Proposed Regulatory Framework

for Evaluating the Methane Hazard due to Vapor Intrusion

by Bart Eklund

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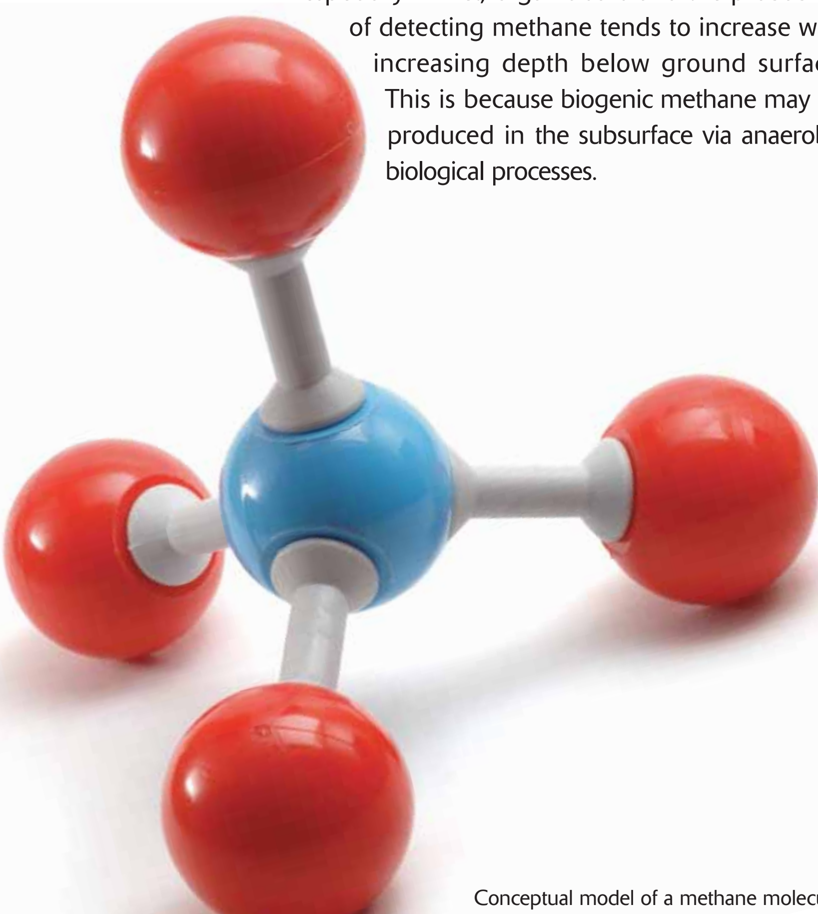
Methane is often found at percent levels in soil gas and it has become a chemical of concern at some vapor intrusion (VI) sites. The evaluation of methane, however, differs fundamentally from the evaluation of volatile organic compounds (VOCs) and the regulatory framework for addressing methane is either nonexistent or inadequate in most cases.

The following discussion addresses the differences in conceptual site models for VI evaluations involving methane versus those involving VOCs, the physical properties of methane, the fate and transport of methane in soil, and existing regulations for methane. The key decision points for regulating VI of methane are listed and a framework for evaluating methane hazard is proposed.

Methane is often present in the unsaturated zone, especially in wet, organic soils and the probability of detecting methane tends to increase with increasing depth below ground surface. This is because biogenic methane may be produced in the subsurface via anaerobic biological processes.



Conceptual model of a methane molecule.

Even "clean" fill soil can generate methane if it has some organic fraction and is wet and devoid of oxygen. The biogas produced by microbes in the subsurface consists of roughly 50% methane and 50% carbon dioxide. Any bubble of biogas or soil gas readings taken near the location where biogas is produced may contain relatively high concentrations of methane.

The explosive range for methane at 1 atm of pressure is 5–15%. The lower explosive limit (LEL) of 5% is higher than, for example, gasoline or the BTEX compounds. Soil acts as a natural flame arrestor, so methane in a typical soil matrix cannot explode. So, there is no LEL for soil gas (methane in a large void in the soil is a different scenario). The soil gas, however, can lead to a hazard if a sufficient volume of gas migrates into enclosed or poorly ventilated spaces where ignition sources are present.

Conceptual Model

Potential VI of methane is fundamentally different than potential VI of VOCs for several reasons, as summarized in Table 1.

For VOC releases, we start with a given mass of VOCs in the subsurface and this tends to slowly decrease over time due to degradation, volatilization, and other processes. For methane, however, gas production can start whenever conditions are conducive.

In VI studies, it is common practice to use concentration data and compare indoor concentrations to outdoor concentrations, indoor concentrations to soil gas concentrations, and so forth, and draw conclusions based on these comparisons. In such comparisons, it is important to recognize that concentration is used as a surrogate, or proxy, for what is truly important, which is mass flow. For gas transport, mass flow is concentration multiplied by gas flow rate. We usually focus on concentration because flow rate is difficult to measure and we can make conservative assumptions about flow rate (e.g., vapor intrusion is 5 L/min into a residential-sized building, building ventilation is about 0.5 air changes per hour, etc.).

For VOCs, the concentration present in soil gas is directly related to the potential risk. In general, the higher the VOC concentration in soil gas, the greater the potential for indoor air impacts due to VI. For methane, this is not the case. Even small rates of methanogenesis will result in soil gas concentrations approaching 50% at the point of generation. There is essentially no correlation between methane gas production rates and methane concentrations in soil gas at the point of generation.

With VOCs, the focus is almost always on chronic exposure and, therefore, VI evaluations address long-term average concentrations. For methane, we're concerned about the worst-case short-term conditions.

Investigations of past methane explosions invariably show that pressure-driven (advective) flow occurred. If a utility line or pipeline has a break, large volumes of gas under high pressure can be released and move through the soil. Similarly, the large gas generation that occurs at municipal solid-waste (MSW) landfills can result in pressure-driven flow into overlying or nearby buildings. In some cases, methane in soil gas can be induced to move by pressure gradients resulting from barometric pressure changes or infiltrating water.

Fate and Transport

Methane can be generated in soils (via microbes called methanogens) and also can be consumed in soils (via microbes called methanotrophs). All soils tend to be either net sources or sinks of methane. Within a given soil column, methane may be produced at depth where the soils are anaerobic and any vapors migrating upwards may be consumed within shallower soil layers where the soils are aerobic.

Methane production may begin in an area if the conditions are conducive. Subsurface conditions may change over time and methanogenesis may begin without a recent leak or spill. The generally accepted mechanisms for degradation of petroleum hydrocarbons in groundwater start with aerobic degradation. Once the available oxygen is gone, other process such as denitrification, iron reduction, and sulfate reduction may occur. Only after these pathways have been exhausted will methanogenesis (i.e., biogas production) begin. Methanogenesis is not a favored pathway. A site may have relatively widespread dissolved non-aqueous phase liquid (NAPL), for example, but only isolated pockets of methane. This may be due, in part, to the specific micro-environments present across the site.

Table 1. Comparison of VOCs and methane for vapor intrusion.

VOCs	Methane
Given starting mass	No given starting mass
Mass flux is related to concentration in soil gas	Concentration in soil gas is not a good proxy for mass flux
Focus on long-term average concentrations	Focus on short-term maximum concentrations
Typical attenuation factors are $\sim 10^{-3}$ or lower	Attenuation factor must be >0.05 to reach 5% indoors
Transport via diffusion with advection important near buildings	Transport via advection is the main concern
Soil gas levels for some VOCs inversely proportional to oxygen levels	Soil gas levels for methane inversely proportional to oxygen levels

A huge amount of literature is available where the emission flux of methane has been measured from various types of soils or other sources. Based on previous literature searches, the emission fluxes of methane from various sources can be approximated as shown in Table 2. The highest reported methane flux was 14,000,000 $\mu g/m^2$-sec from a crack at a landfill surface that allowed for preferential migration of landfill gas.[1]

Removal mechanisms for methane in soil gas also can be an important process. Surface soils tend to be capable of destroying large amounts of methane via aerobic degradation. Oxidation rates up to about 1 L per minute per square meter are possible (40 g/m^2-hr). This is far higher than rates of diffusion through soil columns, so methane generally will be 100% removed if there is an aerobic soil layer beneath a building.

Table 2. Typical emission fluxes for methane from various source types.

Emission Source	Typical Emission Flux (μg CH_4/m^2-sec)
Wetlands	0.1
Lakes	0.5
Tundra, moors	<3
Rice fields	6
Manure	>15
MSW landfills	<4,000

Regulations

In general, methane in soil gas is not regulated in the United States, but there are federal regulations for certain specific types of sites. For MSW landfills, there is a requirement that methane must not exceed 25% of the LEL (i.e., 1.25% methane in indoor air) within buildings or other facility structures and not exceed the LEL in soil gas at the property boundary.[2]

For tunnels and other underground construction, the Occupational Safety and Health Administration (OSHA) defines a potentially gassy operation as one where there is 10% or more of the LEL (i.e., 0.5% methane) measured 12 inches from the roof, face, floor, or walls for more than a 24-hr period.[3] The operation is considered to be gassy if >10% of the LEL is measured for three consecutive days.

Local fire codes or building safety plans often include something similar to the U.S. Environmental Protection Agency (EPA) MSW action level (e.g., 20% or 25% of the LEL) as an action level for indoor air to trigger evacuation.

There are some existing regulations or guidance documents put forth in recent years for methane in soil gas in California. Portions of southern California have underlying thermogenic (fossil) methane. This methane originates deep in the earth and can move under pressure to the surface. Action levels from various California regulations or guidance have recently been summarized.[4] The existing methane guidance, as with VI guidance in general, is evolving and existing guidance is often contradictory and not always based on valid technical assumptions. In general, the California documents are considered to be overly conservative and are not good templates for developing a regulatory framework for methane.

Decision Matrix

There are three key parameters for evaluating hazards related to soil gas and these parameters should be considered in conjunction with one another rather than independently:

1. Methane concentration in soil gas;
2. Differential pressure; and
3. Whether or not the soil gas is saturated with methane or biogas.

Methane Concentration

If the soil gas concentration of methane is low enough, no hazard exists. A de minimis level for screening purposes is 1.25% (i.e., 12,500 parts per million [ppm]). Any methane concentrations below this level are trivial in terms of hazard. There is no concentration of methane in soil gas that is intrinsically unsafe, but methane concentrations above 40% in soil gas suggest that biogas production is locally significant and merits further investigation. The biogas produced by microbes is roughly one-half methane, so methane at high concentrations can be found in soils, even clean fill, if conditions are conducive for methanogenesis. For decision-making purposes, it is important to determine if there is significant methane generation over a reasonably large area.

Differential Pressure

Diffusion of soil gas is not expected to result in an unsafe indoor environment; pressure-driven flow is necessary to move the volumes of gas required to result in indoor air approaching the LEL for methane. Therefore, differential pressure (ΔP) is an important variable to measure. If significant biogas production is underway, elevated pressures will be observed. A screening value of 2 in. H_2O has been proposed.[5] Pressures below this screening value are considered to be negligible and pressures above this screening value require further consideration. If the pressure exceeds 2 in. H_2O, methane soil gas control measures should be implemented. This might involve engineering controls at buildings of concern (e.g., venting systems) and/or source reduction (e.g., provide alternative electron receptors).

Differential pressure for a given site will be a function of the permeability of the soil. A given rate of biogas production will result in a lower differential pressure in more permeable soils. For example, differential pressures within MSW landfills tend to be <10 in. H_2O even though the rate of biogas production is high, because the waste material is highly permeable. The 2 in. H_2O rule-of-thumb results in a rate of advective transport that is approximately 30 times higher than diffusive transport in soils with a permeability of 10^{-8} cm^2 (e.g., sandy soils). This screening value may need to be made more conservative for sites with soils that are more permeable than 10^{-8} cm^2.

Soil Gas Saturation

Isolated "hot spots" of high methane concentration in soil gas generally are not a concern, but widespread elevated concentrations suggest that biogas production is or has been significant. At methane concentrations of 40% and above, biogas likely is being generated at a sufficiently high rate to completely displace other gases from the soil. Below this level, the gas production rate is likely to be too small to displace other gases from the soil pore spaces. For added conservativeness, 30% can be used as a rule-of-thumb (rather than 40%).

If a large reservoir of methane exists in the soil gas near a building, it may pose a potential hazard even if there is no on-going gas production or elevated differential pressure. Under certain circumstances, the methane can be induced to move (e.g., extremely low barometric pressure, methane flashing out of formerly confined groundwater, etc.). Therefore, if the soil gas surrounding a building is largely "whole" or undiluted biogas (e.g., if CH_4 + CO_2 are >90%), it would be prudent to mitigate even if the differential pressure was below the rule-of-thumb discussed above.

Decision-Making Framework

A generic framework for decision-making that outlines the logic and thought process most often used in VI evaluations was developed and is presented in Table 3. The framework builds upon prior work by John Sepich and others. The decision matrix is based on a combination of indoor air data and shallow soil gas data. These are two very important lines of evidence, but are not the only lines of evidence that may need to be considered for a given building. So, the decision matrix cannot completely replace the typical case-by-case evaluation that considers all available information (e.g., soil gas oxygen levels) and is intended for informative purposes to illustrate the general thought process proposed for use in VI evaluations.

Table 3. Decision matrix for methane in soil gas and indoor air.

Shallow Soil Gas Concentration[a]	Indoor Air Concentration None Available	<0.01% (i.e., <100 ppm)	0.01 to <1.25%	> 1.25%
<1.25% to 5%	No further action	No further action	No further action[b]	Immediately notify authorities, recommend owner/operator evacuate building
>5% to 30% [c]	No further action unless $\Delta P > 2$ in. H_2O[b]	No further action unless $\Delta P > 2$ in. H_2O[b]	No further action unless $\Delta P > 2$ in. H_2O[b]	Immediately notify authorities, recommend owner/operator evacuate building
>30% [c]	Collect indoor air data	Evaluate on case-by-case basis	Evaluate on case-by-case basis	Immediately notify authorities, recommend owner/operator evacuate building

Notes: [a]Maximum methane soil gas value for area of building footprint. [b]Landowner or building owner/manager should identify indoor sources and reduce/control emissions. If no sources are found, additional subsurface characterization and continued indoor air monitoring are recommended. [c]The potential for pressure gradients to occur in the future at a given site should be considered.

This table is intended for sites with existing buildings. To address future development, no further action is required if the shallow soil gas concentration is <30% and ΔP <2 in. H_2O. If the combined soil gas concentrations of methane and carbon dioxide are >90%, mitigation should be considered.

The general form of the matrix is based on that used by the New York State Department of Health in 2006.[6] Recommended actions are given based on the measured values in indoor air and shallow soil gas. In this way, the matrix addresses both current conditions and future conditions (e.g., if the shallow soil gas concentrations are sufficiently high, action may be recommended even if the current indoor air quality is acceptable). Methane should be evaluated in terms of short-term, maximum effects rather than long-term, average conditions, as is done for VOCs. Therefore, averaging of methane soil gas concentrations is not recommended and Table 1 is based on maximum measured values within or very near the building footprint. Nonetheless, it should be recognized that VI of isolated pockets of methane will be mass-limited.

There are several assumptions inherent in Table 3. One, there is no soil gas methane concentration that is inherently dangerous. It is important to consider concentration, differential pressure, and the volume of methane present in the soil. Two, if methane levels indoors reach 1.25%, this requires immediate action, regardless of whether or not VI is contributing to the indoor air levels. This action level is 25% of the LEL for methane in indoor air and if this concentration is detected, it suggests that explosive conditions may exist somewhere in the building. Three, indoor methane values that equal or exceed 100 ppm are sufficiently above typical background levels that it suggests a methane source is present. In such cases, it is prudent to further investigate to determine whether methane readings anywhere in the building approach the LEL of 5%. In many cases, elevated indoor concentrations are found to be due to unlit pilot lights or other indoor sources.

The decision matrix for methane is intended for commercial/industrial buildings, which are assumed to be slab-on-grade construction and have some form of ventilation. The decision matrix is not applicable small, unventilated spaces in the subsurface, such as utility vaults, which are more prone to VI issues.

Summary

Vapor intrusion of methane requires a different conceptual model than VI for petroleum hydrocarbons and chlorinated solvents. At this time, there is very little guidance for methane at VI sites and what guidance does exist is of limited usefulness. Relevant information about the basic underlying concepts of methane fate and transport is briefly summarized here. A decision matrix is presented that can be used to "screen out" sites with minimal potential hazard. **em**

References

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