 1) sub-slab extraction or air injection systems; and 2) crawl space ventilation systems.

The first three alternatives for controlling off-site migration are passive control measures; accordingly, their operation and maintenance requirements are usually nominal. The extraction and air injection systems utilize wells, piping, and blowers, and therefore require routine operational care and maintenance. Normally, extraction systems require a flare or comparable device to burn the gases, whereas air injection systems require no flare. All types of systems require monitoring to verify their effectiveness.

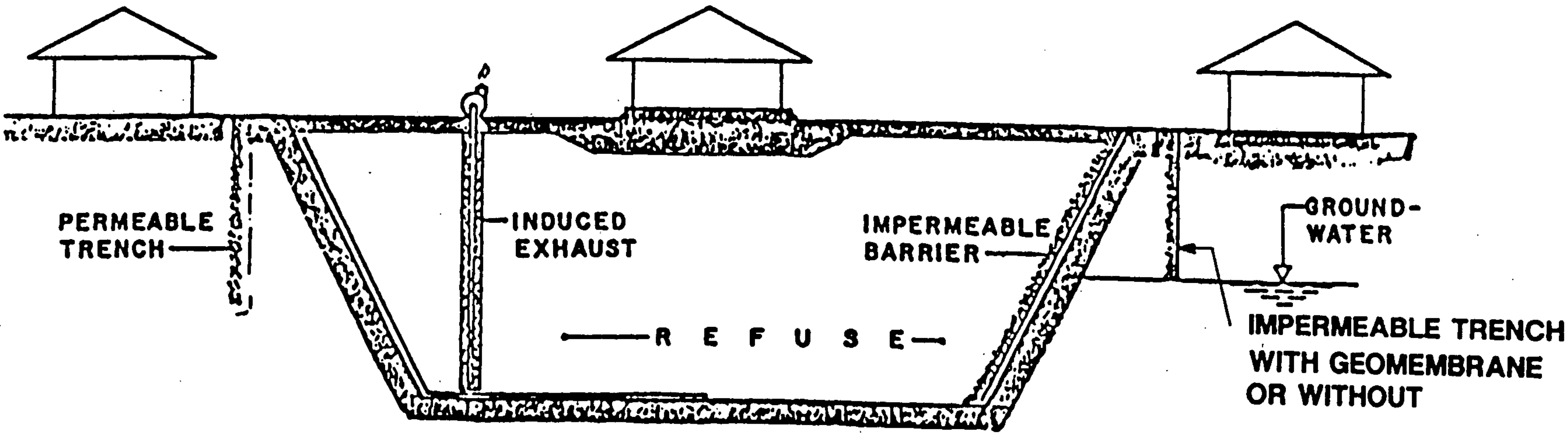
The lateral movement of landfill gas can be controlled by either barrier or ventilation systems (see Figure 1). Gas movement can be controlled by barriers constructed of relatively impermeable materials. Ventilation control systems intercept gas that is moving laterally and provide a low resistance path to the surface. Common locations for gas control systems are shown in Figure 2.

1. Barrier System.

   Barrier systems are constructed outside of the landfill area and extend to a low permeability bottom seal or natural barrier (e.g., bedrock or groundwater). Impervious liner materials used to control gas flow include geomembranes or to a lesser extent natural clays. Selection of geomembrane materials should be based on the performance required. Table 1 lists important properties that should be exhibited by the geomembrane. In the past, materials which have been used for control of landfill gas include polyvinyl chloride (PVC), chlorinated polyethylene (CPE), and Hypalon. More recently, high density polyethylene (HDPE) has been gaining use. Materials used are typically 20 to 60 mils thick.



SCHEMATIC OF
ALTERNATIVE GAS CONTROL SYSTEMS
FIGURE 1



COMMON LOCATIONS FOR
GAS CONTROL SYSTEMS
FIGURE 2

TABLE 1

DESIRABLE PROPERTIES OF MEMBRANE MATERIALS

PROPERTY	PURPOSE
o Relatively low permeability	To isolate the area to be protected from landfill gases
o High resistance to puncture and tearing	To ensure the integrity of the membrane in order to effectively isolate the area from gas flow
o Ease of seaming, patching	To ensure the continuity of the barrier
o Durability	To provide long-term protection from the continued generation of landfill gas
o Good elongation characteristics	To withstand, without rupturing, a significant elongation
o Flexibility	To preclude stiffening when ambient temperatures are relatively low
o Reasonable cost	To ensure cost-effective design
o Inert Nature	To resist chemical and microbiological attack

Natural soil barriers may serve as efficient barriers to gas migration, provided that the soil is properly graded and is maintained in a nearly saturated condition. The soil selected must have a high enough fines content to achieve the necessary level of low permeability. Generally, this will mean soils predominantly of a clayey nature, and may include soils classified as ML, CL, MN, or CH according to the Unified Soil Classification System (ASTM D-2487). Dry soils (even dry clays) are ineffective barriers, as they include voids through which gas can migrate.

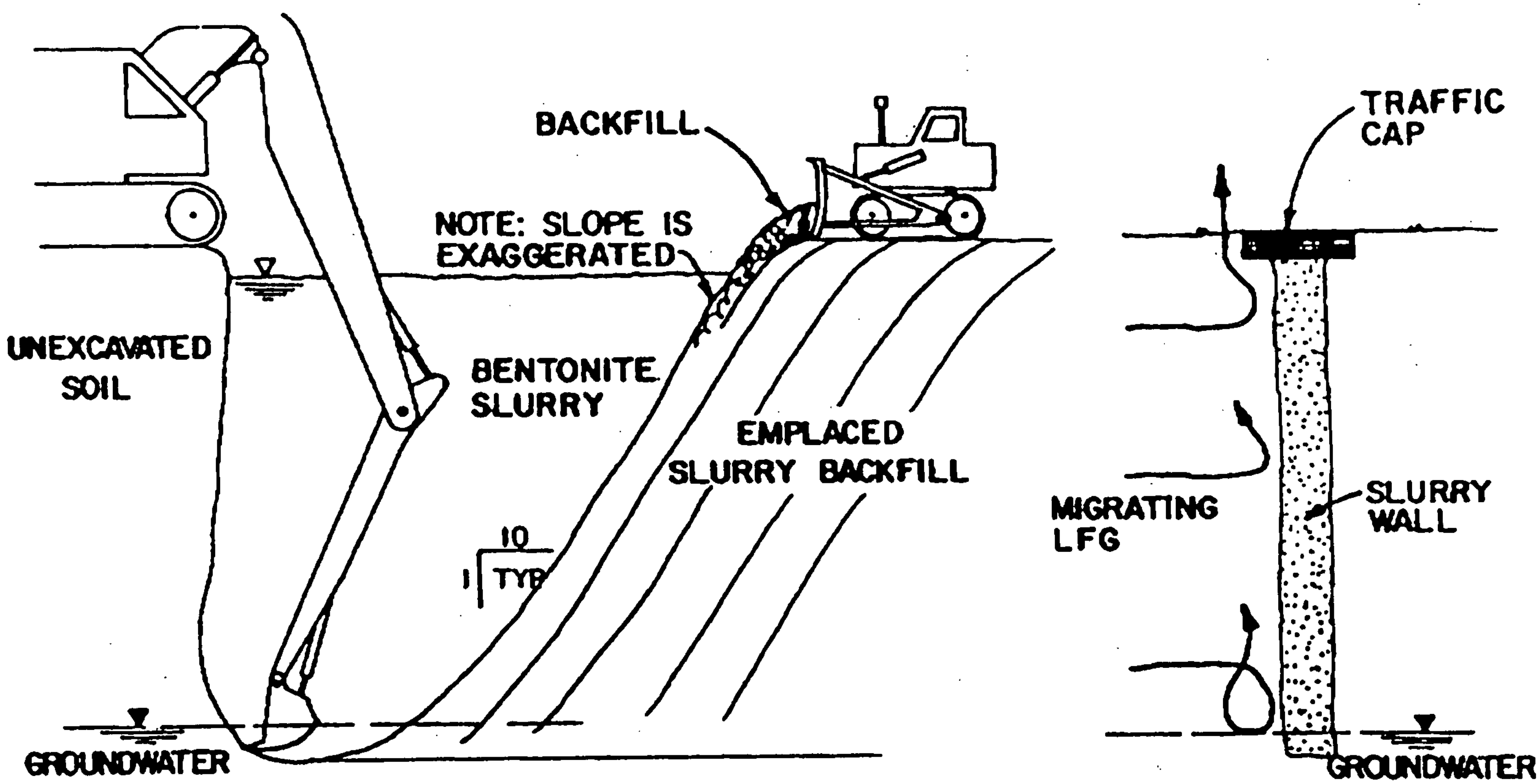
Slurry walls are non-structural barriers constructed primarily to intercept and impede the flow of fluids underground. The two basic types of slurry walls are soil bentonite (SB) and cement bentonite (CB). Depending on the nature of the project, either method may have technical or economic advantages over the other. Slurry walls have been installed at several landfills to control LFG migration.

In both SB and CB construction, a 2 to 4 ft wide trench is excavated using a backhoe or other specialized equipment. The trench is prevented from collapse by keeping it full of bentonite slurry during excavation. Bentonite is a type of commercially-available clay which swells to 10 to 13 times its dry volume upon complete hydration. In the case of SB walls, the trench is subsequently backfilled with a mixture of soil (normally spoils from the trench) and bentonite slurry (Figure 3). With the CB method, cement (or cement and additives) is added to the bentonite slurry and allowed to set and subsequently harden. Both methods produce a barrier with low permeability to gases or liquids.

Permeability values for liquids through slurry walls range from 1×10^{-5} to 1×10^{-8} cm/sec for SB and CB walls. For this reason, and because they are usually less costly, SB walls are more commonly used.

Generally, SB walls cost less than CB walls to construct, particularly if the material excavated from the trench is suitable for use as backfill. However, SB walls usually require a larger work area in order to store and mix excavated soils with bentonite slurry. In general, minimum work areas on the order of 50 ft wide are required for SB wall construction.

The use of CB walls may be advantageous at sites where work space is limited and the excavated materials are unsuitable as backfill material (e.g., building rubble or trash). However, they are more costly to construct because the materials used (cement and cement set-up retarders) have to be imported to the site. The disposal of excavated soils is an added cost. However, no backfill mixing operation is required with CB walls as with SB walls.



PROFILE
(UNDER CONSTRUCTION)

CROSS SECTION
(FINISHED)

CONSTRUCTION OF A SOIL BENTONITE SLURRY WALL FOR LANDFILL GAS CONTROL
FIGURE 3

Grouting techniques have been used in the engineering field primarily to increase the stability of coarse-grained soils by filling in the pore spaces; to provide underpinning or increased bearing capacity to foundations; and to seal cracks and joints in concrete materials and underground structures. When applied, grouts set as rigid materials with relatively low porosities. Grout curtains also have been used to control the outflow of liquid pollutants at disposal sites.

2. Vent Systems.

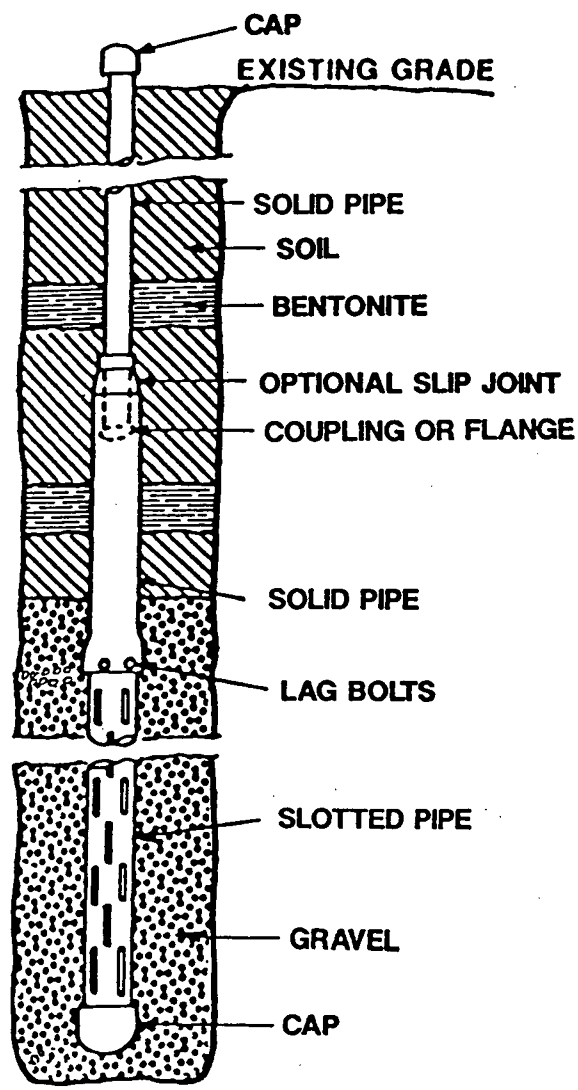
Vent systems to control landfill gas migration include trenches, gravel filled vent wells, and combinations thereof. Venting may be accomplished through either passive or induced exhaust systems. Regulatory agencies are moving away from passive systems and requiring active systems to deal with controlling the landfill gas.

Passive vent systems rely on highly permeable material placed in the path of gas flow. Porous material can be placed in a trench between the landfill and the area to be protected. Perforated pipe can be laid within the porous material to function as a collector manifold, directing the gas to a point of controlled release through frequent vertical riser pipes. The primary requirement of the porous material is that it be highly permeable to gas flow. Gravel is a relatively low cost material that can be effective provided that it does not contain a large percentage of fine materials, and is not subject to breakdown due to the acidic nature of condensate.

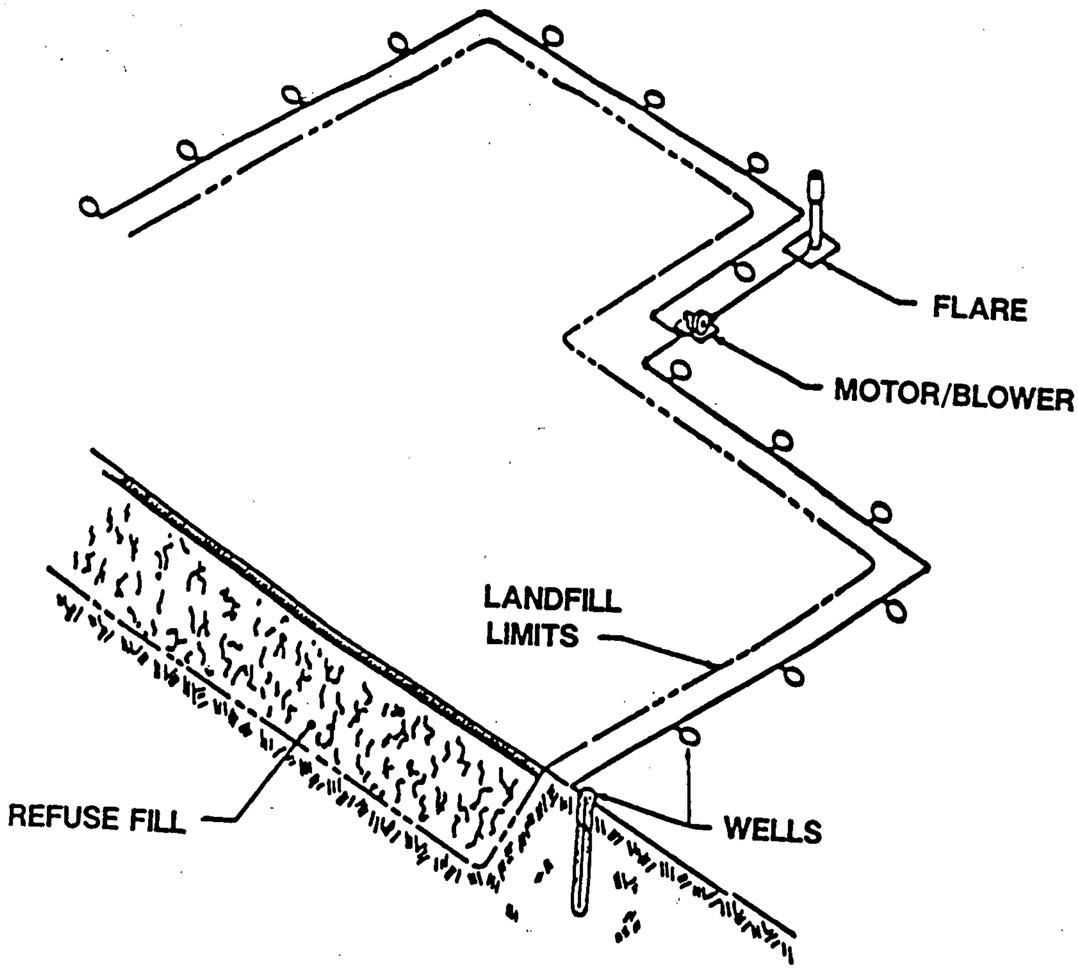
An induced exhaust (active or extraction) system consists of a series of gravel filled wells and/or trenches. Both wells and trenches utilize pipe (slotted or overlapping with annular spacings through which LFG is collected. A typical well is shown in Figure 4. These wells can be located outside of the actual landfill limits (see Figure 5) or can be installed within the landfill (see Figure 6). A typical trench and internal trench layout is included in Figure 7.

The location of the system, whether in or out of the landfill, is a key design decision and is dependent on a variety of factors including:

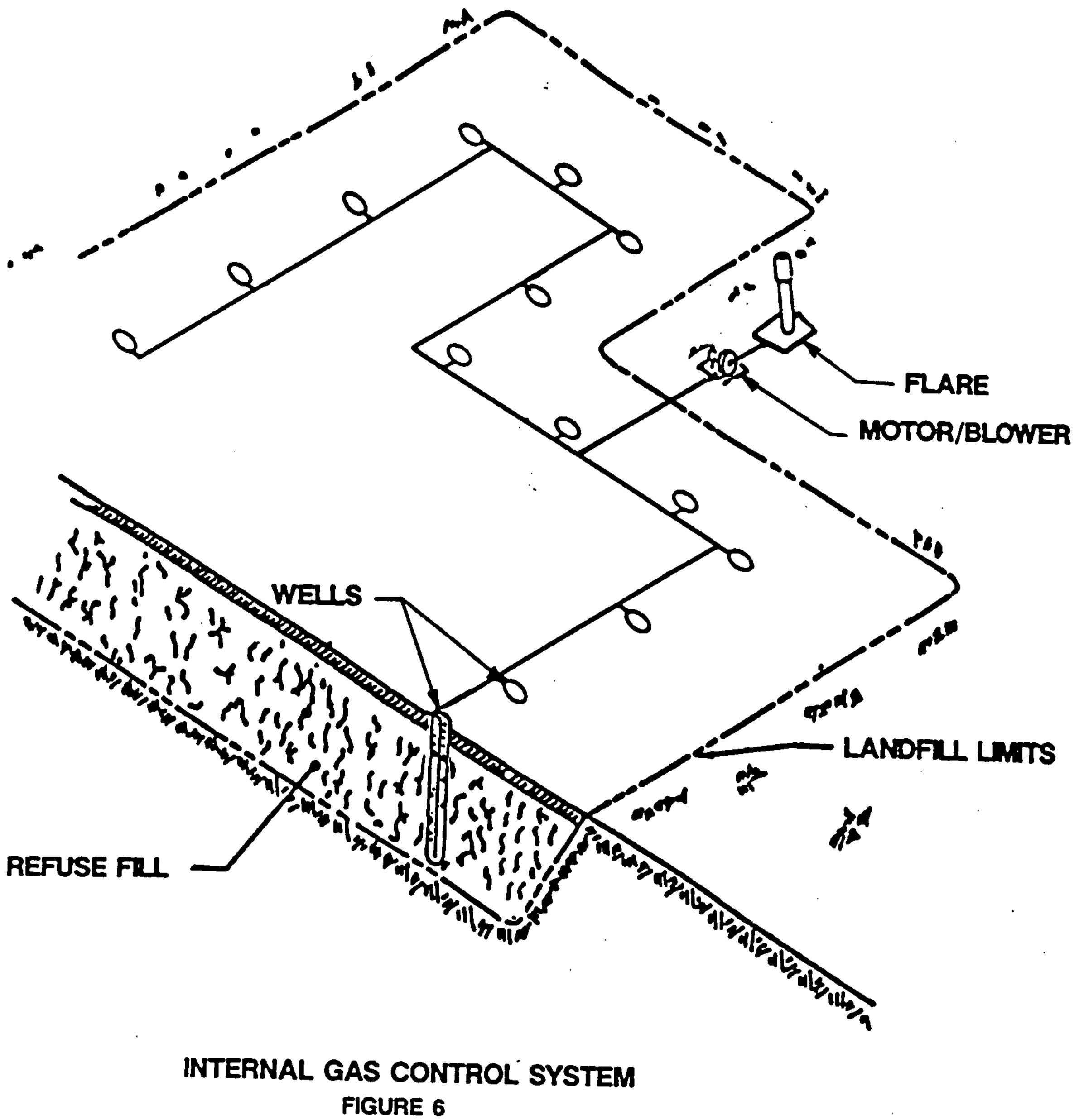
- site geology
- limits of waste fill
- site topography
- property boundaries
- level and extent of migration.
- owner and operator requirements
- permit and permitting agency requirements



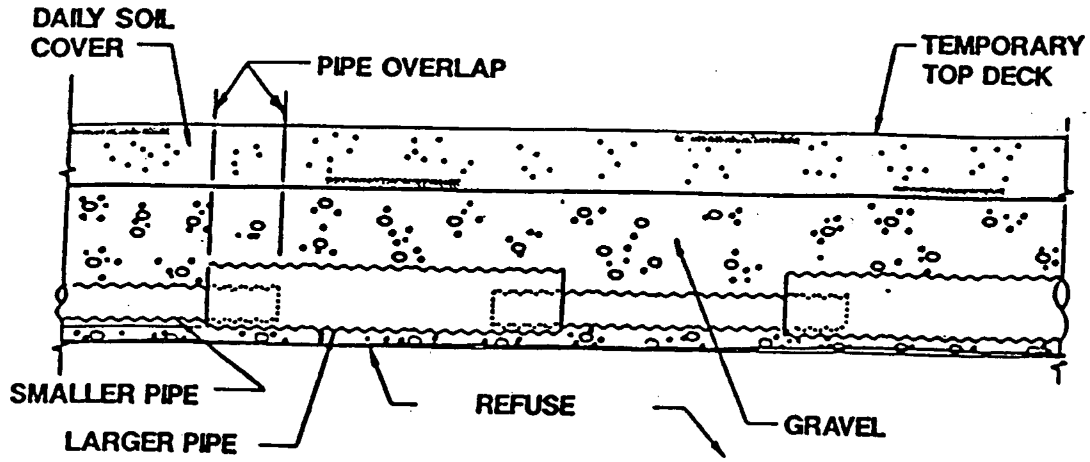
TYPICAL EXTRACTION WELL
FIGURE 4



EXTERNAL GAS CONTROL SYSTEM
FIGURE 5

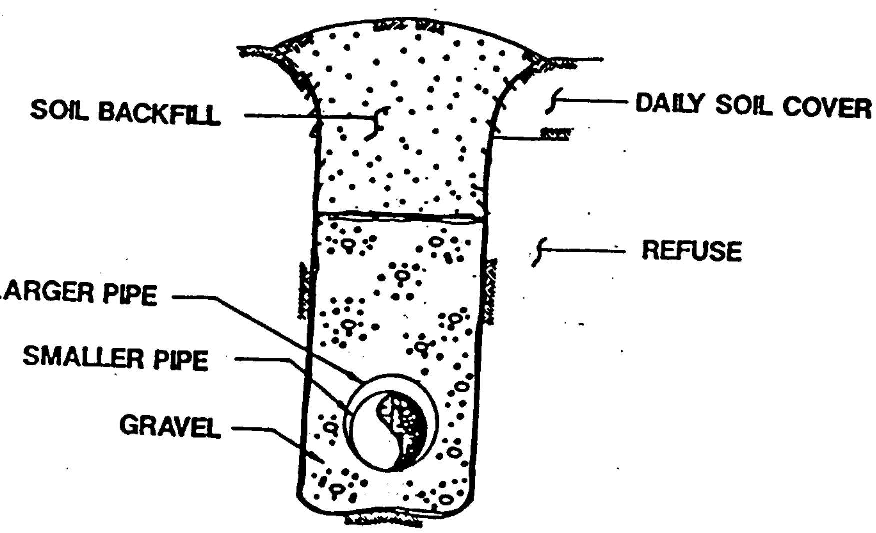


INTERNAL GAS CONTROL SYSTEM
FIGURE 6

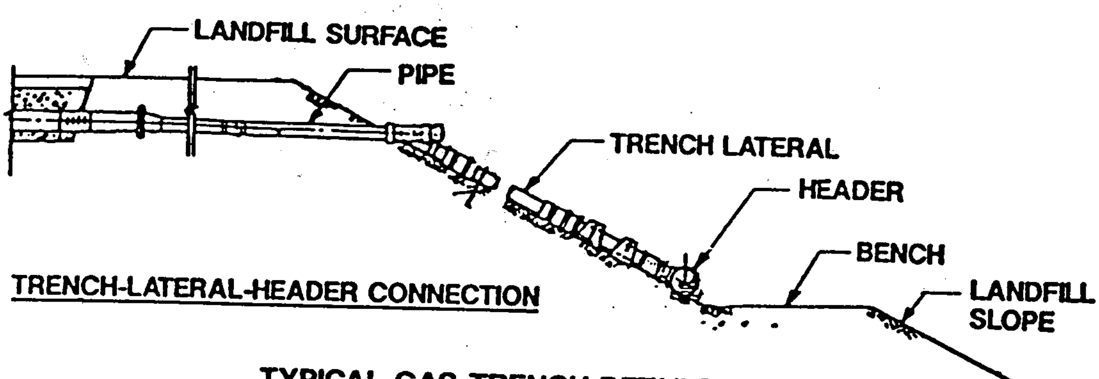


TRENCH PROFILE

NOTE: PIPE IS TYPICALLY POLYMER COATED CSP FOR DEEPER LANDFILLS AND CAN BE HDPE FOR SHALLOWER LANDFILLS.



TRENCH SECTION



TRENCH-LATERAL-HEADER CONNECTION

TYPICAL GAS TRENCH DETAILS

FIGURE 7

All other things being equal, it is best to install gas systems in the landfill, to control gas at its point of generation. This is true for two reasons. First, refuse is more porous than soil so removal efficiency per unit of energy is superior. Second, there is less likelihood of mixing air and LFG in explosive concentrations when operating an internal gas collection system.

Laterals connect well and/or trenches with a main LFG header system. The gas withdrawn at each well or trench is collected in a pipe network known as the gas collection header. A motor/blower unit draws the gas to a central point where the gas is either discharged to the atmosphere, or burned in a flare or energy recovery system to control malodors and VOC emissions.

The piping materials used in trenches, wells, or for gas collection headers should be compatible with the landfill environment. Typically, the pipe used in the landfill gas systems is polyvinyl chloride (PVC), high density polyethylene (HDPE), or fiberglass-reinforced plastic (FRP). Pipe materials are discussed in more detail in the section below. Some systems have used polymer coated corrugated steel pipes for site specific reasons.

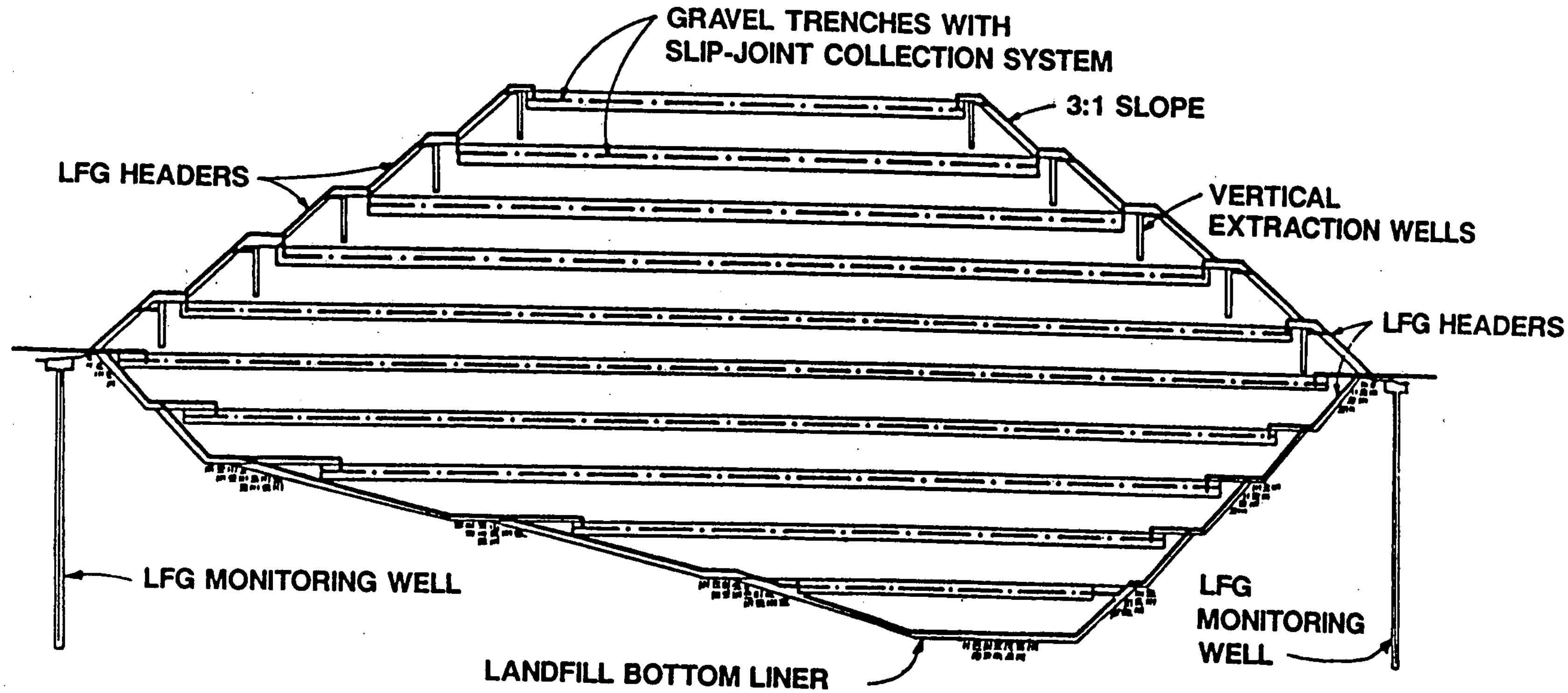
Motor/blowers and flares used for induced exhaust systems will be discussed in more detail in the following section on landfill gas recovery. Every gas control system should also include a series of monitoring probes placed between the control system components and the area to be protected. These probes are used to assure that the installed system is effectively controlling the migration of the landfill gas. Probes are often constructed from PVC or HDPE materials.

3. Air Injection.

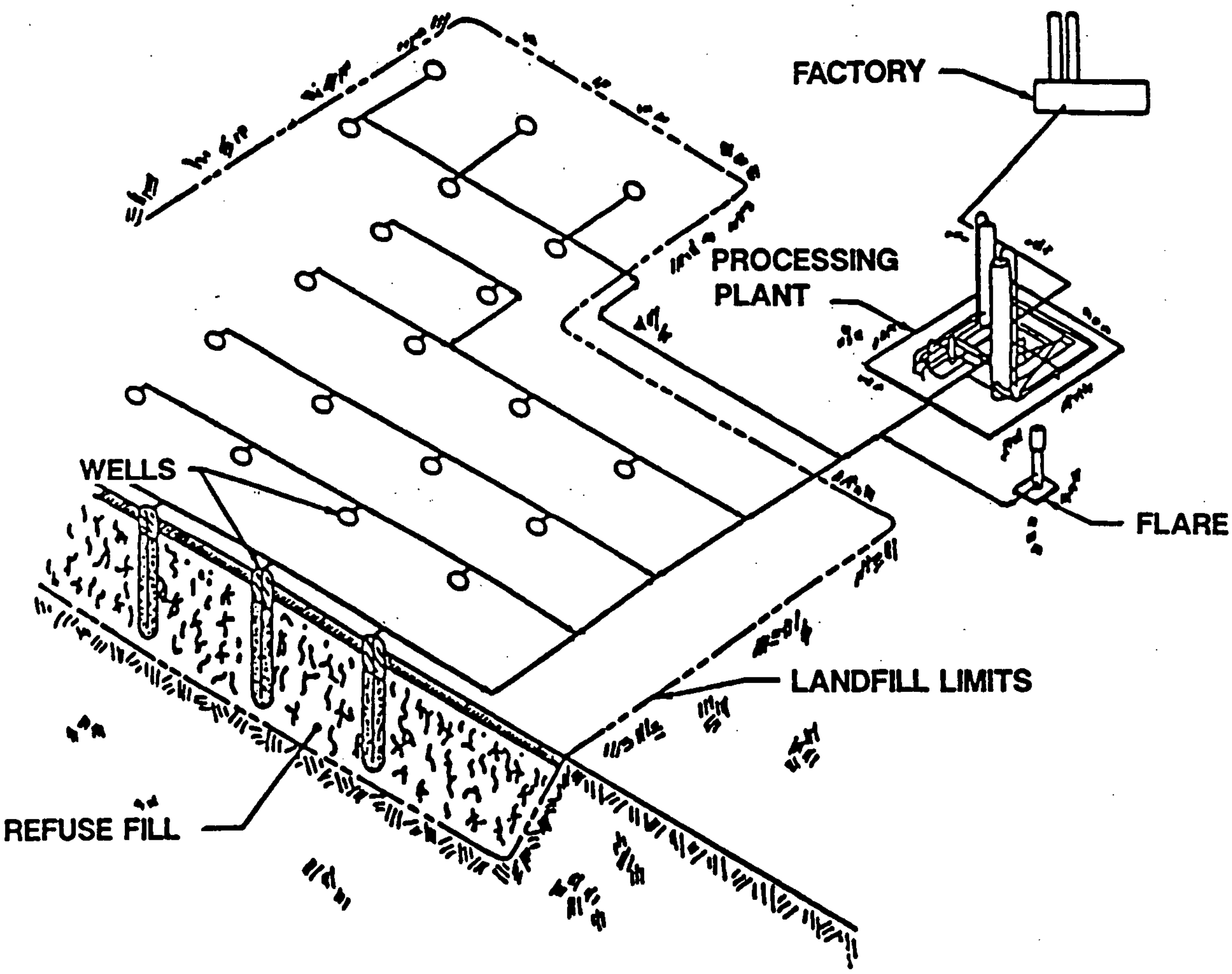
In addition to barrier and ventilation control systems, air injection systems can provide gas control by injecting air into natural soils adjacent to a landfill to (1) provide a positive pressure zone overcoming gas migration into surrounding native soils; (2) dilute gas concentrations with air to non-hazardous levels. The components of air injection systems (wells, pipes, blowers, etc.) are generally the same as induced exhaust systems described above.

C. GAS RECOVERY

Typical gas recovery systems in use today (see Figures 8 and 9) employ LFG trenches and/or extraction wells. They typically consist of perforated or overlapping



SCHEMATIC OF HORIZONTAL LFG COLLECTION SYSTEM
FIGURE 8



GAS RECOVERY SYSTEM
FIGURE 9

pipe casing placed in the refuse, backfilled with permeable material (such as gravel), and sealed with impermeable material to prevent the inflow of air. Suction is applied to each extraction trench and well to withdraw the gas and transport it to a processing area by means of a pipe network referred to as a gas collection header. A motor/blower unit or compressor is usually the source of the applied suction. The LFG is typically combusted in a specially designed flare to insure efficient combustion. The gas extracted from the landfill with a motor/blower or compressor usually undergoes some sort of dehydration or moisture knock-out (see Figure 10).

Landfill gas can be used directly "as is" or upgraded to a higher heating value. Medium-Btu gas can be used or sold for industrial boilers-burners, cogeneration (heat and electricity), electrical generation, on-site space heating and/or hot water heating, lighting, and recreational uses. Landfill gas can be upgraded to pipeline standard (high-Btu) gas for injection into nearby utility company pipelines. Processed landfill gas can also be used to fuel conventional vehicles with converted carburetion systems.

Raw landfill gas can be used for space heating or hot water heating. The only processing required may be simple water and particulate removal depending on the make-up of the LFG. There is no need for an elaborate and expensive processing technology. Furthermore, since such uses do not require large volumes of gas, they are suited to the many smaller landfills across the country.

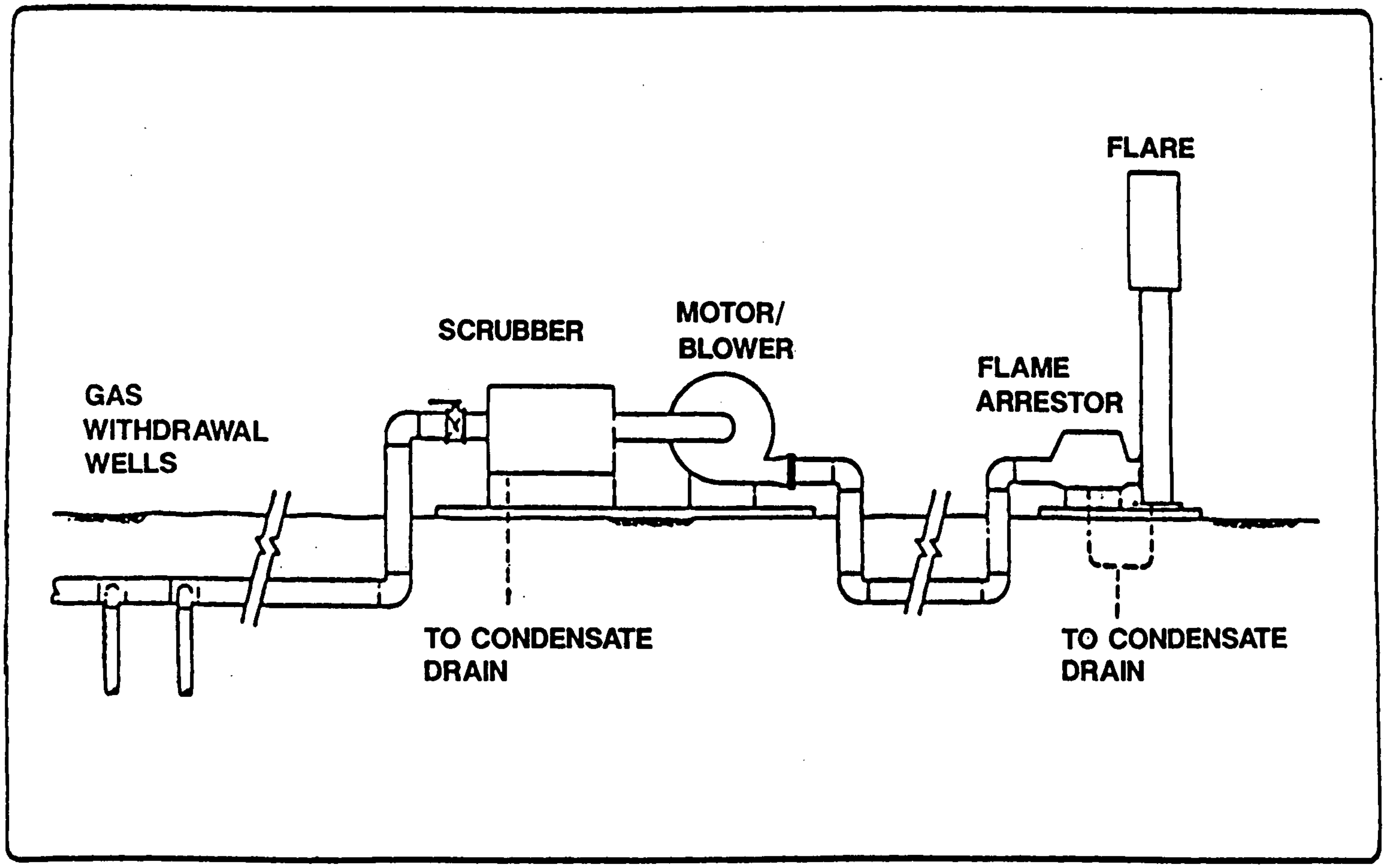
Pipeline quality gas (upgraded to about 1,000 Btu) can be used for any application for which natural gas is used. Consequently, most large landfills pursue this application of landfill gas. In addition to moisture and particulate removal, processing includes CO_2 and trace compound removal.

No matter what the application, the recovery system contains a gas collection system, which includes the following components.

1. Pipe.

   Typically polyvinyl chloride (PVC), high density polyethylene (HDPE), and/or fiberglass-reinforced plastic (FRP) pipe is used for LFG collection systems.

   PVC is produced by refining petroleum into naphtha, then to ethylene. Ethylene and chlorine are then combined to form vinyl chloride which is reacted with a catalyst to form PVC. The PVC resin (or powder) is then mixed with a variety of additives to form the desired specific formulation of PVC required. The additives can include pigments, lubricants, stabilizers, and modifiers. The amounts and types of these additives have a significant effect on the final PVC product. For example CPVC pipe (chlorinated PVC) exhibits better temperature resistance than regular PVC.



LANDFILL GAS COLLECTION SYSTEM
FIGURE 10

PVC formulations used for piping purposes contain no plasticizers and little of the other ingredients mentioned. These are known as rigid PVC's and are differentiated from the plasticized, or flexible PVC's, such as those used to make upholstery or luggage.

Standards for PVC pipe are given in ASTM D 1784. This identifies PVC with six different cell classes, which group the pipe by various physical characteristics. Most of the time in landfill gas collection work, the designer must decide between Schedule 40 and Schedule 80. Schedule 40 is a thinner walled pipe than Schedule 80 and cannot be threaded. Schedule 80 PVC pipe may be threaded and is used for more severe applications at higher working pressures.

PVC's in general can be joined by adhesive heat, or mechanical methods. Rigid PVC pipe is usually joined by adhesives. There are specific types of adhesives recommended for use with both Schedule 40 and 80 pipe, and one must be careful to use the appropriate type.

PVC pipe has excellent resistance at room temperature to salts, alcohol, gasoline, ammonium hydroxide, and sulfuric, nitric, acetic, and hydrochloric acid, but may be damaged by ketones, aromatics, and some chlorinated hydrocarbons. PVC becomes excessively brittle below 40°F, and the maximum temperature ranges from 150 to 220°F depending on the type of PVC. PVC pipe will not support combustion.

Polyethylene (PE) pipe is made from high density polyethylene (HDPE). HDPE is a thermoplastic material polymerized from ethylene at controlled temperatures and low pressures. Ethylene is a member of the olefin group that also includes propylene and butylene. This helps to account for HDPE's waxy feel.

HDPE's are generally divided into two density ranges: 0.941-0.959 gms/cc and 0.960-0.963 gms/cc. Polymers having densities lower than 0.960 gms/cc are manufactured by polymerizing ethylene in the presence of an alpha olefin comonomer such as butene-1 or hexene-1. The comonomer's presence is included in order to control the crystalline structure and therefore the chemical and physical properties of the HDPE. The types of HDPE pipe used in the landfill gas industry fall into the lower density category mentioned above. This lower density results in an improvement in impact resistance, environmental stress crack resistance, and flexibility. ASTM D 1248 classifies PE's into four types depending on the density of the natural resins.

HDPE pipe is classified according to ASTM D 2513, which employs a four digit material designation code. This specification defines the polyethylene pipe types most familiar to those in the LFG industry- e.g. PE 3408. Because of the wide variety of polyethylene pipe materials used today, an additional ASTM standard (D 3350) was developed to augment ASTM D 2513.

HDPE pipe must be joined by heat methods. Pipe segments and fittings are fused to one another at temperatures in the 400 degree F range. Different thicknesses and types of pipe require different temperatures. There is no known suitable adhesive for polyethylene.

Fiberglass-reinforced plastic piping typically is noted for its thermal and dimensional stability, chemical resistance, strength, durability, and good electrical properties. Epoxies reinforced with fiberglass have very high strengths and resistance to heat. Chemical resistance of the epoxy resin is excellent in nonoxidizing and weak acids, but not good against strong acids. Alkaline resistance is excellent in weak solutions. The glass reinforcement is many times stronger at room temperature than plastics, does not lose strength with increasing temperature, and reinforces the resin effectively up to 300°F. It is intended for long, straight runs rather than for systems containing many fittings. The glass reinforcement is located near the outside wall, protected from the contents by a thick wall of resin and protected on the outside by a thin wall of resin. Chemical resistance may be affected by any exposed glass. Epoxy resin has a higher strength at elevated temperatures than polyester resins, but is not as resistant to attack by some fluids.

Polyester resins reinforced with fiberglass have good strength and chemical resistance, except to alkalies. Some special materials in this class, based on bisphenol, are more alkali resistant. The recommended service temperature range is 0 to 220°F. The pipe is rated as self-extinguishing.

When selecting the material to use, a number of factors should be considered. Ultimately, the service life of a pipe material will depend on the intrinsic durability of the material and the conditions under which it is exposed during service.

Some of the specific factors that must be considered when selecting a pipe material are discussed below.

Chemical Resistance-

Extensive research has been done on the chemical resistance of plastic pipe materials and numerous charts are available that give the relative resistance of a material to a specific chemical. Not as clearly understood however, is the resistance of plastic materials to the mixtures of chemicals that may present themselves to a pipe in actual service conditions in the landfill environment. Research done by the

U.S. Environmental Protection Agency (EPA) on plastic materials used for linings has shown a wide variety of changes in physical properties can occur after exposure simulating service conditions. Among these are large weight gains (swelling) and loss of strength.

Strength-

Pipe strength is dependent on the type of material the pipe is made from, the wall thickness of the pipe, and its installation. In most landfill gas collection systems, the collector pipes are not buried very deeply (typically less than 10 feet). Some collection trenches in deep canyon landfills can have as much as 200 feet to 400 feet of refuse above them. Materials utilized in these circumstances must be able to withstand the overburden. Many successful uses of polymer or asphalt coated corrugated steel pipe has been used in these circumstances. For typically shallow landfills, however, since the collector pipes are operating under a vacuum, one must consider both the vacuum in the pipe, which is tending to pull it in from the inside, as well as the dead load on top of the pipe, which is tending to crush it from the outside. Additionally, any live loadings (such as at a road crossing) must be considered.

Rigid and flexible pipe deal with strength in the service environment in two very different ways. With rigid pipes, the strength of the pipe itself is the predominant source of support against crushing. Flexible pipes rely on the backfill around them to act as a system (pipe and soil) to resist crushing.

Strength considerations for both HDPE and PVC pipes have been extensively researched and are well documented in manufacturers literature. Published strength characteristics are specified at certain temperatures. Actual service temperatures are very important and must be considered in designing the pipe system so that changes in strength characteristics due to elevated temperatures are accounted for in the material selected.

Stress Cracking-

There are four types of stress cracking that can occur in plastics under certain conditions. They are:

- Environmental
- Solvent
- Thermal
- Oxidative

All plastics are subject to solvent, thermal, or oxidative stress cracking when improperly applied or installed. Of the four categories above, environmental stress cracking is the only one that is restricted to Type IV density HDPEs. Most all of the PE3406's and 3408's have excellent resistance to environmental stress cracking, because they are produced from high molecular weight copolymers.

Thermal Expansion and Contraction-

All materials change dimensions as a result of temperature changes. A temperature increase results in an increase in size, a temperature decrease results in a decrease in size. HDPE and PVC differ greatly in their respective changes in size as temperature changes. PVC expands 0.00003 inches per inch of length per degree F of temperature change. HDPE pipe is three times that at 0.00009 inches/inch/degree F. In a buried environment, where the temperature fluctuations should be minimal and the pipe is supported on all sides by soil, thermal expansion is of less concern. However, in systems where the collector pipes are above ground, thermal expansion and contraction must be accounted for in the design.

Weather Resistance-

Changes in the physical properties of plastic pipe can be caused by various kinds of exposure to the outdoor environment. Weather effects can be minimized or eliminated by the proper storage and installation of the pipe. Materials not protected from ultraviolet radiation with the addition of carbon black (e.g., PVC) should be protected both during storage and in service to prevent degradation from UV radiation. Certain UV resistant coatings can be applied to the pipe.

2. Blowers and Compressors.

A blower or compressor is used to create a vacuum to withdraw the landfill gas from the LFG collection trenches and wells and transport it to the processing location. Many types of blowers and compressors have been used for landfill gas recovery. The amount of gas, the vacuum required for collection, and the pressure required for processing or end use of the gas are key factors in selection of an appropriate blower or compressor.

When ordering a blower or compressor, consideration must be given to the material of construction due to the corrosive nature of the gas. Most manufacturers offer units constructed from a variety of materials and optional protective coatings. Landfill gas control and recovery systems have used blowers and compressors from many different manufacturers including Aerovent, Allis Chalmers, Gardner-Denver, Hauck, Hoffman, Lamson, Paxton, Roots, Ingersol Rand, Cooper Bessemer, etc.

Free water and particulates should be removed from landfill gas prior to the gas being introduced into a motor blower or being used as an engine fuel. There are three types of blowers in use in landfill gas systems. A brief description of each type of machine as well as the advantages and disadvantages of each are as follows:

a. Centrifugal Blowers (single and multi-stage)

Centrifugal units are classified as "constant pressure (or vacuum), variable volume (flow)" machines. In other words, variable flow rates may be achieved across the entire performance curve. Flow variation is achieved by use of a butterfly valve attached to the inlet of the unit. Advantages and disadvantages are:

1. Advantages (single stage):

   o Easy to operate
   o Simple
   o Low cost

2. Disadvantages (single stage):

   o Low head pressure
   o Should be protected against surge

3. Advantages (multi-stage):

   o Higher head pressures possible

4. Disadvantages (multi-stage):

   o Must be protected against surge

b. Positive Displacement Lobe Type Blowers

Positive displacement or rotary lobe units are the opposite of centrifugal units. They are classified as "constant volume, variable pressure" machines. Volume may only be varied by a speed change of the rotating lobe via a variable frequency controller or sheave adjustment ratio change. Advantages and disadvantages are:

1. Advantages:

- o Higher discharge pressure
- o Fixed flow rate

2. Disadvantages:

- o Noisy
- o Fixed flow rate
- o More subject to damage from LFG than centrifugal blowers

3. Flares and Flame Arresters.

Open Flame Flares

Open flame flares, also known as "candle" or "pipe" flares, have been widely used on landfills for years. Pipe flares offer an economical method of disposing of the landfill gas. Sometimes they are no more sophisticated that an open pipe lit periodically with a burning rag.

However, sophisticated pipe flares (operating at higher flow rates and tip velocities) require flame stabilizers to prevent the flame from extinguishing itself. Also in these units, windshields allow the flame to establish itself and resist high wind conditions, and automatic energy saving pilots sense the landfill gas flame and automatically relight the flare if necessary.

Enclosed Flares

Enclosed flares (also known as ground flares) differ from open flame flares in that both landfill gas and the air flows are controlled. While landfill gas is "pushed" through the flame arrester and burner tips by a blower, the flare stack "pulls" or drafts the air through air dampers and around the burner tips.

Enclosed flares are used in landfill gas applications for one of two reasons (to hide the flame and control the emissions). Enclosed flares designed solely to hide the flame are often referred to as "invisible flares". These flares are normally characterized by a short stack height of 20 to 30 ft. Residence times are typically about 0.3 seconds.

At full landfill flow rates, the flame inside an invisible flare is often close to the top of the flare. In many cases, invisible flares are designed to enclose the "flame envelope", but allow "tails" of flame to burn above the top of the flare. As landfill gas is primarily methane and carbon dioxide, the flame tails are clear and might only be seen at night. Emissions from invisible flares are very dependent upon the landfill gas flow and methane concentration.

Enclosed flares used to minimize NOx, CO, and hydrocarbon emissions while at the same time maximize the destruction of trace compounds such as vinyl chloride and aromatic compounds, are known as emission control enclosed flares. These requirements are often contradictory, requiring design compromises to maximize the flare performance. For example, high operating temperatures reduce CO and hydrocarbon emissions, but also increase the NOx levels. The enclosed flare should be designed not only to meet today's emission regulations, but should also be able to operate at more stringent conditions if needed by future regulations.

Emission control enclosed flares are characterized by a 35 to 50 ft overall height. The additional height is a key design requirement for emission reduction as the flare height provides the draft and mixing energy for the landfill gas and combustion air.

In order to prevent a flashback of combusting gases from the flare through the process station and collection system, a flame arrester is inserted in the inlet line to the flare. Typically, the material of construction for flame arresters is stainless steel, aluminum, or other metal alloys.

Flame arresters installed in the horizontal position should have a means of drainage. Flame arrester elements should also be designed so that they are removable for easy cleaning.

A flame arrester should be installed immediately upstream of all flares and an automatic shutdown valve installed in cases where free gas can be vented in an area which may be hazardous.

4. Condensate Handling

Condensate traps must be designed to continuously drain condensate from landfill gas header and transmission lines under both negative and positive operating pressures, and still maintain a seal between the gas stream and the atmosphere. This is most easily accomplished with a U-tube constructed of the same material as the pipe transporting the gas, and properly designed to handle the anticipated condensate and vacuum in the system. A check valve may also be used at the outlet of the trap to prevent air or water flow back into the pipe. Water traps should be designed to withstand a minimum of 12 inches of water column more than the anticipated design vacuum in the system, without losing the water reservoir. Adequate gravel should be provided around the water drain trap to allow for continuous drainage of water from the drain trap back into the landfill.

What can be done with collected condensate depends on the regulations governing the site. Currently, the three most common options are:

a. Return to the landfill

b. Pipe directly into the sewer line for treatment at a wastewater treatment plant

c. Collect and hold in storage tanks on site for periodic removal, treatment, and disposal at a wastewater treatment plant.

The equipment and material used in items b and c above will include pipe, pumps, sumps, and storage tanks. As with gas-carrying system components, all condensate handling components should be corrosion resistant. PVC and PE are the most common types of piping material used for condensate handling. It is recommended that piping used to transport out of solid waste fill be double walled to contain leaks. Many sites are also using double walled tanks for storage of condensate. Landfill owners/operators and engineers should check with the local regulatory bodies to ascertain specific requirements on this.

5. Water Knockout Scrubbers.

Water scrubbers or knockout vessels are often used on control and recovery systems to remove liquids (primarily water) in order to keep the gas from causing corrosion or line freeze-ups.

Water entrainment should not normally exceed one gallon/million cubic foot landfill gas carryover. Consequently, water knockout scrubbers are recommended upstream of blowers, compressors, and pumps. The typical water droplets should not exceed 25 microns in size. Scrubbers should be drained using a negative pressure water trap.

6. Electrical Equipment and Fixtures for Processing Stations.

Processing station electrical equipment and fixtures should typically be classified as Class 1, Division 2, Group D of the National Electric Code. A distance of 10 feet from gas handling equipment should normally be adequate to make the area non-classified. Guidelines for classification should be API, recommended practice 500B, or NFPA 70C. Some local codes may be more restrictive than the aforementioned, and should be examined prior to design. Generally, NEM 7 explosion proof enclosures should be used in areas near the flare and blowers and NEM 4 enclosures used in other areas.

Electrical installations should be in accordance with API RP 540 and National Electrical Code or local codes where applicable.

Any areas with gas handling or processing equipment should have a fence with a minimum of 8 feet in height with barbed wire on top.

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