

LANDFILL GAS COLLECTION AND GROUNDWATER PROTECTION

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ABSTRACT

Landfill Gas (LFG) has been identified as a major source of contamination of groundwater underlying landfills. Contaminants consist primarily of volatile organic compounds (VOCs) such as methylene chloride, trichloroethene, and tetrachloroethene.

Three mechanisms for vapor phase VOC migration from a landfill to groundwater are predominant. These are: 1. Direct contact of landfill gas containing VOCs with groundwater, 2. Vapor phase VOC migration through the unsaturated zone surrounding a landfill, and 3. LFG Condensate water formation in the unsaturated zone and subsequent migration to groundwater.

Current LFG collection practices are not geared towards controlling the potential for groundwater contamination caused by LFG. By not recognizing this major source of contamination, landfill operators are missing a major opportunity to reduce costs and minimize future liability of future groundwater impacts. Existing or future LFG collection systems can be upgraded, augmented with unsaturated zone remediation, or collection system operations modified to significantly reduce the potential for VOC contamination of groundwater.

INTRODUCTION

Most of the landfills throughout the U.S. are affected by the migration of volatile organic compounds to groundwater. In a recent study (Plumb) of the results of monitoring RCRA Appendix IX compounds at 479 disposal sites, 84 percent of the

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detectable compounds were VOCs. Many of these same landfills have or will have landfill gas collection systems in place to control landfill gas migration. The purpose of this paper is to describe methods for protection of groundwater by modifying existing operational procedures or existing collection systems.

Both lined and unlined landfills are prone to migration of VOCs by vapor or liquid phase transport or a combination of the two. Clay lined facilities are subject to migration by diffusion through the clay layer and desiccation cracks. Geosynthetic liners are subject to leaks and resulting diffusion through the unsaturated zone beneath the liner.

CONTAMINANT MECHANISMS

The four basic mechanisms which cause groundwater contamination by VOCs are described briefly in **Table 1**: A more complete discussion of these mechanisms are the subject of previous papers [10].

TABLE 1

Mechanism	Pathways to Groundwater
1. LFG condensate formation	Liquid phase
2. LFG contact with groundwater	Vapor phase
3. Leaching of VOCs in unsaturated zone	Vapor phase, then liquid phase
4. Leachate migration	Liquid phase

The first three mechanisms are essentially similar, all involve the movement of the VOCs through the landfill boundary by vapor phase transport. The contribution from each of the three mechanisms is dependent on numerous factors such as site geology, hydrogeology, and climate. **Table 2** describes some of the factors which affect the contribution of each mechanism.

TABLE 2

Mechanism	Factors Increasing Contamination	Factors Decreasing Contamination
LFG Condensate Formation	<ul style="list-style-type: none"> • Warm Landfill Gas • Cool Soils 	<ul style="list-style-type: none"> • Cool Landfill Gas • Warm Soils
Direct Contamination	<ul style="list-style-type: none"> • Shallow Groundwater • Permeable Soils 	<ul style="list-style-type: none"> • Deep Groundwater
Leaching in the Unsaturated Zone	<ul style="list-style-type: none"> • Water Infiltration • Low In-situ Bacterial Populations 	<ul style="list-style-type: none"> • Low Rainfall • Low Permeable Soils

Henry's Law

The first three mechanisms described above are all based on absorption of the VOCs from the vapor phase to the liquid phase. The magnitude of the absorption and the resulting relative concentrations of the VOCs in the air and water phases can be calculated using Henry's Law. Henry's law is expressed as follows:

$$X_{AQ} = \frac{P_x}{K} \quad (1)$$

where:

X_{AQ} = Aqueous concentration of the gas
 K = Henry's Law constant at specified temperature
 P_x = Partial pressure of the gas

To demonstrate the partitioning of an individual compound between the water phase and the vapor phase, LFG is assumed to contain benzene as the only contaminant. The assumed concentration is 1000 ppb. The resulting Benzene concentration (X_B) in the water phase is calculated as follows.

$$X_B = \frac{1 \times 10^{-6} (1 \text{ atm} - 0.0313 \text{ atm})(78 \text{ g/g} \cdot \text{mol})(1 \times 10^6 \text{ mg/g})}{(5.43 \times 10^{-3} \text{ m}^3 \text{ atm/g} \cdot \text{mol})(1000 \text{ L/m}^3)} \quad (2)$$

= 13.9 ug/l Benzene

where:

K = $5.43 \times 10^{-3} \text{ m}^3 \text{ atm/g} \cdot \text{mol}$ is the Henry's Law constant for Benzene at 20°C
 $78 \text{ g/g} \cdot \text{mol}$ = the molecular weight of Benzene
 0.0313 atm = the correction for the vapor pressure of water

GROUNDWATER PROTECTION

Protection of groundwater from LFG originated VOC contamination can be accomplished by several methods. These methods consist of removing VOC mass from the unsaturated zone, reducing the rate of migration of LFG outside the landfill boundary, or stripping VOC emissions at the source.

1. Improved LFG Collection

VOC migration outside the refuse prism can be minimized by increasing the efficiency of current landfill gas collection practices. Current collection practices

are based on the requirements for lateral migration of methane at the facility property boundary or the requirements for hydrocarbon emissions to the atmosphere. Collection practices commonly follow the accepted rule of thumb that 80% of the landfill gas generated can be collected economically.

A cost appraisal of the real costs incurred by VOC contamination of groundwater will significantly raise the 80% rule to a level approaching 100%. The cost to upgrade a collection system or operation procedures is much lower than the astronomical costs that can be associated with a groundwater treatment system.

2. Increase Volatilization of VOCs in the Unsaturated Zone

The process of removing VOCs from soil has been used extensively to remediate contaminated soils. This process used in situ strips contaminants from the unsaturated zone using air to volatilize the VOCs. This process is also supplemented by bacterial degradation of the VOCs in an aerobic environment. Of these two mechanisms, volatilization will be the primary method for most VOCs, which are generally not easily decomposed in an aerobic environment.

The process of volatilization of VOCs effectively removes VOC mass which would otherwise be subject to leaching, diffusion, or absorption into the groundwater. The areas most conducive to volatilization are near the landfill perimeter.

3. In situ Degradation of VOCs in the Unsaturated Zone

VOCs in the unsaturated zone can also be removed by bacterial decomposition. Methanotrophic degradation of chlorinated hydrocarbons can be reasonably effective. The methane present in the landfill gas is used as a fuel source for the bacteria for co-metabolism. The difficulty with this process is maintaining a stable source of oxygen diffusion into the subsurface.

Each of these methods for reducing migration can be incorporated into a single system to maximize effectiveness. The relative importance of these methods and the specific design parameters are dependent on the characteristics of the site, including the following:

- Soil bacterial populations
- Soil physical properties
- VOC constituents present
- Mass of contaminant present
- Relative influence of factors driving migration

COST OF PROTECTION vs. GROUNDWATER REMEDIATION

The question remains “Why not just wait and see if contamination takes place, then I’ll clean it up?” This is the state of current regulatory practice, which forces the landfill operator to spend huge sums of money to detect and remediate contamination, but assumes that lined landfills are the only means of prevention. This approach omits the primary cause of landfill impacted groundwater contamination and potentially the cheapest means to prevent it.

The primary reason for reducing the groundwater contamination potential of LFG is the economic benefit of preventing contamination of the groundwater aquifer. This benefit can be demonstrated by examining the benefits three general scenarios:

- Reduce LFG migration to the refuse boundary
- Remove or degrade VOC mass in the unsaturated zone
- Treat contaminated groundwater

TABLE 3

Action	Benefits	Deficiencies
Improve LFG Collection	<ul style="list-style-type: none"> • Lowest cost of three options • Reduced monitoring costs • Source reduction • Eliminates horizontal spreading of contamination 	<ul style="list-style-type: none"> • Higher capital and operator cost vs. normal LFG collection practices
Unsaturated Zone Remediation	<ul style="list-style-type: none"> • Source reduction • Lessens the probability of additional migration 	<ul style="list-style-type: none"> • Higher cost than improved collection • Additional control points required • Disposal of vapors
Groundwater Treatment	<ul style="list-style-type: none"> • Treats contamination only • Acts as Containment for Further Migration 	<ul style="list-style-type: none"> • No source reduction • Highest cost of three options • Longer Treatment

The first two options are the most economical due to the lower costs of pumping air or gas versus pumping water and the ability to control the source of contamination. Improved collection will generally be the lowest cost of the three options because of existing systems and operations. Although lower cost groundwater treatment options

than pump and treat may be feasible, none of these options address the basic problem of controlling the source. Without source reduction, no improvement in groundwater quality can be expected for a considerable period of time.

By minimizing the potential for horizontal spreading of contamination due to vapor phase diffusion, LFG collection can significantly reduce the potential for contamination. As noted in previous papers, [10] horizontal diffusion in the vapor phase can increase the potential for contamination by up to 500%. By reducing the effects of horizontal diffusion, the potential magnitude of contamination can also be reduced.

Several methods for improving LFG collection or remediating the unsaturated zone can be implemented which do not present major capital or operations expenditures. A description of these methods follow:

IMPROVED LFG COLLECTION

An unheralded, but promising method for improving LFG collection efficiency uses the concepts of the effects of atmospheric fluctuations on the availability of landfill gas [8] to increase collection. These concepts can be employed to adjust gas collection rates according to barometric effects.

Barometric Adjustment Methods

The efficiency of a landfill gas collection system can be affected by fluctuations in the barometric pressure. As barometric pressure increases over the surface of a landfill, the landfill tends to store more gas because higher pressures in the landfill are necessary to force the gas out of the landfill. Falling barometric pressure alternatively results in the landfill releasing more gas. Standard operation of a gas collection system is to adjust extraction rates to minimize air infiltration in the landfill. The result of this is that the system is adjusted to collect gas based on the minimum rate that is available during the day. The gas that becomes available as a result of daily barometric pressure fluctuations is not collected and subsequently can become a source of low level migration.

The fluctuating availability of landfill gas can be accounted for by adjusting the gas collection rate as gas becomes available. This can be done by automatically adjusting the gas extraction rate at either individual wells or the total field as a function of rising or falling barometric pressure. Another alternative is to control extraction well flow rates to maintain a constant absolute pressure.

Decreasing Radius of Influence

Another method of improving LFG collection efficiency is to reduce the radius of influence of the collection wells. This reduces the effects of non-heterogeneity of the refuse and soil and allows for a fine-tuning of the collection system. The drawback of this approach is that it requires more collection wells to cover the same area of landfill. Due to the unknown nature of the landfill characteristics, this type of approach is generally a phased installation as more information is gathered about well performance.

Collection Modifications

Additional design or operation modifications should be considered which will optimize collection system efficiency, including the following:

- Utilize perimeter collection wells to reduce the rate of migration.
- Careful placement of well perforations to favor LFG collection nearest the soil/refuse interface.
- Use flow-based well adjustment procedures to optimize collection efficiency.
- Improved operator training to maximize collection system efficiency (this may be the cheapest and most effective way to increase collection efficiency).

UNSATURATED ZONE REMEDIATION

Unsaturated zone remediation consists of removing VOC mass from the zone below the landfill and at the perimeter to reduce the source of contamination. The best way to remove this mass is through the use of vapor extraction methods. The cost of implementing vapor extraction can be minimized by using the existing LFG collection system to dispose of the contaminants. Two ways in which this can be done are described as follows:

- Use the existing collection piping to combine the vapor stream with the LFG. This is feasible only if the vapor stream does not create unacceptable levels of oxygen in the piping or does not inhibit the combustion process of the flare or other disposal method.
- Use the vapor stream as a combustion air source for the flare. This is feasible only if sufficient oxygen is present in the vapor stream and the air/fuel ratios are acceptable.

GROUNDWATER TREATMENT

Although groundwater treatment has already been described as the most expensive option, many landfills are or will be in a treatment mode. A new or existing LFG collection system can be used to reduce the cost of treating contaminated groundwater. Groundwater treatment systems generally require an input of energy and a process control system. A landfill gas collection system can be used to supplement these requirements to minimize both capital costs and long term operation costs.

Vapor Extraction/Air Sparging

A highly cost-effective method for removal of VOC contamination from the unsaturated zone and groundwater is the use of in situ vapor extraction. Removal of VOCs from groundwater by a combination of vapor extraction and air sparging may be an economically attractive method. A landfill gas collection system can be utilized in a number of ways to minimize the cost of this process:

- Utilize the gas system combustion process to destroy VOC vapors removed from the unsaturated zone. Some vapors may be in high enough concentrations to use the gas collection piping for conveyance.
- Low concentration vapors can be destroyed by delivery into the combustion process by means of the combustion air stream.
- Backup blowers can be used for vapor extraction.
- The collection system controls can incorporate controls for the vapor extraction system to reduce the cost of construction and operation.

Air Stripping

A highly cost-effective method for treating VOC contaminated groundwater is the use of air-stripping. Air-stripping results in the VOCs being transferred to the vapor phase which then require removal or destruction prior to exhaust of the air. A landfill gas combustion process can be used to destroy the VOCs, generally as part of the combustion air source.

CONCLUSIONS

Until recently, LFG migration has not been looked at seriously as a source of contamination of groundwater. As more evidence is compiled which points to this as a major source of contamination, modifications to system design and operation procedures will be necessary. Low-cost methods are available for the landfill operators that recognize the opportunity to minimize future treatment and liability costs.

REFERENCES

1. Baehr, A.L. "Selective Transport of Hydrocarbons in the Unsaturated Zone to Aqueous and Vapor Phase Partitioning." *Water Resources Research*, V.23, No. 10 pp. 1929 - 1938. 1987.
2. Johnson, Paul C., Ettinger, Robert A. "Considerations for the Design of In Situ Vapor Extraction Systems: Radius of Influence vs. Zone of Remediation." *Ground Water Monitoring and Remediation*, Summer 1994, pp. 123 - 128.
3. Johnson, P.C., Stanley, M.W., Kemblowski, Byers, D.L., Colthart, J.D. "A Practical Approach to the Design, Operation, and Monitoring of In Situ Soil-Venting Systems." *Ground Water Monitoring and Remediation*, Spring 1990, pp. 159 - 178.
4. Keenan, D.T., Ham, R.K. "Beneficial Use of Landfill Gas for On-site Thermal Leachate Treatment." *Seventeenth International Madison Waste Conference*, September 21-22, 1994, University of Wisconsin-Madison.
5. Lu, A.H., Kunz, C.O. "Gas-Flow Model to Predict Methane Production at Sanitary Landfills." *Environmental Science and Technology*, V. 15, pp. 436-440, April 1981.
6. Marley, Michael C., Hazebrouck, David J., Walsh, Matthew T. "The Application of In Situ Air Sparging as an Innovative Soils and Ground Water Remediation Technology." *Ground Water Monitoring and Remediation*, Spring 1992, pp. 137 - 145.
7. Plumb Jr., R.H. "The Occurrence of Appendix IX Organic Constituents in Disposal Site Ground Water." *Ground Water Monitoring and Remediation*, Spring 1991, pp. 157 - 164.
8. Prosser, Richard W. "The Effects of Atmospheric Pressure on the Availability of Gas From a Landfill." *Proceedings from the Technical Sessions of the Twenty Third Annual International Solid Waste Exposition*, sponsored by Governmental Refuse Collection and Disposal Association, August 1985.
9. Tchobanoglous, G., H. Theisen, S. Vigil. Integrated Solid Waste Management, Engineering Principles and Management Issues, McGraw-Hill. New York, N.Y. 1993.
10. Prosser, Richard W., and Janecek, Alan J. "Landfill Gas and Groundwater Contamination." In review for publishing by American Society of Civil Engineers. 1995.