A Review of Soil Gas Migration in Natural Gas Incidents

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Introduction

In 1988, I participated in a soil gas migration study in Nevada. It was conducted by others, but a great deal of data was produced and analyzed.

The testing in Nevada in 1988 was specifically designed to test the theory that gas migrates through an annular space around the pipeline.

It was necessary in that case for gas to travel 700 feet along the outside of a pipeline in order for that theory to explain the explosion. It was found to be incorrect.
Introduction

Summary of the Nevada Test Results

– Minor concentrations of tracer gas were detected as far as 90 feet from the source.

– A positive gas flow rate through the soil was measured 70 feet from the source.

– Visual indications showed gas was pushed through asphalt as far as 20 feet radially from the source and could be seen pushing dust through the asphalt.
Introduction

Since I measured a small gas flow rate 70 feet from the source, I began testing whether gas explosions occur farther than a 50 foot radius from a leak.

I have found after reviewing numerous cases that gas explosions farther than 50 feet from a gas leak are very rare.

David Heldenbrand, PE CFI
Introduction

Why did I do this presentation?

NO meaningful studies regarding this subject have ever been conducted.

This presentation will:
• Examine the results of the Nevada soil gas migration testing program.
• Review a number of NTSB and state OPS reports.
• Summarize data from cases in which I have been personally involved over the past 30 years.
Outline of Presentation

- Does Gas from a Leak “Follow the Pipeline”?  
  - What Do Bar Hole Surveys Show?
- Does Natural Gas from a Leak Only Migrate Up?
- What Gas Flow Rate is Necessary to Cause an Explosion?
- How Does Soil Type Affect Soil Gas Migration?
- How Does Pipeline Pressure Affect the Migration of Natural Gas?
- How Does the Flow Rate of a Gas Leak Affect Natural Gas Migration?
- What Other Factors May Affect Soil Gas Migration Explosions?
- How Much Time Does it Take for Gas to Migrate and Cause an Explosion?
Outline of Presentation

• Summary
• Conclusions- Do All of These Cases Have Something in Common?
• What Does All This Mean?
• How, Then, Does a Soil Gas Migration Explosion Occur?
• How Do Sewer Lines or Other Utilities Affect Soil Gas Migration?
• Suggestions for Improvements in Future Investigations.
• Future possible applications for this information.
Does Gas from a Leak Follow the Pipeline?
Does Gas from a Leak Follow the Pipeline?

• The soil conditions at the Nevada site were dry, well graded sand and gravel, so it was a highly permeable soil.
• The backfill for the pipeline was the original soil.
• After three weeks of testing, no evidence was generated to conclude that gas followed the pipeline to cause this explosion.
• As I encountered other cases, I observed numerous different conditions that existed, but very few cases were found where the gas migrated significantly greater than 50 feet to cause an explosion.
• Let us examine some specific examples.
Does Gas Follow the Pipeline?

The two theories of whether gas “follows the pipeline” or not consist of either the *annular space theory* or that gas follows loose backfill material. I have found that most cases involve no loose or new or more porous backfill at all. We will discuss both.

David Heldenbrand, PE CFI
Theoretical “Annular Space” Caused by Temperature or Pressure Variations

- This is an Autocad drawing of a theoretical “annular space”. Take note that there are no dimensions.
- In addition, there are:
  - No photos of any annular space
  - No measurements of any annular space
  - No soil parameters for an annular space
  - No length parameters
  - No temperature variation parameters
  - No pressure variation parameters
  - No flow rate parameters
- In fact, no studies whatsoever verify that this theoretical “annular space” actually exists.

I contend that there is no annular space at all.
Does Gas from a Leak Follow the Pipeline?

Let’s examine the following cases:

• Ft. Worth, TX - October 4, 1971
• Odessa, WA - December 26, 2008
• Williamsport, PA - January 25, 1977
• Jackson, MS - December 24, 2008
• Rancho Cordova, CA - December 24, 2008
• Annandale, VA - March 24, 1972
• Bowie, MD - June 23, 1973
The gas service that fractured was to a residence on one side of the street but *the explosion took place at the residence closest to the leak.*

Interestingly enough, a second explosion occurred in N. Richland Hills, Texas (which is near Ft. Worth) on the same day. Heavy rains occurred in the area the day of both explosions.
Figure 1.—Plan of the accident site.
Does Gas from a Leak Follow the Pipeline?

- Odessa, WA- The structure was 60 feet from the leak, but there was **no gas service to the structure.** The initial OPS investigation concluded that natural gas was not the cause specifically because there was no gas service to the structure.

- Williamsport, PA- The structure was 70 feet from the leak. **No gas service to the structure.**

- Jackson, MS- Similar to the case in Ft. Worth, TX. A leak was found on one service line but the fire again occurred at the house closest to the leak. **Also, the fire was on the opposite end of the house from the gas meter.**
Does Gas from a Leak Follow the Pipeline?

- **Rancho Cordova, CA** - Gas service was on the other side of the house from the leak on the main.

- **Bowie, MD** - Gas migrated over **120 ft.** following the contour of the ground **not** the pipeline.

- **Annandale, VA** - Extremely loose fractured shale backfill existed in the new water and sewer line ditch. *This is the farthest recorded distance from a leak to an explosion*—240 feet.

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Does Gas from a Leak Follow the Pipeline?

Let’s examine the Annandale case.

• Backfill material in the water and sewer line trenches was fractured shale, so the soil had maximum permeability. The gas line ditch was a less permeable select fill material with six inches of soil and asphalt on top.
• No bar hole survey was reported.
• The three houses that burned were closest to the leak and the trenches.
• Gas was smelled in the house within 30 minutes of the fracture.
• The explosion occurred within 60 minutes of the contractor-induced fracture.
• NBS noted that tracer gas penetrated sealed basement block walls.
• Tracer gas arrived at the house farthest from the leak within 30 minutes.
• The NTSB concluded that the gas did not follow the gas line but followed the extremely loose backfill in the adjacent water line and sewer line ditches.
Does Gas from a Leak Follow the Pipeline?

Bowie, MD

The Bowie, MD case is interesting because the spread of the gas is both *uphill and downhill* in an elliptical shape. It is *not related* to the route of the pipelines.
Does Gas from a Leak Follow the Pipeline?

Summary

The annular space theory is that the pipeline swells and shrinks with temperature and/or pressure variations thus creating a void along the surface of the pipe for the gas to travel along.

There are no photographs, no measurements, no research papers, and no hard evidence of any “annular space”. So, contrary to common perceptions, there is, simply, no evidence that this “annular space” actually exists and there is no evidence that gas “follows the pipeline”.

David Heldenbrand, PE CFI
What do Bar-hole Surveys Show with Regard to Gas Following the Pipeline?

Bar hole surveys are extremely useful at locating the highest concentration of gas in an area and locating a leak in the pipeline. So, where does one typically conduct the survey?--- On top of the route of the pipeline, which tends to reinforce the theory that “gas follows the pipeline”.

Occasionally, however, the extent of the migration in all directions is documented.
What do Bar-hole Surveys Show with Regard to Gas Following the Pipeline?

We will examine several cases as follows:

• Portales, NM- May 23, 1982
• Queen Creek, AZ- Feb 2, 2004
• Crystal Springs, MS- February 4, 1986
• Bowie, MD- June 23, 1973

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Minimal explosion damage- Gas came through the pipe chase in the floor two weeks after the gas leak was stopped
The explosion at the Watkins Furniture Store was caused when a contractor, who was laying a water line, cut the PE gas line and repaired it himself with a PVC coupling. The line pulled out of the coupling several years later. The gas migrated about **50 feet perpendicular to the water and gas lines to cause the explosion**. The gas also migrated along the sandy backfill of the water line 400 feet *downhill* and 100 feet *uphill* in the ditch line. There was no gas service to the structure.

I conducted this soil gas survey myself.
What do Bar-hole Surveys Show with Regard to Gas Following the Pipeline?

Bowie, MD

In this case, the migration pattern of the gas is clearly not related to the gas line. Closer examination from Google maps shows that the ground surface slopes downward from the house that ignited. The gas leak was in the middle of the migration pattern, so some of the gas went uphill and some of the gas went downhill and at a 45 degree angle to the gas lines. Rains occurred prior to the explosion possibly pushing some of the gas farther than normal. Residual gas readings existed a year later.

David Heldenbrand, PE CFI
Bowie, MD again. Migration pattern is **172 feet uphill, 318 feet downhill and 145 feet across**. The house that exploded was 120 feet uphill and the closest house was 72 feet from the leak. The elliptical pattern is not related to the pipeline, but might be related to drainage pattern.

The house at 12404 was on 3-4 feet of fill dirt.

Interestingly, elevated soil gas readings were recorded a year after the explosion.
What do Bar-hole Surveys Show with Regard to Gas Following the Pipeline?

These four cases are representative of many bar-hole surveys that I have conducted and have reviewed by other investigators.

The bar-hole surveys show that the gas spreads out in all directions for the most part. Yes, some factors influence the pattern (Bowie, MD) but for most cases, the gas migration pattern is radial or elliptical. So, investigators cannot assume that the gas linearly “follows the pipeline” to cause a fire or explosion.

David Heldenbrand, PE CFI
Does Natural Gas from a Leak Only Migrate Up?
Does Natural Gas from a Leak Only Migrate Up?

The specific gravity of natural gas is about 0.60. Natural gas in open atmosphere is lighter than air and tends to float up.

But, we see numerous cases where natural gas is forced downward through the soil. This must be caused by gas pressure.
Does Natural Gas from a Leak Only Migrate Up?

What evidence is there on this subject?

- Sepulpa, Oklahoma - About 1987
- Saratoga Springs, Utah - 2/07/2007
- Holly Springs, Mississippi - 4/03/2008
- Jackson, Mississippi - 12/24/2008
- Queen Creek, Arizona - 2/2/2004
Does Natural Gas from a Leak Only Migrate Up?

I first had questions on this issue in a case in Sepulpa, Oklahoma. A building exploded after a plastic gas line had cracked. The gas line was removed about a month prior to my site investigation. Bar hole readings a month after the accident were high in a number of locations around the building. The gas line was only 3 feet deep and it had been dug up and removed, so it seemed very unlikely to me that all the residual gas would not have been dissipated a month after the explosion if gas only went upwards.

David Heldenbrand, PE CFI
Does Natural Gas from a Leak Only Migrate Up?

In another case in Saratoga Springs, Utah, a gas line was struck by a directional drilling crew about 40 feet from a home with poured concrete basement walls and a poured concrete floor slab.

A simulated leak with an air compressor showed flow into the basement all along an expansion joint seam at the bottom of the basement wall. That would be about 5 feet lower than the depth of the pipeline. This shows not only that gas can be pushed downward but gas pressure was forcing gas into the basement. The results were witnessed as far as 40 feet from the simulated leak immediately upon the startup of the pressure source.
Does Natural Gas from a Leak Only Migrate Up?

Holly Springs, Mississippi

A gas explosion occurred in Holly Springs, Mississippi where a cracked cast iron gas line leaked gas for an unknown period of time. Bar-hole surveys that I conducted several weeks later showed elevated LEL readings over an extensive area between the gas line and the home. There was no natural gas service line to the home, and the ground sloped significantly downward to a creek behind the home. The home had a basement constructed of concrete block walls. The leaking gas was forced over 40 feet laterally and 3 to 5 feet below the level of the pipeline. These results are similar to the previous case in Utah.

David Heldenbrand, PE CFI
Does Natural Gas from a Leak Only Migrate Up?

Another similar case occurred in Jackson, Mississippi on December 24, 2008.

A ¾-inch service line pulled out of a coupling to a house located uphill from the leak. If gas traveled uphill and followed the gas line, that would have been the house that would have burned.

Instead, the house downhill but, again, closer to the leak ignited. Also, the gas service line to this house was on the opposite end of the house from where the gas showed clear evidence of entering the house.
Does Natural Gas from a Leak Only Migrate Up?

Queen Creek, Arizona

On January 15, 2004, an odor complaint resulted in the location of a pipeline leak. The leak was repaired and vapor extraction techniques were begun immediately. Two weeks later, however, on February 4, 2004, a very small explosion occurred (as shown previously) in a kitchen island. Elevated bar-hole readings were found as far as 150 feet away. The gas company continued vapor extraction for six weeks prior to ordering an extensive geotechnical program to determine why standard vapor extraction techniques had not evacuated the remaining vapors.

David Heldenbrand, PE CFI
Minimal explosion damage- Gas came through the pipe chase in the floor two weeks after the gas leak stopped
Does Natural Gas from a Leak Only Migrate Up?

Queen Creek, Arizona

The pipeline was installed at a three foot depth and the numerous vapor extraction wells were drilled to 5-6 feet. The geotechnical firm drilled 23 borings in the area to design a solution. They determined detailed soil parameters and measured the LEL in the soil that was being extracted. **The results were remarkable.**

Six weeks after the leak had been stopped, **elevated LEL readings were being recorded at depths up to 35 feet.**

This is the only case I could find where an incident occurred **after** the leak had been repaired. In all other cases, **gas pressure** forced gas into the structure.

David Heldenbrand, PE CFI
A Flow Net Diagram of the Arizona Site
Does Natural Gas from a Leak Only Migrate Up?

The soil borings identified a less porous layer of soil in the top 5-6 feet, but greater porosity below that level. The geotechnical company concluded that the reason for the extent of migration and the depth of migration was the less permeable layer, but the less permeable layer was below the pipeline.

However, in the other cases that were examined, no soil borings were conducted AND the extent of lateral migration in those cases was similar.
Does Natural Gas from a Leak Only Migrate Up?

The data from the cases listed above is very clear that natural gas (even though it is lighter than air) can be forced by gas pressure to levels well below the elevation of the pipeline. Bar-hole testing only measures to a 3 foot depth, so it is misleading to assume that gas cannot be pressured downward. **We can conclude that gas pressure from a leak forces gas in a generally hemispherical pattern into the ground from the leak.**
What Gas Flow Rate is Necessary to Cause an Explosion?
What Flow Rate is Necessary to Cause an Explosion?

First, we need to establish a benchmark of gas flow rate into a structure to cause an explosion.

• Annandale, VA- NBS stated 720 CFH was needed to cause that explosion. This was calculated by using 10% of the volume of the home with an infiltration rate of one air change per hour.

• San Juan, Puerto Rico- NTSB recorded an in situ flow rate of 102 CFH adjacent to the structure that exploded.

• IAAI study-House Full of Gas- used over 100 CFH

This is just to have a comparative number, not to establish a minimum figure for an explosion.
What Flow Rate is Necessary to Cause an Explosion?

Infiltration rate in a structure is a very important factor to the determination of necessary gas flow rate into any structure. This subject matter is beyond the scope of this presentation. The above values are independent of any particular incident except Puerto Rico.
How Does Soil Type Affect Soil Gas Migration?
How Does Soil Type Affect Soil Gas Migration?

Soil type **must** be a factor as to how far gas would travel to cause an explosion, right?

**Soil porosity** is the percentage of pore space in soil. **Permeability is the ability of a fluid to move through soil.** More porous soils are usually more permeable if the pores are connected and allow flow through the soil.

Henry Darcy empirically derived a set of (basically) constant values to relate flow through various types of soils.
Permeability

Just as the porosity of a soil affects how much water it can hold, it also affects how quickly water can flow through the soil. The ability of water to flow through a soil is referred to as the soil's permeability. As you can probably guess, the permeability of gravel is higher than that of clay. But can you guess how much higher? Click the button below to see how long it might take water to travel 1 meter in different soil types...
How Does Soil Type Affect Soil Gas Migration?

From the information above, if gas migration was related to soil type and, thus, the permeability of the soil, there should be dramatic differences in the distance from a gas leak to an explosion and/or in the frequency of incidents in clay soil compared to other soils.

What I have found is that standard permeability equations are not applicable to soil gas migration explosions. The following information will explain.
# Chart of Darcy Constant for Various Soil Types

*(From Zimmerman)*

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>( k ) (Darcies)</th>
<th>( k ) (m(^2))</th>
</tr>
</thead>
<tbody>
<tr>
<td>coarse gravel</td>
<td>(10^3 - 10^4)</td>
<td>(10^{-9} - 10^{-8})</td>
</tr>
<tr>
<td>sands, gravels</td>
<td>(10^0 - 10^3)</td>
<td>(10^{-12} - 10^{-9})</td>
</tr>
<tr>
<td>fine sand, silt</td>
<td>(10^{-4} - 10^0)</td>
<td>(10^{-16} - 10^{-12})</td>
</tr>
<tr>
<td>clay, shales</td>
<td>(10^{-9} - 10^{-6})</td>
<td>(10^{-21} - 10^{-18})</td>
</tr>
<tr>
<td>limestones</td>
<td>(10^0 - 10^2)</td>
<td>(10^{-12} - 10^{-10})</td>
</tr>
<tr>
<td>sandstones</td>
<td>(10^{-5} - 10^1)</td>
<td>(10^{-17} - 10^{-11})</td>
</tr>
<tr>
<td>weathered chalk</td>
<td>(10^0 - 10^2)</td>
<td>(10^{-12} - 10^{-10})</td>
</tr>
<tr>
<td>unweathered chalk</td>
<td>(10^{-9} - 10^{-1})</td>
<td>(10^{-21} - 10^{-13})</td>
</tr>
<tr>
<td>granite, gneiss</td>
<td>(10^{-8} - 10^{-4})</td>
<td>(10^{-20} - 10^{-16})</td>
</tr>
</tbody>
</table>
If a 100 cfh flow rate can cause an explosion, how many square feet would be required to supply that flow rate?

Flow Rate Through Soils Using Darcy's Formula
Length = 50 ft.

\[ q_{sc} = 0.003164 \frac{kAT_{sc}(P_1^2 - P_2^2)}{P_{sc}T(\mu z)_iL} \]

Conditions:
- Z - compressibility factor = 1
- T - Temperature is constant = 0
- Length [ft] = 50
- \( P_z \) [psi] = 14.696
- \( \mu \) [cp] = 0.012

David Heldenbrand, PE CFI
How many square feet would be required to cause an explosion at 50 feet and 50 psi?

<table>
<thead>
<tr>
<th>Soil</th>
<th>Permeability (mD)</th>
<th>Area (sq.ft.)</th>
<th>Inlet Pressure (psia)</th>
<th>Flow Rate (SCFH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse Gravel Max</td>
<td>1.E+07</td>
<td>0.000168492</td>
<td>64.70</td>
<td>100.00</td>
</tr>
<tr>
<td>Coarse Gravel Min</td>
<td>1.E+06</td>
<td>0.00168492</td>
<td>64.70</td>
<td>100.00</td>
</tr>
<tr>
<td>Sands, Gravels</td>
<td>1.E+06</td>
<td>0.00168492</td>
<td>64.70</td>
<td>100.00</td>
</tr>
<tr>
<td>Fine Sand, Silt</td>
<td>1.E+03</td>
<td>1.68491662</td>
<td>64.70</td>
<td>100.00</td>
</tr>
<tr>
<td>Sands, Gravels</td>
<td>1.E+03</td>
<td>1.68491662</td>
<td>64.70</td>
<td>100.00</td>
</tr>
<tr>
<td>Fine Sand, Silt</td>
<td>1.E-01</td>
<td>16,849.17</td>
<td>64.70</td>
<td>100.00</td>
</tr>
<tr>
<td>Clay, Shales Max</td>
<td>1.E-03</td>
<td>1,684,916.62</td>
<td>64.70</td>
<td>100.00</td>
</tr>
<tr>
<td>Clay, Shales Min</td>
<td>1.E-06</td>
<td>1,684,916,617.88</td>
<td>64.70</td>
<td>100.00</td>
</tr>
</tbody>
</table>
How many square feet would be required to cause an explosion at 50 feet and 0.5 psi?

<table>
<thead>
<tr>
<th>Soil</th>
<th>Permeability (mD)</th>
<th>Area (sq.ft.)</th>
<th>Inlet Pressure (psia)</th>
<th>Flow Rate (SCFH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse Gravel Max</td>
<td>1.E+07</td>
<td>0.04475074</td>
<td>15.20</td>
<td>100.00</td>
</tr>
<tr>
<td>Coarse Gravel Min</td>
<td>1.E+06</td>
<td>0.44750736</td>
<td>15.20</td>
<td>100.00</td>
</tr>
<tr>
<td>Sands, Gravels</td>
<td>1.E+06</td>
<td>0.44750736</td>
<td>15.20</td>
<td>100.00</td>
</tr>
<tr>
<td>Fine Sand, Silt</td>
<td>1.E+03</td>
<td>447.50736025</td>
<td>15.20</td>
<td>100.00</td>
</tr>
<tr>
<td>Sands, Gravels</td>
<td>1.E+03</td>
<td>447.50736025</td>
<td>15.20</td>
<td>100.00</td>
</tr>
<tr>
<td>Fine Sand, Silt</td>
<td>1.E-01</td>
<td>4,475,073.60</td>
<td>15.20</td>
<td>100.00</td>
</tr>
<tr>
<td>Clay, Shales Max</td>
<td>1.E-03</td>
<td>447,507,360.25</td>
<td>15.20</td>
<td>100.00</td>
</tr>
<tr>
<td>Clay, Shales Min</td>
<td>1.E-06</td>
<td>447,507,360,251.65</td>
<td>15.20</td>
<td>100.00</td>
</tr>
</tbody>
</table>

David Heldenbrand, PE CFI
How Does Soil Type Affect Soil Gas Migration?

So, the permeability factor between gravel and clay is a billion, but neither the frequency of incidents nor the distance that the gas migrates appears to have any significant relationship to the permeability of the soil.
# How Does Soil Type Affect Soil Gas Migration?

## Let's Summarize

<table>
<thead>
<tr>
<th>Location</th>
<th>Soil Type</th>
<th>Distance to Explosion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Queen Creek, AZ</td>
<td>Clayey sand and sandy silt</td>
<td>50 feet</td>
</tr>
<tr>
<td>Jackson, MS</td>
<td>Dense wet clay</td>
<td>70 feet</td>
</tr>
<tr>
<td>Odessa, WA</td>
<td>Rock and volcanic ash</td>
<td>60 feet</td>
</tr>
<tr>
<td>Saratoga Springs, UT</td>
<td>Frozen silty clay</td>
<td>40 feet</td>
</tr>
<tr>
<td>Ft. Worth, TX</td>
<td>Dense clay</td>
<td>40 feet</td>
</tr>
<tr>
<td>Rancho Cordova, CA</td>
<td>Silty clay loam</td>
<td>50 feet</td>
</tr>
<tr>
<td>Union, NJ</td>
<td>Gravely sandy loam</td>
<td>50 feet</td>
</tr>
<tr>
<td>Bowie, MD</td>
<td>Not known</td>
<td>120 feet</td>
</tr>
</tbody>
</table>

David Heldenbrand, PE CFI
Intermission
How Does Pipeline Pressure Affect the Migration of Natural Gas?
How Does Pipeline Pressure Affect the Migration of Natural Gas?

Pressure in the gas pipeline

The pressure range in this study was gas distribution line pressure of below 60 psi. Some lines operate at a pressure as low as 0.25 psi.

An incident occurred in Wilmington, DE on July 2, 2003 where a gas line at 0.25 psi was snagged by a contractor and created a line separation directly inside the adjacent building. So, with no soil gas migration involved, an explosion occurred within 15 minutes.
How Does Pipeline Pressure Affect the Migration of Natural Gas?

Another incident at 0.25 psi occurred in San Juan, Puerto Rico on November 21, 1996. The gas was a propane/air mixture in this case. A crack leaking at an *in situ* flow rate of 102 CFH migrated into a structure 15 feet away and caused an explosion in which 33 people died.

If gas is forced through the ground under pressure, then the specific gravity of the gas would have little to do with whether it travels up or down.
How Does Pipeline Pressure Affect the Migration of Natural Gas?

In Philadelphia, PA on May 11, 1979, a cast iron gas line operating at 0.25 psi cracked and caused a gas leak. About 30 minutes later, an explosion occurred 20-30 feet from the gas leak. The distances were not recorded but were scaled from aerial photographs.
How Does Pipeline Pressure Affect the Migration of Natural Gas?

A review of pipeline pressures between 0.25-60 psi as they relate to soil gas migration reveals **no relationship between pipeline pressure and the distance gas migrates to cause an explosion**.

The following list from NTSB reports shows pipeline pressure and distance from the leak to the structure that exploded.
How Does Pipeline Pressure Affect the Migration of Natural Gas?

<table>
<thead>
<tr>
<th>Location</th>
<th>Date</th>
<th>Pressure</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Philadelphia, PA</td>
<td>5/11/1979</td>
<td>0.25 psi</td>
<td>20-30 feet</td>
</tr>
<tr>
<td>Williamsport, PA</td>
<td>1/25/1977</td>
<td>10 psi</td>
<td>70 feet</td>
</tr>
<tr>
<td>Bowie, MD</td>
<td>6/23/1973</td>
<td>20 psi</td>
<td>120 feet</td>
</tr>
<tr>
<td>Annandale, VA</td>
<td>3/24/1972</td>
<td>22 psi</td>
<td>240 feet</td>
</tr>
<tr>
<td>Jackson, MS</td>
<td>12/24/2008</td>
<td>45 psi</td>
<td>70 feet</td>
</tr>
<tr>
<td>Rancho Cordova, CA</td>
<td>12/24/2008</td>
<td>55 psi</td>
<td>45 feet</td>
</tr>
<tr>
<td>Portales, NM</td>
<td>5/23/1982</td>
<td>25 psi</td>
<td>60 feet</td>
</tr>
<tr>
<td>Odessa, WA</td>
<td>12/26/2008</td>
<td>30 psi</td>
<td>60 feet</td>
</tr>
</tbody>
</table>

David Heldenbrand, PE CFI
How Does Pipeline Pressure Affect the Migration of Natural Gas?

So, as we examine the data above, the pipeline pressure is not a primary factor in the distance that gas could flow to cause an explosion.

We have looked at soil type which should be a major determinant as to the distance gas migrates to an explosion, and pipeline pressure which should be the second most important factor. But, as was the case with soil type, there is no apparent relationship between pipeline pressure and distance to an explosion.
What Other Factors May Affect Soil Gas Migration Explosions?

David Heldenbrand, PE CFI
What Other Factors May Affect Soil Gas Migration Explosions?

If the soil type does not have a profound impact on gas migration distance and frequency, what about other factors such as:

• Asphalt- No evidence in the Portales case.
• Frozen ground- No evidence in the Utah case
• Rainfall- No evidence that the gas travels any farther
Does Asphalt, Frozen Ground or Rainfall Cause Extended Soil Gas Migration?

In any particular situation where asphalt, frozen ground or rainfall has occurred before an explosion, none have caused the gas to spread noticeably farther than in cases where there was no rain or frozen soil.

In the cases where the gas was found farthest from the leak, there was no frozen ground. (Annandale, Bowie and Portales). In cases where there was rainfall before the explosion, the distance the gas traveled was, again, not exceptional.
How Does the Leak Flow Rate Affect Natural Gas Soil Gas Migration?
How Does Flow Rate of the Gas Affect Natural Gas Soil Gas Migration?

The biggest problem with evaluating this factor is lack of data. Immediately after a gas explosion, the gas line is repaired. To measure gas flow in situ, one would need to cut the line some distance away and measure the in situ flow rate. That would require a severe disruption of service to other customers at a minimum. It is also extremely impractical and possibly unsafe.

The case in San Juan, Puerto Rico provided in situ migration and explosion data of 105 cfh.

A case in Sublett, KS showed an in situ flow rate of 3200 cfh at 9 psi where the distance to the explosion was about 20 feet. Pipeline pressure was 30 psi, so full pipeline pressure and, thus, full flow rate were not measured.

The flow rate of the leak prior to the explosion could vary even if no changes were made. At the testing in Nevada, high flow rates into the soil were constant, but flow rates at any particular test location varied.

David Heldenbrand, PE CFI
How Does Flow Rate of the Gas Affect Natural Gas Soil Gas Migration?

The testing in Nevada provided the only available data on this subject. On all gas leak situations, there is only one flow rate, so we cannot typically test the affects of different flow rates on soil gas migration at actual incident sites even if we measured in situ flow rates.

Let’s start with the testing setup used in order to properly examine the data received from Nevada.
How Does Flow Rate of the Gas Affect Natural Gas Soil Gas Migration?

Note: Readings were recorded every 20 ft. after the closest test port at 8 ft.
How Does Flow Rate of the Gas Affect Natural Gas Soil Gas Migration?

Tracer Gas Test #1
15 psi at 300 CFH

David Heldenbrand, PE CFI
Tracer Gas Test #2
57 psi at 780 CFH

Tracer Gas Test #3
60 psi at 4500 CFH
So, as the flow rate increased from 2400 CFH to up to 11,400 CFH, the distance that air flow was detected reached a maximum of 68 feet. As flow rate increased to 19,200 CFH, however, the flow out of the other ports along the pipeline stopped and, then, all the air flowed out of a large ground fracture about 9 feet perpendicular to the pipeline. This is the only test of which I am aware where actual testing occurred to attempt to document gas flow along an “annular space”. While a tracer gas was detected 88 feet from the source and gas flow was recorded as far as 68 feet from the source, neither indicate that a higher than expected flow rate of gas existed along the annular space of the pipeline.

David Heldenbrand, PE CFI
How Does Flow Rate of the Gas Affect Natural Gas Soil Gas Migration?

Summarizing some of the results, the following conclusions can be reached:

A very small percentage of the total flow was ever recovered from the theoretical “annular space”.

An input flow rate 40 times greater than when initiated still produced a very small percentage of the total flow. Much less than 1% of the injected gas flow rate was ever recovered from the pipeline annulus and never farther than 68 feet regardless of the injection flow rate.
How Does Flow Rate of the Gas Affect Natural Gas Soil Gas Migration?

As the flow rate into the injection point increased over the three week period from 300 CFH to as much as 19,200 CFH, the flow rate out of the test points increased marginally to a distance of up to 68 feet. However, as the flow rate increased to close to 19,200 CFH, the distance the flow was detected collapsed to a point to where all the air injected was emitted from an area about 9 feet of the injection point.

As I reviewed all the data, I saw clear evidence of the ground fracturing and, as time and/or the flow rate increased, the fracturing increased closer to the injection point.

David Heldenbrand, PE CFI
How Does Flow Rate of the Gas Affect Natural Gas Soil Gas Migration?

So, as the flow rate (of a leak) increased, neither the flow rate out of the test points nor the concentration of the tracer gas showed evidence of gas following the pipeline or any pattern other than the gas is simply pressured through the soil in a spherical pattern. The gas pressure drops off rapidly as the distance from the injection point increases, but some pressure does exist in the soil for at least 68 feet from the injection point possibly as much as 150 feet, but it appears that insufficient pressure exists past about 50 feet from a leak to cause an explosion.

David Heldenbrand, PE CFI
How Long Does it Take for Gas to Migrate to Cause an Explosion?
How Long Does it Take for Gas to Migrate to Cause an Explosion?

It must take a long time for gas to “migrate” through the soil to cause an explosion, shouldn’t it? The gas has to be forced slowly through the tight soil, so it has to take a long time, right?

Let’s look at some cases where we do know the time factor.

- Annandale, VA - 240 feet in 30 minutes at 22 psi
- Philadelphia, PA - 30 feet in 15 minutes at 0.25 psi
- Chicago Heights, IL - 40 feet in 30 minutes at 28 psi
How Long Does it Take for Gas to Migrate to Cause an Explosion?

So, in cases where we know when the leak started because a contractor hit the line, the time from the initiation of the leak to the time of the explosion can be remarkably short.
Summary

• Gas from a leak can travel **40-50 feet** to cause an explosion in a broad range of conditions.
• Gas is forced by pressure downward as far a **35 feet**.
• The distance gas flows cannot be closely related to soil type.
• The distance from a leak to an explosion is **not proportional** to pipeline pressure.
• Gas has been recorded to migrate **50 feet in 30 minutes** to cause an explosion.
• This data shows that none of these conditions are particularly unusual in a broad range of known or unknown conditions.
• So, how do we explain these facts that all seem so unusual?
What Might These Cases Have in Common?

During the testing program in Nevada in 1988, several interesting facts became apparent:

1. **Gas flow** out of the ground was measured as far as 68 feet from the injection point.

2. Flow into the ground was 11,400 CFH but the flow out at one location was only 0.34 CFH, so only 0.003% went along the pipeline and 99.997% migrated somewhere other than along the pipeline.

3. The flow rate out of the ground changed over time at any one location.
What Might These Cases Have in Common?

4. When the testing program was completed, and the injection point dug up, a large void had been created all around the injection orifice.

5. The soil that was displaced from around the injection point must have been transported somewhere. Where did it go?

6. The gas must have opened up fractures in the soil and some of the dust had been forced down the widened channels. This physically displaced the soil particles that were originally around the injection orifice.

7. If the gas pressure or flow separates soil particles and allows gas flow through these microchannels, then gas pressure can extend much farther from the leak than if fracturing did not occur.
What Does This All Mean?

If the gas from a gas leak radiates from the leak in a spherical pattern and the leak rate is fixed, there is only a limited distance that the gas is concentrated enough or under enough pressure to cause an explosion.

So, from existing data, gas explosions within 50 feet of a leak are very common. Numerous flow paths could explain explosions within this distance.

There are quite a number of factors that affect that distance, but the research here has revealed that natural gas explosions at a distance of over 100 feet are extremely rare and few explosions have occurred at a distance over 50 feet.

The data from the testing in Nevada is consistent with the observed data collected from NTSB reports.
What Does This All Mean?

The soil fracturing that was repeatedly observed and confirmed in the testing in Nevada does, in my opinion, apply to all gas migration explosions. Previous theories that the gas migrated “so far” because of special conditions are unnecessary. A 50 foot migration distance to an explosion is “not excessive” or “unusual”.

There is no documented case where the gas followed the pipeline itself any farther than would normally be expected from microchannels created spherically in the soil caused by gas pressure and gas flow. Bar hole surveys do not show a linear path.

David Heldenbrand, PE CFI
What Does This All Mean?

Since the gas is forced through the soil by pressure, “caps” such as snow or rain or ice are extremely ineffective. Additionally, there was no documented case where any of these “caps” extended the gas migration farther than would normally be expected anyway.
How Does an Explosion Occur?

If the gas from a leak spreads out so uniformly, how does an explosion take place?

If the gas does not follow the gas line or get trapped by ice or asphalt, and migrates uphill and downhill, **how is there enough gas concentration and flow to overcome room infiltration to cause a house explosion?**

Maybe the following diagrams will help envision how this may occur.
Top of Soil

Darcy Flow
300 cfh
Lost to
Other Fractures

100 cfh

25 cfh 25 cfh 25 cfh 25 cfh
How Does an Explosion Occur?

So, after 26 years of review and analysis and comparing numerous factors, and examining actual data from personal testing and other sources, I have concluded that house explosions caused by gas migration occur as a result of gas being forced under pressure to form fissures in the soil. This condition allows gas to migrate much farther than “expected”. The marginal gas pressure remaining at 50-100 feet, for example, is very small (hundredths or tenths of an inch of water column, possibly) but is enough to force the gas through pipe chases, seams or other voids that exist in all structures at a sufficient cumulative flow rate to cause an explosion or fire.

David Heldenbrand, PE CFI
How Do Sewer Lines Affect Gas Migration Explosions?

Gas following sewer lines or flowing within sewer lines are a common conclusion regarding gas migration explosions.

Let’s examine the mechanics of that theory.
How Do Sewer Lines Affect Gas Migration Explosions?

The theory that gas enters the sewer line depends on the theory that gas follows the gas pipeline first, then transfers to the sewer line.

So, if the gas does not follow the gas pipeline, then there cannot be enough gas flow to enter the sewer line.

Let’s look at some graphics to demonstrate this point.
How Do Sewer Lines Affect Gas Migration Explosions?

Hole in Sewer Line

Leak in Gas Line

David Heldenbrand, PE CFI
How Do Sewer Lines Affect Gas Migration Explosions?

So, as the gas spreads out from the leak, the pressure decreases rapidly from the leak source, but low pressure extends long distances. The Pepcon testing clearly shows this fact.

So, unless the sewer line is within a foot or two of the gas leak itself, there is very little pressure or flow to drive enough gas into a vented sewer line to cause an explosion.

Bar hole tests confirm that there is very little pressure in the soil even short distances from the leak. If this were not the case, gas would be blowing out of bar holes relatively close to the leak.
Suggestions for Future Investigations

The testing that was done in 1988 raised many questions that have been very difficult to address since that time.

Assembling this basic information has been extremely laborious. It should not be that way. To refine or even refute my conclusions, basic data should be routinely acquired.

- Pipeline pressure
- Distance from the leak to the structure
- Closest structure
- Pipeline route

David Heldenbrand, PE CFI
Suggestions for Future Investigations

• Soil conditions (even approximate would help)
• Uphill or downhill from the pipeline to the site
• Special conditions- other utility routes
• In situ flow rate (very difficult to obtain)
• Path of entry into home-Even if it cannot be determined, state it on a form. Sometimes the entry path is very clear and that would be helpful.
• Assuming that the gas “followed a pipeline” can be very misleading and the above information leads me to conclude that it is, simply, erroneous.

David Heldenbrand, PE CFI
Suggestions for Future Investigations

• Possibly, in the future with better data, this can all be refined and/or corrected. However, if we keep perpetuating the same misinformation, we will never be able to improve our investigations. That is what I hope to correct in the future.

David Heldenbrand, PE CFI
Practical Applications for First Responders

• This study has shown that a majority of explosions occur within a 50 foot radius of an underground gas leak. With that in mind, possibly safer ways to investigate gas leaks can be developed.

• For example,
  – If the leak location is known (contractor hit), then evacuate within a 50 foot radius. If that is done, the chances of injuries from an explosion would be significantly reduced.
  – If the leak location is not known, park emergency vehicles at least 100 feet from the reported leak. This will reduce ignition sources until better information can be obtained.
Practical Applications for First Responders

– If sewer manhole covers are readily accessible, check the sewer for gas with the CGI to make a quick and easy assessment of any spread of an underground gas leak in the area by this means. If there is gas in the sewer line, a much broader approach to the incident is needed.

– Focus on protecting people and equipment within a 50 foot radius first.
Practical Applications of First Responders

• The data shows that the vast majority of gas fires and explosions occur within 50 feet of the leak, so that is the danger zone. Gas farther than 50 feet from the leak is usually too diluted to ignite. Both of these statements are generalities. Exceptions are certainly possible. If critical choices need to be made, concentrate on a 50 foot radius, first.

• If the leak location is not known, a 100 foot radius from the caller would be prudent.
Practical Applications for First Responders

Unknown Leak Location from Call In
Risk Assessment

• The data shows that a large percentage of incidents occur within 50 feet of a leak.
• So, structures farther than 50 feet from a pipeline would be much less likely to be affected by a gas leak than structures within a 50 foot radius of a pipeline.
• If a gas line is on one side of the street, the houses on the other side (more than 50 feet away) are much less likely to be affected by a gas leak.
Soil Scrub of Odorant

• This review has shown that it is very likely that gas travels very fast from gas pipelines to cause an explosion.
• Odorant scrub is caused by the adsorption of odorant molecules onto the surface area of dry soil particles.
• Odorant scrub is, therefore, extremely “surface area” dependent.
• This theoretical mechanism for soil scrub is, then, vastly reduced if the soil fractures to form numerous channels (little interstitial migration as is commonly assumed). Indeed, people smell gas from an underground gas leak frequently. This is, at least, anecdotal evidence that soil scrub of odorants is very inefficient in a gas explosion scenario. Simply accepting the premise that odorant is scrubbed from the gas may not be a correct assumption.

David Heldenbrand, PE CFI
Soil Scrub of Odorants

David Heldenbrand, PE CFI
Evacuation of Residual Gas in the Ground

• After review of numerous incidents and the testing that has been done, it is my opinion that **forcing fresh air into the ground** from the leak point may be much faster and more effective that trying to pull it out at several locations.

• Gas migration testing in Nevada clearly showed the **fracturing of the soil**.

• Evacuation techniques at Queen Creek were very ineffective until the wells were drilled to 35 feet.

• Using existing channels would be the fastest way to dilute the gas in the ground. Maybe to less than an hour.

David Heldenbrand, PE CFI
Evacuation of Residual Gas in the Ground

• Bar holing out to 0% gas may not be necessary particularly in the early stages of an incident.
• Foundation surveys every 5 feet past a 50 foot radius from the leak may serve very little practical purpose.
• Once the gas leak is stopped, gas presence in the soil past the 50 foot radius presents little, if any, danger.
• Data has shown that gas pressure from a leak forces gas through the soil very rapidly. Use the channels formed by pressure and flow to push out the residual gas quickly. Evacuating gas from the ground collapses these channels and makes remediation very time consuming.

David Heldenbrand, PE CFI
Evacuation of Residual Gas in the Ground

• Pushing air through channels previously filled with gas will only dilute the gas and dilute it quickly. It should not spread combustible concentrations any farther than they already exist.
Thank You

Thank you for your time and attention. There has been a great deal of information and extremely varied concepts have been presented. Hopefully, I have simplified them and categorized them in a relatively concise and understandable manner. If you have any questions or comments, please feel free to contact me at any time.

David Heldenbrand, PE CFI
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