Stray Gas in Water Well Systems

Water Well Construction and Service Practices for the Safety of the Contractor, the Property Owner, and Others
Presentation Overview

I. Health and Safety Effects from Gases
II. Geologic Settings and Gases
III. Well Location and Construction Methodologies to Mitigate Gases
IV. Well Operations and Gases
V. After-Drilling Operations
VI. Groundwater Analyses and Treatment Methodologies
Reduce and Mitigate Problematic Concentrations of Stray Gases in Water Well Systems

Introduction

As a benefit to members of the National Ground Water Association, this document provides the water well system professional (WWSP) with basic knowledge for gases that may be encountered during well drilling/construction and suggested practices to reduce and mitigate elevated stray (or fugitive) gas levels. Because of varying geologic conditions and other factors, it is not practical to develop a totally prescriptive guideline.

Subsurface gases may occur dissolved in groundwater or as a gas in the head space of a water supply. Sometimes the concentrations of select gases will prove to be unacceptably high even after careful site selection and well construction, or after cleaning an existing well. The WWSP can recommend cost-effective options to mitigate such problems. For instance, it may be less expensive for the consumer to install an appropriate watertight vented well cap to lower concentrations of a gas than to replace or deepen an existing well or to use a more expensive drilling technology to replace a new well. Such decisions are site-specific and, thus, based on careful analysis by the WWSP.

For the purposes of the best suggested practices document it is not essential for the WWSP to understand groundwater chemistry or how stray gases form, although there are extensive studies and related publications that document these processes. However, the WWSP will benefit from knowing the geologic settings, as well as the human-related activities that may contribute to gas presence in water well systems.

- Section 1 offers background on the health and safety issues related to stray gases commonly encountered by water well system professionals.
- Section 2 is guidance about how geologic conditions and land-use settings may affect the concentrations of gases in groundwater.
- Section 3 provides a description of well location and construction methodologies to minimize the buildup of gases.
- Section 4 examines well function and stray gases.
- Section 5 deals with post-drilling operations.
- Section 6 describes groundwater sampling methods and treatment options.
What is the National Ground Water Association?

• Largest membership organization of groundwater professionals
• U.S. and international membership
• Dedicated to advancing groundwater knowledge
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• Products depicted in this presentation are for illustrative purposes and do not constitute an endorsement by the National Ground Water Association of that particular design, configuration, or producer
Stray gas, water wells, and Hollywood

• Private Investigator Jake Gittes in the motion picture, *The Two Jakes*

• Here’s a scene...

Video clip for educational purposes only. *The Two Jakes* is copyrighted by Paramount Pictures, 1990.
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What gases?

- Carbon dioxide
- Carbon monoxide
- Dissolved oxygen
- Hydrogen sulfide
  - Sulfur-reducing bacteria
- Methane
- Radon
- Sulfur dioxide
I. Health and Safety Effects from Gases

• No one should ever enter a confined space to aid an unconscious worker without proper air sampling and safety equipment.
Carbon dioxide ($\text{CO}_2$)

- Odorless and heavier than air
- Can be present in groundwater where calcium and bicarbonate ions are in solution
- Fortunately, carbon dioxide is almost never in high enough concentrations in groundwater to be noticed
- Although in high enough concentrations it can be a deadly health threat, it is not toxic or explosive.
  - Symptoms: headache, dizziness or unconsciousness or asphyxiation
Carbon monoxide (CO)

- Carbon monoxide cannot be detected by sight, odor, or taste
- Exposed humans will likely display symptoms such as headache, dizziness, nausea, “cherry-red” flushed face, and unconsciousness
Dissolved oxygen

- There is no direct human risk from dissolved oxygen
Hydrogen sulfide (H$_2$S)

• Uncontained gas can be freely released and spread rapidly
• Highly toxic and flammable
  – Has no lasting odor in very high concentrations due to olfactory fatigue
  – As little as a 30-second exposure to concentrations as low as 1,000 ppm can kill humans
Hydrogen sulfide (H$_2$S)

- Will arrest respiration completely and makes rapid artificial respiration necessary for life
  - Slower poisoning will cause nausea, stomach distress, belching, coughing, headaches, dizziness, eye irritation, and blistering of lips.
  
  The gas is heavier than air and burns with a blue flame, producing sulfur dioxide. It forms an explosive mixture with air from 5.9 to 77.2 percent by volume
Hydrogen sulfide (H\textsubscript{2}S)

- Drilling crew members should be informed of characteristics, dangers, safety procedures, and first-aid procedures.
- Personnel should work in pairs; more personnel may be necessary for a job site of this nature.
- Adequate ventilation should be maintained upwind including the use of an approved fan and exhaust system.
Hydrogen sulfide ($\text{H}_2\text{S}$)

- Personnel should always wear the proper respiratory protection, self-contained or supplied air breathing apparatus, and a lifeline when working in a suspected atmosphere.
- They must be instructed in the use of personal protective equipment. Testing equipment should be available and used before entering any area where doubt exists as to the presence of hydrogen sulfide gas.
Hydrogen sulfide (H$_2$S)

- Tests should be made for presence and concentration. Unless tests indicate it is safe to do so, no one should enter any area suspected of containing hydrogen sulfide gas unless he is equipped with suitable approved respiratory equipment and a safety belt and lifeline.
- Situate the drilling rig so prevailing winds blow from the rig.
Methane

• Methane is not a health problem; but a safety problem because it is explosive and flammable
• Water well system professionals have reported employees being burned or having equipment damaged
  – Methane gas venting from the well ignited as they uncapped a well, or were doing work that created a spark in the well or at the wellhead
Methane

- The human symptoms of excessive methane exposure can include headache, dizziness, nausea, or unconsciousness
- Methane detection meters should be on the job site at all times
- Workers entering a well pit must be equipped with self-contained air packs and clothed with static-free garments
Sulfate-reducing bacteria

• Although their stain creating characteristics are annoying, sulfate-reducing bacteria are not a direct human health risk
Sulfur dioxide

• Sulfur dioxide mists and vapors cause irritation of the respiratory tract, as well as potentially systemic acidosis or pulmonary edema at moderate concentrations
Sulfur dioxide

• Can be corrosive to the mouth, throat, and esophagus, with immediate pain and burning
• Uncontrolled vomiting may occur
• Skin contact will produce
  • Redness, pain, and severe burn
• Splashing into the eye by sulfur dioxide can cause blurred vision, redness, pain, and severe tissue burns
II. Geologic Settings and Gases

• Knowledge of local hydrogeologic conditions and where gases have been encountered in water well construction may be applied to attempt to avoid new instances of gas intrusion.
III. Well Location and Construction: Mitigating Gases

• Generally, well design cannot mitigate the risks from gases unless the gas formation is cased off and water obtained from another aquifer
IV. Well Operations and Gases

- Explosive gases will concentrate in confined spaces until such density that there is the risk of ignition.
Well Operations and Gases

• When gas is present in water well
  – Immediately notify the property owner
  – Allow the well to vent to the atmosphere
    – not to an enclosed space
• Normally, a wellhead is outside and a typical vent will be adequate
• If wellhead is inside an enclosure or a well house, then the wellhead must be vented to the outside and above the eave height of the well house
Vented well cap image courtesy of Baker Monitor Manufacturing
Pump Cavitation

• Gases can adhere to the impellers of a submerged well pump. When the gas bubble collapses it can damage the pump’s impellers, leading to premature pump failure

• Adhered gas will block water movement, reducing the volume of water pumped from the well system
Pump Cavitation

• When the pump and its impellers are at rest, gas will migrate off the impeller and float up and out of the groundwater.

• Placing the well system’s check valve one pipe joint above the submersible pump head can help to mitigate this condition.
  – Shroud is not as effective as setting the pump at a deeper depth within the well.
Well Operations and Gases

• **Carbon Dioxide (CO₂)**
  
  • Under ambient pressure conditions, the amount of carbon dioxide in solution remains constant
  
    – Pressure near a well is reduced by pumping and carbon dioxide then comes out of solution as bubbles of gas
Well Operations and Gases

- **Carbon Dioxide (CO$_2$)**

  - Calcium carbonate may precipitate from carbon dioxide presence when the chemical equilibrium of the groundwater is disturbed.

  - To minimize calcium carbonate deposition when a well is pumped, head losses must be kept as low as possible.

  - Low entrance velocities through well intakes of maximum inlet area will help keep head losses low.
Well Operations and Gases

• Carbon Monoxide (CO)
  – Carbon monoxide is highly toxic and explosive if ignited. Although commonly related to the exhaust from internal combustion engines, carbon monoxide also sometimes forms by the slow oxidation of organic material such as peat, lignite, or coal
  – Due to the risk of carbon monoxide poisoning gasoline-powered engines near wellheads should be well ventilated and kept distant from humans and animals
Well Operations and Gases

• **Dissolved Oxygen**
  
  – Although dissolved oxygen may be found in shallow wells in unconfined aquifers, dissolved oxygen is almost never in high enough concentrations in groundwater to be noticed. High concentrations of dissolved oxygen are usually near zero in aquifers found at depths greater than 150 feet.
Well Operations and Gases

**Dissolved Oxygen**

- Dissolved oxygen equal to or greater than two mg/L will be corrosive.
- Dissolved oxygen may cause water to attack galvanized iron and some brass, while iron oxide scale may accumulate on the inner surfaces of iron pipes when iron is put into solution by low pH water combined with dissolved oxygen.
- Iron oxide scale will reduce the water carrying capacity of pipe.
Well Operations and Gases

• **Dissolved Oxygen**
  – Water in a pressure tank may contain far more than 10 mg/L of oxygen, for instance
  – When corrosion occurs in water-distribution or pumping equipment, the water supply may have an undesirable taste or odor and red water may be common
Well Operations and Gases

• **Hydrogen Sulfide (H₂S)**
  – Humans almost always know when hydrogen sulfide is present in groundwater. Although colorless, hydrogen sulfide gas has an initial odor typically described as that of rotten eggs. It is one of a few water contaminants human senses can detect at low concentrations – as low as 0.5 mg/L.
Well Operations and Gases

• **Hydrogen Sulfide (H₂S)**
  – Hydrogen sulfide forms when there is a decomposition of organic sulfur-containing materials under reducing conditions, which are easily absorbed by water
  – Hydrogen sulfide can be corrosive to metals such as iron, steel, copper, and brass
  – Small amounts of hydrogen sulfide can be corrosive – as little as less than 1 mg/L can cause severe corrosion
Well Operations and Gases

- **Hydrogen Sulfide (H₂S)**
  - Metal exposed to hydrogen sulfide can become structurally weakened through a process known as hydrogen embrittlement.
  - Embrittlement involves the movement of hydrogen in the atomic form into the metal crystalline lattice of steel.
  - Well screens can experience a catastrophic failure, and can be caused by hydrogen sulfide concentrations as low as 20 ppm, if exposure time is long enough.
• **Sulfate-reducing bacteria**
  – Sulfur gases, normally hydrogen sulfide, typically come from sulfate-reducing bacteria reacting with the sulfate compounds in groundwater
  – These bacteria are natural inhabitants of groundwater
  – They can become more prevalent in essentially oxidizing wells when biofouling builds up
Well Operations and Gases

• **Sulfate-reducing bacteria**
  – The remedy is to
    • a) know they are present;
    • b) use materials that resist sulfide corrosion, and
    • c) periodically clean the well
  – The best means for treatment is to remove the sulfur. This can be done by air injection and flushing the filter bed with chlorine during the backwash
Well Operations and Gases

• **Methane**
  – Where methane is suspected of being present, several steps must be taken immediately including:
    • Stopping smoking, welding, or other activities using open flames or sparks
  – Positive ventilation devices must be installed in the borehole and run continuously
Well Operations and Gases

• **Radon (Rn)**
  
  – In a few areas where local water supplies are derived from wells in uranium-rich rock and the water is used within a week or two from the time it is pumped from the ground, significant amounts of radon can enter indoor air when the water is exposed to the air within a house, such as in a shower or sink.
Well Operations and Gases

• **Sulfur dioxide (SO$_2$)**
  – The sulfur gases (normally hydrogen sulfide) typically come from sulfate reducing bacteria reacting with the sulfate compounds in the groundwater. The gas can be vented off but periodic cleaning of the water system to remove the source is the better treatment.
  – Sulfur dioxide can react with steel pipe result in a buildup of scale and to pipe failure.
V. After-Drilling Operations

- Mixing groundwater of differing gas levels within the same well is not recommended
- Some local and state regulations prohibit interconnection of multiple aquifers within the same well
“Breather” Wells

• So-called “breather” wells have been found in unsaturated permeable rock above the water level and below the top of the completion interval
  – With exposure of unsaturated permeable rock to the completion interval, air can move into or out of the rock, and thus, they are affected by barometric pressure
  – Under high barometric conditions these wells will take in oxygen, and expel oxygen under low barometric conditions
“Breather” Wells

- They typically have a surface casing and a top of completion interval that is above the non-pumping water level in the well
“Breather” Wells

- These conditions can lead to oxygen deprivation for workers at well sites that finish in pits
  - Deadly low oxygen levels as low as five percent have been noted (the atmosphere norm is 20.95%)
  - Likewise nitrogen levels as high as 90 percent have been noted (norm is 78.08 percent)
“Breather” Wells

• Well pits and well houses were utilized prior to the development of pitless adapters and frost- and freeze-proofed well pumping system components
Why were there well pits?

- Predate pitless adapters
- Frost- and freeze-proof the well pumping system, including the pressure system

Pitless adapter image courtesy of Baker Manufacturing
VI. Groundwater Analyses and Treatment Methodologies

• Typical Gas Testing Costs
  – It is essential that samples being tested utilize an approved laboratory

• Gas Treatment Choices
  – Testing water where gases are a concern is an important strategy for residential water well system owners
Gas Treatment Choices

• **Carbon Dioxide**
  – The best treatment option is to pump into an atmospheric tank and allow the carbon dioxide to vent

• **Carbon Monoxide**
  – The best treatment option is to allow the carbon monoxide to vent
Gas Treatment Choices

• **Dissolved Oxygen**
  – If treatment were required, the best option may be to pump into an atmospheric tank and allow the oxygen to vent

• **Hydrogen Sulfide**
  – Hydrogen sulfide treatment options: aeration, carbon filters (limited to low levels), chlorination, ion exchange, manganese greensand filtration, oxidation and oxidizing filters, ozone, use of a standard filter tank with an automatic vent mounted on top
Gas Treatment Choices

• **Sulfate-reducing bacteria**
  – Sulfate-reducing bacteria can be treated by shock chlorination of the well and by adding a chlorination system on the incoming water, but *not* by continuous chlorination of the well itself.
  – Continuous chlorination is not effective because the water coming in varies in volume so it is impossible to balance the feed rate of chlorine so that the system is always over chlorinated.
Gas Treatment Choices

• **Methane**
  
  – Some public health officials offer differing guidance for dealing with methane, largely because of the risk created by the explosive capacity of the gas
  
  – Some officials fear venting can create an explosive hazard and instead suggest that wells be decommissioned and replaced
Gas Treatment Choices

- **Methane**
  - Venting the casing and/or the well cap allows methane to escape before it can accumulate in distribution lines, water heaters, pressure tanks, water treatment equipment, or well houses
  - Venting casing effective if gas is free in the well and not tied up in the water
  - Groundwater with methane pumped into a pressurized tank may lead to rare circumstance when a water faucet is opened and running water will “burn”
Gas Treatment Choices

- **Methane**
  - Outside holding tank may allow methane to escape to the atmosphere
  - Isn’t a totally effective solution
Gas Treatment Choices

• **Methane**
  – Aeration at the point of entry can remove methane gas
    • Aeration pulls gas in suspension from the water
Gas Treatment Choices

- **Methane**
  - The vent pipe needs to be above the eave height of the well house or house if the atmospheric tank is in the basement or utility room.
  - Aeration equipment must be specifically modified by the manufacturer to deal with methane. Systems that are not designed to deal safely with methane may permit dissolved gases to seep out of the water into the atmosphere. Because methane is flammable, any spark or gas accumulation in an aeration system can result in an explosion.
Gas Treatment Choices

• **Radon**
  – The two most common technologies used for POE treatment are granular activated carbon (GAC) adsorption and aeration
  – POU devices, such as those installed on a tap or under the sink, treat only a small portion of the water in the home and are not as effective in reducing radon; radioactive materials also can build up on the filters of these devices and become a hazard
Gas Treatment Choices

• **Sulfur Dioxide**
  – It can be treated by shock chlorination, or by a chlorine feed system on the incoming water
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