Health and Safety Risks for Workers Involved in Manual Tank Gauging and Sampling at Oil and Gas Extraction Sites

The National Institute for Occupational Safety and Health (NIOSH) and the Occupational Safety and Health Administration (OSHA) have identified health and safety risks to workers who manually gauge or sample fluids on production and flowback tanks from exposure to hydrocarbon gases and vapors, exposure to oxygen-deficient atmospheres, and the potential for fires and explosions.

Introduction

Workers at oil and gas extraction sites could be exposed to hydrocarbon gases and vapors, oxygen-deficient atmospheres, and fires and explosions when they open tank hatches to manually gauge or collect fluid samples on production, flowback, or other tanks (e.g., drip pots) that contain process fluids. Opening tank hatches, often referred to as “thief hatches,” can result in the release of high concentrations of hydrocarbon gases and vapors. These exposures can have immediate health effects, including loss of consciousness and death.

Recent NIOSH and OSHA research showed that workers could be exposed to hydrocarbon gases and vapors when they work on or near production and flowback tanks. This means workers can face significant health and safety risks when they manually gauge or sample tanks [Esswein et al. 2014; Jordan 2015]. These risks are in addition to the risk of exposure to hydrogen sulfide (H₂S), a well-recognized chemical exposure hazard for those who work in the oil and gas extraction and production industry [OSHA].

NIOSH and OSHA also identified nine worker fatalities that occurred while workers manually gauged or sampled production tanks from 2010–2014 [NIOSH 2015]. Exposures to hydrocarbon gases and vapors and/or oxygen-deficient atmospheres are believed to be primary or contributory factors to the workers’ deaths [Harrison et al. 2016].

Working on or near oil and gas production tanks is of particular concern because these tanks may contain concentrated hydrocarbon gases and vapors that are under pressure. When the thief hatch is opened, the release of these pressurized gases and vapors can expose workers. Second, the gases and vapors can displace oxygen, creating an oxygen-deficient environment. Third, the hydrocarbon gas and vapor concentrations can exceed 10% of the lower explosive limit (LEL), creating a chance for fires and explosions. Exposure to hazardous atmospheres and fire/explosion risks will vary depending on tank contents and operating conditions, the presence of ignition sources, and other factors (Box 1, page 3).

What’s in this Alert?

This Hazard Alert describes the safety and health hazards when workers manually gauge or sample fluids from production, flowback, or other tanks. It recommends ways to protect workers by eliminating or reducing exposures to hazardous atmospheres, and actions employers should take to ensure that workers are properly aware of the hazards and protected from exposure to hydrocarbon gases and vapors. This alert is a supplement to the OSHA Alliance Tank Hazard Alert released in 2015 [National STEPS Network 2015].
Hydrocarbon Gas and Vapor Release from Production and Flowback Tanks

Petroleum hydrocarbons can exist as liquids, gases, and vapors. Production liquids (e.g., crude oil and condensate) at oil and gas extraction sites can release dissolved hydrocarbon gases such as methane, ethane, propane, and butane. Production liquids also evaporate to produce vapors such as pentane, hexane, benzene, and xylene. Hydrocarbon gases and vapors are often referred to as volatile organic compounds, or “VOCs.” Hydrocarbon gases contained in crude oil are readily released into the air at ambient temperature and pressure.

When a thief hatch is opened, substantial amounts of hydrocarbon gas and vapor (>100,000 parts per million) can be released [Jordan 2015], and in some cases this release can continue even after the initial headspace pressure is released. Furthermore, the composition of hydrocarbons in crude oil is complex, and the relative concentrations of specific gases and vapors are highly variable. When a worker opens a tank, the worker’s breathing zone can immediately become an acutely toxic mix of concentrated hydrocarbon gases and vapors. Depending on weather conditions, the plume may disperse or engulf workers atop and around tank batteries.

Appendix A shows how hydrocarbon gases and vapors behave when they are released from a production tank. Appendix B lists exposure limits for common hydrocarbon gases and vapors.

Health Hazards of Hydrocarbon Gases and Vapors

Acute exposures to hydrocarbon gases and vapors can affect the eyes, lungs, and central nervous system. If present in sufficient concentrations to displace oxygen, this exposure can sensitize the heart to stress hormones, such as catecholamines, causing abnormal rhythms and ventricular fibrillation that can lead to sudden death [Adgey et al. 1995; Bass 1970; Martinez et al. 2012; NIOSH 2005a,b,c; Poklis 1976; Reinhardt et al. 1971; Riihimäki and Savolainen 1980]. Even a brief exposure (30 seconds or less) to high concentrations of hydrocarbons and a low-oxygen atmosphere can result in the rapid onset of respiratory depression, hypoxia, and fatal cardiac arrhythmias [Miller and Mazur 1984]. Pre-existing coronary artery disease may exacerbate the risk. These exposures can also have narcotic effects, causing dizziness, rapid disorientation, and confusion that could lead to loss of judgment, narcosis, and incapacitation [Drummond 1993; Sugie et al. 2004]. Some hydrocarbons are also known carcinogens (e.g., benzene) [ATSDR 2007].
Box 1.

Factors that may increase worker exposure to hydrocarbon gases and vapors and flammable atmospheres

1. Produced Fluid and Reservoir Characteristics
   - Condensate and lighter crude (versus heavy crude)
   - Unstabilized (non-degassed) crude oils
   - High gas to oil ratio fluids
   - High temperature fluids
   - High production volumes/early in production

2. Operational and Task-related Factors
   - Drilling out plugs during completion operations
   - Tanks that are not isolated prior to opening hatch
   - Interconnected tanks (tank batteries)
   - Tanks using flare systems with backpressure on the vapor space
   - Flowback operations
   - Working around tanks with vapor recovery units
   - Maintenance work
   - Working around separators/enclosed spaces

3. Environmental Factors
   - Higher temperatures
   - Weather inversions
   - Higher altitude
   - Low wind speed

Factors that may decrease worker exposure to hydrocarbon gases and vapors and flammable atmospheres

1. Engineering Controls
   - Remote or automatic gauging and sampling
   - Blowdown valves
   - Tank sampling taps
   - Thief hatch pressure indicators, etc.

2. Work Practices
   - Working upwind and at a distance from open hatches

3. Personal Protective Equipment (PPE)
   - Flame retardant clothing
   - Appropriate respiratory protection
   - Impermeable gloves
Worker Fatalities during Manual Tank Gauging and Fluid Sample Collection, 2010–2014

NIOSH researchers, OSHA officials, and academic occupational health researchers investigated reports of worker deaths from 2010 through 2014 associated with manual tank gauging and the collection of fluid samples (Appendix C). During the 5-year period, NIOSH researchers identified nine fatalities involving these tasks. Three deaths occurred in North Dakota, three in Colorado, one in Texas, one in Oklahoma, and one in Montana.

All fatalities occurred at crude oil production tanks. Four took place during tank gauging, and five happened during fluid sample collection at an open thief hatch by pumpers/truckers. For all fatalities, the employees were working alone or not being observed by a co-worker. Unprotected exposures to high concentrations of hydrocarbon gases and vapors and/or displacement of oxygen are believed to be primary or contributory factors in each fatality [Harrison et al. 2016]. Exposure to H₂S was ruled out as a cause in all nine cases. A narrative description of each of the nine fatalities can be found on the NIOSH “Fatalities in the Oil and Gas Extraction Industry” (FOG) database web page (http://www.cdc.gov/niosh/topics/fog/data.html).

Oxygen concentrations well below normal (oxygen concentration in ambient air = 21%) were documented in two fatal incidents. While investigating the Case #1 death at the site, OSHA's compliance officer measured oxygen levels in the range of 11% to 12% approximately one foot above the open hatch. A data-logging four-gas monitor worn by the worker at the time of death in Case #7 recorded that the oxygen level fell to as low as 6.9%. The same worker had also worn the monitor during a previous incident, during which the oxygen level fell to as low as 9.1%, and remained consistently below 15% for a six-minute interval. Exposure to atmospheres with these low concentrations of oxygen can rapidly overcome workers and bring about unconsciousness without warning. Also, in both incidents, the monitor worn by the worker in Case #7 documented that the worker’s environment exceeded the LEL.

NIOSH Evaluation of Worker Exposures during Flowback and Production Activities

In 2013, NIOSH evaluated worker exposures to a variety of chemicals during flowback and production activities at six well sites in Colorado and Wyoming [Esswein et al. 2014]. Exposure assessments included full-shift and short-term personal breathing zone (PBZ) and area air sampling. Direct-reading instruments were also used to characterize peak and short-term exposures to hydrocarbon gases and vapors. This study found that most workers gauging tanks (15 of 17; 88.2%) had benzene exposures exceeding the NIOSH-recommended exposure limit (REL) of 0.1 parts per million (ppm) as a time-weighted average (TWA) for a full shift. Some exposures also exceeded the NIOSH short-term exposure limit of 1 ppm as a 15-minute average for benzene. Worker exposures to benzene did not exceed the OSHA permissible exposure limit (PEL) criteria (1 ppm as a TWA) and biological monitoring results did not exceed criteria established by the American Conference of Governmental Industrial Hygienists for benzene [OSHA 2012]. However, average benzene exposures for workers who gauged tanks were approximately five times greater than for workers not gauging tanks. In the same study, direct-reading instruments detected benzene peak concentrations at open hatches exceeding 200 ppm, and sustained atmospheres as high as 40% of the LEL adjacent to separators and flowback tanks. Concentrations above 10% of the LEL are considered a risk for fires or explosions and are classified as Immediately Dangerous to Life and Health (IDLH) by OSHA and NIOSH. Workers at the sites did not use respiratory protection while gauging tanks.

OSHA Evaluation of Exposures to Workers during Tank Gauging

In 2014, OSHA industrial hygienists conducted evaluations at oil and gas extraction well sites in North Dakota. The sites were identified by observing active tank-gauging operations. The evaluations characterized worker exposures during manual tank gauging for full-shift, short-term, and peak concentrations of hydrocarbon gases and vapors, and flammable and oxygen-deficient environments. Samples collected approximately one foot above open hatches found IDLH concentrations of hydrocarbon gases and vapors, including propane, pentane, methyl butane, hexane, 2-methyl pentane, and 3-methyl pentane (Table 1).

Worker sampling also documented overexposures to benzene for short-term, ceiling, and 8-hour TWA concentrations, based on the OSHA PELs. Potentially flammable (>10% LEL) and oxygen-deficient atmospheres (<19.5% oxygen) were identified on production tanks when thief hatches were opened during gauging and sampling [Jordan 2015]. Samples documented total hydrocarbon gas and vapor concentrations of 179,000 ppm and 219,000 ppm in the plumes above two thief hatches. Laboratory analyses identified break-through of hydrocarbon gases in the sampling media, indicating that actual concentrations might have been greater than reported.
Sample collection methods are under development to more accurately assess hydrocarbon gas and vapor concentrations during manual thieving (i.e., sampling) and gauging. Consistent with the NIOSH field research, the OSHA evaluations identified worker exposure risks for hydrocarbon gases and vapors, and fires and explosions.

Table 1. Hydrocarbon Gas and Vapor Concentrations Measured by OSHA Approximately 1 Foot Above Open Production Tank Hatches (North Dakota, 2014).

<table>
<thead>
<tr>
<th>Gas or Vapor</th>
<th>Concentration (average ppm)</th>
<th>IDLH* (average ppm)</th>
<th>Severity**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propane</td>
<td>43,000</td>
<td>2,100</td>
<td>&gt;20 x</td>
</tr>
<tr>
<td>Butane(s)</td>
<td>100,000</td>
<td>1,900</td>
<td>&gt;50 x</td>
</tr>
<tr>
<td>Pentane(s)</td>
<td>28,000</td>
<td>1,500</td>
<td>&gt;20 x</td>
</tr>
<tr>
<td>n-Hexane</td>
<td>4,500</td>
<td>1,100</td>
<td>&gt;4 x</td>
</tr>
<tr>
<td>Benzene</td>
<td>100-400</td>
<td>500</td>
<td>&lt;1 x</td>
</tr>
</tbody>
</table>

*Immediately Dangerous to Life or Health concentrations expressed as 10% of the LEL

**Severity = Airborne Concentration Expressed as ppm / IDLH (ppm)

Appropriate Respiratory Protection

Although air-purifying respirators with organic vapor cartridges can protect against vapors (such as benzene, hexane, toluene, and xylene), they are ineffective against light hydrocarbon gases (such as methane, ethane, propane, butane, and pentane) because these gases quickly pass through the activated charcoal sorbent in respirator cartridges [Freedman et al. 1973; 3M 2013]. Air-purifying respirators also have other important limitations. They do not protect against oxygen-deficient atmospheres or concentrations of hydrocarbons exceeding the maximum use concentration (Occupational Exposure Limit X the Assigned Protection Factor) for the respirator/cartridge ensemble.

Workers using half-face or full-face air-purifying respirators while tank gauging will not be protected against exposures to light hydrocarbon gases and vapors and oxygen-deficient atmospheres. At least one worker who died was wearing an air-purifying respirator at the time of his death. Supplied air respirators (e.g., air-line or self-contained breathing apparatus [SCBA]) can protect workers from toxic exposures and oxygen-deficient atmospheres — provided the user is wearing the respirator correctly in accordance with the OSHA Respiratory Protection Standard (29 CFR 1910.134) [OSHA 2006].

Conclusions

Exposure assessment studies conducted by NIOSH and OSHA have identified worker health and safety risks that occur when workers open thief hatches and manually gauge and sample fluids from production and flowback tanks. Toxicological data, inherent factors from the oil collection process, and exposure assessments provide evidence that gauging and sampling tanks present significant hazards to workers, including risks for exposures to oxygen-deficient atmospheres, inhalation exposures to concentrated petroleum hydrocarbon gases and vapors, and fires and explosions.

Moreover, nine fatalities identified over five years were associated with working close to open hatches of crude oil production tanks. Exposures to hydrocarbon gases and vapors and/or oxygen-deficient atmospheres are believed to be primary or contributory factors to these workers’ deaths.

Hydrocarbon gas and vapor emissions from production and flowback tanks are wide-ranging. Consequently, it is difficult to predict the magnitude of risk from any specific gauging or sampling task. Factors that can affect the extent of the occupational exposures are presented in Box 1, page 3. These factors should be considered as part of worker exposure assessments.

NIOSH and OSHA recommend that employers take the following steps to ensure that workers are properly aware of the hazards and protected from exposure to hydrocarbon gases and vapors.
NIOSH & OSHA Recommendations for Manual Tank Gauging and Fluid Sample Collection

1. Implement alternative tank gauging and sampling procedures that enable workers to monitor tank fluid levels and take samples without opening the tank hatch.

2. Retrofit existing tanks with dedicated sampling ports (i.e., tank sampling taps [American Petroleum Institute 2013]) that minimize worker exposures to hydrocarbon gases and vapors, thereby eliminating the need to routinely open thief hatches to sample. These sampling taps should minimize the magnitude of hydrocarbon plumes and should limit the need for workers to access the top of tanks.

3. Install thief hatch pressure indicators to provide an immediate visual indicator of tank pressures and potential hazards. Pressure indicators can show workers the pressure in the tank and allow a trained worker to follow appropriate procedures, such as actuating a blowdown valve, venting gas to a flare, or using appropriate respiratory protection, such as a self-contained breathing apparatus or an air-line respirator.

4. Conduct worker exposure assessments to determine exposure risks to volatile hydrocarbons and other contaminants. Employers may consult an occupational safety and health professional trained and certified in industrial hygiene and who has knowledge and experience with combined flammable gas and vapor exposures to ensure that an appropriate air-sampling strategy is used.

5. Provide hazard communication training in a language that employees understand to ensure that general site workers, tank gaugers and samplers, water haulers, drivers, and others who open tank hatches understand the hazards associated with opening tanks and the precautions necessary to conduct this work safely. These hazards include reduced oxygen environments, flammability hazards and possible ignition sources, and the potential for concentrations of hydrocarbons that can approach or exceed IDLH concentrations. Post hazard signage at access stairs, catwalks, and/or tanks to alert workers about the hazards associated with opening thief hatches and precautions that must be taken.

6. Ensure that workers are trained on — and correctly and consistently use — calibrated multi-gas and oxygen monitors that measure percent LEL and oxygen concentration. Workers should understand the limitations of these monitors as well as appropriate actions to take whenever an alarm occurs or they experience health symptoms (e.g., leave the hazard area, report symptoms to supervisors).

7. Do not permit employees to work alone when tank gauging or working around tanks, thief hatches, or other areas where they may encounter process fluids. Observers should be trained on proper rescue procedures and be stationed outside potentially hazardous areas.

8. As an interim measure, where remote gauging or sampling is not feasible or engineering controls are not implemented, (a) train workers in proper work practices, such as tank-opening procedures, that can minimize risks for exposures, (b) ensure intrinsic safety by proper grounding and prohibiting the use of spark producing devices or equipment, (c) establish administrative controls to reduce the number of times throughout a shift a worker is required to manually gauge tanks, (d) safely reduce tank pressure prior to gauging, and (e) use appropriate respiratory protection, including a supplied air respirator (SAR) and/or self-contained breathing apparatus (SCBA) in areas where IDLH VOC exposures may occur (i.e., during manual tank gauging/sampling). Employers should consult with a trained occupational safety and health professional to determine the appropriate respirator to be used. NIOSH guidance for selecting respirators is at: http://www.cdc.gov/nioshdocs/2005-100/default.html.

9. Wear flame-resistant clothing to protect against burns from fires and explosions. Also, use appropriate impermeable gloves to limit risks for skin exposures to chemicals (e.g., benzene).

10. Establish and practice emergency procedures to provide on-scene, immediate medical response in the event of an incident, such as a collapsed worker, or workers experiencing symptoms of chemical overexposures or exposure to an oxygen-deficient atmosphere.
How Can OSHA and NIOSH Help?

**OSHA** has compliance assistance specialists throughout the nation who can provide information to employers and workers about OSHA standards, short educational programs on specific hazards or OSHA rights and responsibilities, and information on additional compliance assistance resources. Contact your local OSHA office for more information.

**OSHA**'s On-site Consultation Program offers free and confidential safety and health services to small and medium-sized businesses in all states and territories across the country, with priority given to high-hazard worksites. On-site Consultation services are separate from enforcement and do not result in penalties or citations. Consultants from state agencies or universities work with employers to identify workplace hazards, provide advice on compliance with OSHA standards, and assist in establishing and improving their safety and health management systems. To locate the OSHA On-site Consultation Program nearest you, call 1-800-321-6742 (OSHA) or visit [http://www.osha.gov/dcsp/smallbusiness/index.html](http://www.osha.gov/dcsp/smallbusiness/index.html).

**OSHA's and NIOSH's Cooperative Initiatives:** OSHA, NIOSH, and the National STEPS Network have formed an Alliance ([http://www.osha.gov/dcsp/alliances/steps_niosh/steps_niosh.html](http://www.osha.gov/dcsp/alliances/steps_niosh/steps_niosh.html)) to develop products that will reduce fatalities and injuries in this industry. Additionally, OSHA, NIOSH, and several U.S. onshore exploration and production industry trade associations, companies, and individual experts have formed an Emerging Issues Focus Group to further explore worker hazards during oil and gas extraction and to develop practical short- and long-term solutions to protect worker safety and health. Look for products and updates from these groups.

**NIOSH** can help characterize exposures at your workplace and is looking for industry partners to evaluate engineering controls that may reduce exposure to hydrocarbon gases and vapors. NIOSH is also looking for additional partners in drilling and well servicing to help evaluate worker exposures to other chemical hazards and develop controls as needed. Please refer to the document NIOSH Field Effort to Assess Chemical Exposure Risks to Gas and Oil Workers: ([http://www.cdc.gov/niosh/docs/2010-130/](http://www.cdc.gov/niosh/docs/2010-130/)) for details and contact information if you have questions or wish to participate.

In addition, NIOSH has an active program that encourages Prevention through Design considerations so that occupational health and safety aspects are built into equipment during the design phase.

Employers and workers can always request a NIOSH Health Hazard Evaluation. For more information about this program, please visit the website - ([http://www.cdc.gov/niosh/hhe/HHEprogram.html](http://www.cdc.gov/niosh/hhe/HHEprogram.html)).

**Worker Rights**

Workers have the right to:

- Working conditions that do not pose a risk of serious harm.
- Receive information and training (in a language and vocabulary they understand) about workplace hazards, methods to prevent them, and the OSHA standards that apply to their workplace.
- Review records of work-related injuries and illnesses.
- Get copies of test results that find and measure hazards.
- File a complaint asking OSHA to inspect their workplace if they believe there is a serious hazard or that their employer is not following OSHA's rules. OSHA will keep all identities confidential.
- Exercise their rights under the law without retaliation or discrimination.

For more information, see OSHA's page for workers ([https://www.osha.gov/workers/index.html](https://www.osha.gov/workers/index.html)).
**Contact OSHA**

For questions or to get information or advice, to report an emergency, fatality, inpatient hospitalization, amputation or loss of an eye, or to file a confidential complaint, contact your nearest OSHA office, visit www.osha.gov, or call OSHA at 1-800-321-OSHA (6742), TTY 1-877-889-5627.

There are 28 OSHA-approved occupational safety and health State Plans. State Plans are required to have standards and enforcement programs that are at least as effective as federal OSHA’s and may have different or more stringent standards. More information about State Plans is available at: http://www.osha.gov/dcsp/osp/index.html

**Contact NIOSH**

To receive documents or more information about occupational safety and health topics, please contact NIOSH at 1-800-CDC-INFO (1-800-232-4636), TTY 1-888-232-6348, email: cdcinfo@cdc.gov or visit the NIOSH web site at: http://www.cdc.gov/niosh/.

**Suggested Citation:**


**Acknowledgements:**

NIOSH and OSHA acknowledge Robert Harrison, MD, (University of California, San Francisco) for his valuable assistance in identifying worker fatalities related to tank gauging and sampling. NIOSH and OSHA gratefully acknowledge Michael Kosnett, MD, MPH, and Margaret Cook-Shimanek, MD, MPH (University of Colorado, Denver and Colorado School of Public Health) for their expertise and counsel in medical toxicology relating to hydrocarbon exposures and risks for sudden death, and their discussions of a specific fatality investigation.

NIOSH and OSHA also thank and acknowledge Rick Ingram of the National STEPS Network for his enduring leadership at the National STEPS Network and the recently formed OSHA Alliance, along with his support of the NIOSH Field Effort to Assess Chemical Exposures in Oil and Gas Workers.

NIOSH acknowledges our industry partners (and especially their workers) for their leadership in occupational health and safety, as demonstrated by their participation in the NIOSH Field Effort to Assess Chemical Exposures in Oil and Gas Workers.

**Appendix A.**

**Behavior of Hydrocarbon Gases and Vapors in a Production Tank**

1. Hydrocarbon gases and vapors exist in equilibrium with liquid hydrocarbons (e.g., crude oil) in a production tank.
2. Gases (previously in equilibrium with crude oil in a pressurized tank) release to the atmosphere when the tank lid is opened.

When the hatch is opened, a large volume of gases (mostly propane and butane) rush out. These gases can displace oxygen in the immediate work area, and this could asphyxiate workers in the vicinity.

3. Vapors form when liquid hydrocarbons inside the tank evaporate.

As the hatch remains open, heavier hydrocarbon molecules (pentane, hexane, heptane) also begin to leave the tank and enter the workspace. The rate of release is high, and these gases and vapors may reach concentrations that can be toxic or flammable.

4. Hydrocarbon gases and vapors are generated at a slower pace as tank pressure decreases. Lighter hydrocarbon gases and vapors stay aloft; denser gases and vapors seek the ground.

As the hatch continues to remain open, the gases and vapors in the tank are approaching equilibrium with the environment, significantly slowing the rate of emission.
## Appendix B.

<table>
<thead>
<tr>
<th>Compound</th>
<th>REL</th>
<th>PEL</th>
<th>IDLH</th>
<th>LEL (10% LEL)</th>
<th>UEL (10% LEL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>None (asphyxiant)</td>
<td>5,000 ppm (10% LEL)</td>
<td>5.00%</td>
<td>50,000 ppm</td>
<td>15.00%**</td>
</tr>
<tr>
<td>Ethane</td>
<td>None (asphyxiant)</td>
<td>3,000 ppm (10% LEL)</td>
<td>3.00%</td>
<td>30,000 ppm</td>
<td>12.50%**</td>
</tr>
<tr>
<td>Propane</td>
<td>1,000 ppm</td>
<td>1,000 ppm</td>
<td>2,100 ppm (10% LEL)</td>
<td>2.10%</td>
<td>21,000 ppm</td>
</tr>
<tr>
<td>n-Butane</td>
<td>800 ppm</td>
<td>none</td>
<td>1,600 ppm (10% LEL)</td>
<td>1.60%</td>
<td>16,000 ppm</td>
</tr>
<tr>
<td>i-Butane</td>
<td>800 ppm</td>
<td>none</td>
<td>1,600 ppm (10% LEL)</td>
<td>1.60%</td>
<td>16,000 ppm</td>
</tr>
<tr>
<td>n-Pentane</td>
<td>1,120 ppm (610 ppm 15-minute ceiling limit)</td>
<td>1,000 ppm</td>
<td>1,500 ppm (10% LEL)</td>
<td>1.50%</td>
<td>15,000 ppm</td>
</tr>
<tr>
<td>n-Hexane</td>
<td>50 ppm</td>
<td>500 ppm</td>
<td>1,100 ppm (10% LEL)</td>
<td>1.10%</td>
<td>11,000 ppm</td>
</tr>
<tr>
<td>Benzene**</td>
<td>0.1 ppm (1 ppm STEL)</td>
<td>1 ppm</td>
<td>500 ppm</td>
<td>1.20%</td>
<td>12,000 ppm</td>
</tr>
<tr>
<td>Heptane</td>
<td>85 ppm (440 ppm 15-minute ceiling limit)</td>
<td>500 ppm</td>
<td>750 ppm</td>
<td>1.00%</td>
<td>10,500 ppm</td>
</tr>
<tr>
<td>Ethyl Benzene</td>
<td>100 ppm (125 ppm STEL)</td>
<td>100 ppm</td>
<td>800 ppm (10% LEL)</td>
<td>0.80%</td>
<td>8,000 ppm</td>
</tr>
<tr>
<td>Toluene</td>
<td>100 ppm (150 ppm STEL)</td>
<td>200 ppm</td>
<td>500 ppm</td>
<td>1.10%</td>
<td>11,000 ppm</td>
</tr>
<tr>
<td>Xylenes</td>
<td>100 ppm (150 ppm STEL)</td>
<td>100 ppm</td>
<td>900 ppm</td>
<td>0.90%</td>
<td>9,000 ppm</td>
</tr>
<tr>
<td>Mixed Petroleum Hydrocarbons/ Distillates (naphthas)</td>
<td>350 mg/m³ (1800 mg/m³ 15-minute ceiling limit)</td>
<td>500 ppm</td>
<td>1100 ppm</td>
<td>1.10%</td>
<td>11,000 ppm</td>
</tr>
</tbody>
</table>

* When the health-based immediately dangerous to life or health (IDLH) values are greater than 10% of the lower explosive limit (LEL) of the air contaminant, the IDLH value is set at 10% LEL, because explosive hazards are deemed a greater risk than toxicity—NIOSH, Current Intelligence Bulletin 66 ([http://www.cdc.gov/niosh/docs/2014-100/](http://www.cdc.gov/niosh/docs/2014-100/)). An IDLH is a maximum airborne concentration above which only a highly reliable breathing apparatus providing maximum worker protection is permitted [NIOSH 2004]. IDLH values are based on a 30-minute exposure duration. Upper explosive limit (UEL) is the highest concentration (%) of a gas or a vapor in air capable of producing a flash or fire in the presence of an ignition source. Concentrations higher than the UEL are “too rich” to burn.

** International Chemical Safety cards: [http://www.cdc.gov/niosh/ipcs/](http://www.cdc.gov/niosh/ipcs/)


**** Upstream oil and gas operations are exempt from the OSHA Benzene standard, 1910.1028.
## Appendix C.
### Worker Fatalities Related to Oxygen Deficiency and Inhalation of Hydrocarbon Gases and Vapors Among Oil and Gas Extraction Workers—Multiple States, 2010 to 2014

<table>
<thead>
<tr>
<th>Year of death</th>
<th>Age, in years</th>
<th>State</th>
<th>Job Title</th>
<th>Job Task</th>
<th>Description of how person was found</th>
<th>Time of day found</th>
<th>Coroner’s stated cause of death</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2010</td>
<td>MT</td>
<td>Crew Worker</td>
<td>Gauging</td>
<td>Slumped over on the catwalk</td>
<td>3:00 a.m.</td>
<td>Hypertensive and atherosclerotic cardiovascular disease</td>
</tr>
<tr>
<td>2</td>
<td>2012</td>
<td>ND</td>
<td>Flow Tester</td>
<td>Gauging</td>
<td>On catwalk next to open hatch</td>
<td>12:30 a.m.</td>
<td>Hydrocarbon poisoning due to inhalation of petroleum vapors</td>
</tr>
<tr>
<td>3</td>
<td>2013</td>
<td>ND</td>
<td>Truck Driver</td>
<td>Collecting Sample</td>
<td>Slumped over catwalk railing on knees in front of open hatch</td>
<td>10:20 a.m.</td>
<td>Sudden cardiac arrhythmia (primary), morbid obesity and atherosclerotic heart disease (contributory)</td>
</tr>
<tr>
<td>4</td>
<td>2014</td>
<td>OK</td>
<td>Truck Driver</td>
<td>Collecting Sample</td>
<td>On catwalk next to tank, slumped over</td>
<td>10:12 a.m. (time of death)</td>
<td>Undetermined (no autopsy performed)</td>
</tr>
<tr>
<td>5</td>
<td>2014</td>
<td>CO</td>
<td>Truck Driver</td>
<td>Collecting Sample</td>
<td>Hanging from guardrail, hooked by clothing</td>
<td>10:39 a.m. (time of death)</td>
<td>Sudden cardiac death due to ischemic heart disease</td>
</tr>
<tr>
<td>6</td>
<td>2014</td>
<td>CO</td>
<td>Truck Driver</td>
<td>Collecting Sample</td>
<td>Collapsed over open hatch</td>
<td>10:30 a.m.</td>
<td>Atherosclerotic cardiovascular disease</td>
</tr>
<tr>
<td>7</td>
<td>2014</td>
<td>CO</td>
<td>Truck Driver</td>
<td>Collecting Sample</td>
<td>Collapsed over open hatch</td>
<td>1:40 p.m.</td>
<td>Toxic gas inhalation and oxygen displacement by volatile hydrocarbons (primary), atherosclerotic cardiovascular disease and sudden cardiac death (contributory)</td>
</tr>
<tr>
<td>8</td>
<td>2014</td>
<td>TX</td>
<td>Tank Gauger</td>
<td>Gauging</td>
<td>At the bottom of catwalk stairs</td>
<td>4:14 a.m.</td>
<td>Arteriosclerotic and hypertensive cardiovascular disease</td>
</tr>
<tr>
<td>9</td>
<td>2014</td>
<td>ND</td>
<td>Flow Tester</td>
<td>Gauging</td>
<td>Face down, over open hatch</td>
<td>5:00 a.m.</td>
<td>Cardiac arrhythmia, with cardiac hypertrophy, coronary artery hypogenesis, obesity and petroleum hydrocarbon vapors</td>
</tr>
</tbody>
</table>
References


Disclaimer

This Hazard Alert is not a standard or regulation, and it creates no new legal obligations. It contains recommendations as well as descriptions of mandatory safety and health standards [and other regulatory requirements]. The recommendations are advisory in nature, informational in content, and are intended to assist employers in providing a safe and healthful workplace. The Occupational Safety and Health Act requires employers to comply with safety and health standards and regulations promulgated by OSHA or by a state with an OSHA-approved State Plan. In addition, the Act’s General Duty Clause, Section 5(a)(1), requires employers to provide their employees with a workplace free from recognized hazards likely to cause death or serious physical harm. The mention of any non-governmental organization or link to its website in this Hazard Alert does not constitute an endorsement by OSHA or NIOSH of that organization or its products, services, or website.

*Accessibility Assistance: Contact OSHA’s Directorate of Technical Support and Emergency Management at (202) 693-2300 for assistance accessing PDF materials. All other documents, that are not PDF materials or formatted for the web, are available as Microsoft Office® formats and videos and are noted accordingly. If additional assistance is needed with reading, reviewing or accessing these documents or any figures and illustrations, please also contact OSHA’s Directorate of Technical Support and Emergency Management at (202) 693-2300.

**eBooks - EPUB is the most common format for e-Books. If you use a Sony Reader, a Nook, or an iPad you can download the EPUB file format. If you use a Kindle, you can download the MOBI file format.
Sudden Deaths Among Oil and Gas Extraction Workers Resulting from Oxygen Deficiency and Inhalation of Hydrocarbon Gases and Vapors — United States, January 2010–March 2015

Robert J. Harrison, MD1; Kyla Retzer, MPH2; Michael J. Kosnett, MD3;4; Michael Hodgson, MD5; Todd Jordan, MSPHS6; Sophia Ridl2; Max Kiefer, MS2

In 2013, an occupational medicine physician from the University of California, San Francisco, contacted CDC's National Institute for Occupational Safety and Health (NIOSH), and the Occupational Safety and Health Administration (OSHA) about two oil and gas extraction worker deaths in the western United States. The suspected cause of these deaths was exposure to hydrocarbon gases and vapors (HGVs) and oxygen (O2)-deficient atmospheres after opening the hatches of hydrocarbon storage tanks. The physician and experts from NIOSH and OSHA reviewed available fatality reports from January 2010 to March 2015, and identified seven additional deaths with similar characteristics (nine total deaths). Recommendations were made to industry and regulators regarding the hazards associated with opening hatches of tanks, and controls to reduce or eliminate the potential for HGV exposure were proposed. Health care professionals who treat or evaluate oil and gas workers need to be aware that workers might report symptoms of exposure to high concentrations of HGVs and possible O2 deficiency; employers and workers need to be aware of this hazard and know how to limit exposure. Medical examiners investigating the death of oil and gas workers who open tank hatches should consider the contribution of O2 deficiency and HGV exposure.

Workers at oil and gas well sites often manually gauge the level of fluid or collect a sample from storage tanks containing process fluids. These workers climb to the top of the tanks, open a “thief” hatch (a closable aperture on atmospheric tanks, used to sample the tank contents) (Figure), and either place a device into the hatch to measure the fluid level or lower a “thief” sampler (a hollow tube) into the tank to collect liquid samples. In 2013, an occupational medicine physician from the University of California, San Francisco, received a report of a 2012 oil and gas worker fatality in North Dakota; that state’s medical examiner attributed death to the inhalation of petroleum hydrocarbons. The male worker, aged 21 years, was gauging crude oil production tanks on the well site, at night and alone. A coworker found the victim unconscious near the open hatch. Colleagues initiated cardiopulmonary resuscitation, and the worker was transported to the hospital where he was pronounced dead approximately 2 hours later. An autopsy found no obvious signs of traumatic injury. Toxicology testing identified detectable quantities of low–molecular weight hydrocarbons (propane and butane), and evidence of heavier molecular weight hydrocarbons. No indication of exposure to hydrogen sulfide (H2S) was identified. Initially, the death was attributed to cardiovascular disease and later to hydrocarbons. The occupational medicine physician subsequently identified a second worker who died from a sudden cardiac event in 2010 while performing tank gauging; H2S was excluded as a factor. The physician contacted NIOSH and OSHA about these two deaths.

To identify other oil and gas extraction worker fatalities associated with exposure to HGVs, the physician and experts from NIOSH and OSHA reviewed media reports, OSHA case files, and the NIOSH Fatalities in Oil and Gas database. Cases were defined as nontraumatic oil and gas extraction worker deaths occurring during January 2010–March 2015, in which the workers were 1) performing tank gauging, sampling, or fluid transfer activities at oil and gas well sites; 2) working in proximity to a known and concentrated source of HGVs (e.g., an open hatch); 3) not working in a confined space; and 4) not exposed to H2S, fires, or explosions. All available information on identified fatalities was reviewed, including OSHA investigations, coroner and toxicology reports, gas monitor data, and exposure assessment data.

Nine deaths, occurring from January 2010 to March 2105, were identified (Table): six of the deaths occurred during 2014. Three deaths occurred in Colorado, three in North Dakota, and one each in Montana, Oklahoma, and Texas. The median age of workers was 51 years (range = 20–63 years), and all were male. All of the victims were working alone at the time of the incidents and were found collapsed on a tank or catwalk, or at the base of the catwalk stairs. In at least five cases, the hatch was open when the worker was found. Five of the fatalities occurred during the collection of a fluid sample, and four occurred during tank gauging. Toxicologic data on HGVs were not consistently collected during autopsy, but petroleum hydrocarbon vapors were noted as a cause of death for three workers.

Only one of the nine workers was known to have been provided a respirator, but fit-testing had not occurred, and the air-purifying respirator was not suitable for high concentrations of HGVs or O2 deficiency. The exposure assessment conducted by OSHA following the 2010 case found O2 concentrations as low as 11% at 1 foot above the open thief hatch (O2 concentrations.
in ambient air = 21%). In addition, HGV concentrations were in excess of the lower-explosive limit (minimum concentration of a gas necessary to support its combustion in air), suggesting exposures high enough (>10,000 parts per million [ppm]) to cause acute central nervous system symptoms. In case number seven, the worker wore a data-logging, continuous multi gas monitor as a regular work practice. Three weeks before the fatal event, he was examined in an emergency department after experiencing altered consciousness while gauging a tank. Gas monitor data during this event revealed a 5-minute interval, concurrent with his symptoms, when O₂ concentrations were in the range of 10% to 15% and flammable HGVs exceeded the lower-explosive limit. On the day of his death, the gas monitor again indicated that the lower-explosive limit had been exceeded, with O₂ concentrations as low as 7%.

**Discussion**

During January 2010–March 2015, at least nine deaths of oil and gas workers occurred in the United States, with exposure to HGVs a confirmed or suspected factor. Oil and gas extraction is a high-risk industry, with overall occupational fatality rates seven times the national average (1). Although safety hazards in the industry are well-known, few published reports address chemical exposures and acute occupational illness associated with oil and gas extraction. Recent exposure assessments have identified that opening thief hatches and manual gauging or sampling from hydrocarbon-containing tanks, outdoors in nonconfined spaces, is widely practiced and poses substantial and potentially lethal hazards to workers (2–4). These hazards include sudden exposure to high concentrations (>100,000 ppm) of low–molecular weight HGVs, accompanied by displacement of air, resulting in O₂ deficiency. Inhaled O₂ concentrations of <15% can significantly impair central nervous system function, and concentrations of <10% can result in loss of consciousness and possible death within seconds to minutes (5). Low O₂ blood levels (hypoxemia) can exacerbate cardiac ischemia and increase the release of epinephrine (adrenalin). High concentrations (i.e., 50,000 ppm to ≥100,000 ppm) of low–molecular weight hydrocarbons, particularly butane, have been shown in animal studies and human reports to sensitize the heart to epinephrine-induced ventricular fibrillation, a lethal cardiac arrhythmia (6–8). The simultaneous exposure to high levels of low–molecular weight HGVs and a low O₂ atmosphere above an open tank hatch poses a risk for sudden cardiac death. Preexisting coronary artery disease can exacerbate that risk. In addition, high levels of low–molecular weight HGVs can exert anesthetic effects that contribute to central nervous system depression (9). The exposure-assessment samples also showed concentrations of propane, butane, pentane, and 2-methylbutane exceeding 100% of the lower-explosive limit (3). Concentrations of explosive gases in excess of 10% of the lower-explosive limit are considered immediately dangerous to life or health. Because of the nine identified fatalities, the exposure-assessment findings, and the potential mechanism for sudden cardiac death, OSHA, NIOSH and multiple industry stakeholders collaboratively issued a hazard alert on tank gauging at oil and gas well sites (10). In addition, the Bureau of Land Management has proposed changes to current federal regulations concerned with the oil and gas industry.
regulations* that replace outdated technology and practices with remote tank gauging technologies, reducing or eliminating the need for manual tank gauging.

Health professionals need to recognize the signs and symptoms of exposure to high concentrations of HGVs and possible O₂-deficient atmospheres in oil and gas workers. Health and safety professionals need to recognize and act on nonfatal warning signs and symptoms, such as dizziness, confusion, immobility, and collapse in oil and gas workers who might have been exposed to high concentrations of HGVs and to O₂-deficient atmospheres. As required by OSHA regulations, employers should reduce or eliminate the hazard; this can include practices that allow for alternative fluid sample collection points, remote monitoring of fluid levels, proper use of gas monitors, respiratory protection meeting OSHA requirements, and worker training. Employers also need to ensure that workers do not work alone where they might have risks for exposures to high concentrations of hydrocarbons and low-O₂ environments.

Having automated external defibrillators available at worksites is also important. Medical examiners and coroners investigating workplace fatalities need to be aware of the possibility that exposure to high concentrations of HGVs and O₂-deficient atmospheres can result in sudden cardiac death in oil and gas extraction workers. Analysis of antemortem or postmortem blood for documentation of HGV exposure is available from clinical toxicology laboratories.

**Acknowledgments**

Maggie Cook-Shimanek, Eric Esswein, Ryan Hill, Bradley King, John Snawder, Ann Krake.

---

Summary

What is already known on this topic?

Oil and gas extraction workers experience high rates of traumatic work-related fatalities. Tank gauging and sampling activities can expose workers to high concentrations of hydrocarbon gases and vapors (HGVs), in some cases at levels immediately dangerous to life or health.

What is added by this report?

Exposure to high concentrations of HGVs and oxygen-deficient atmospheres during manual tank gauging and sampling can pose a risk for sudden cardiac death. Although the first two deaths described in this series were not immediately recognized as work-related, the occurrence of seven additional deaths under similar circumstances suggests that HGV exposure during manual tank gauging and sampling can be life-threatening.

What are the implications for public health practice?

Health care professionals need to be aware of the risks to oil and gas extraction workers related to exposure to high concentrations of HGVs and to oxygen deficiency. Medical examiners and coroners investigating worksite fatalities need to be aware that these exposures can result in sudden cardiac death and include appropriate toxicology analyses in their investigation. A thorough worksite assessment is warranted if any workers exhibit signs or symptoms of HGV exposure or oxygen deficiency. Implementation of measures to reduce or eliminate HGV exposures is important, including practices that allow for alternative fluid sample collection points, remote monitoring of fluid levels, proper use of gas monitors, respiratory protection meeting the requirements of the Occupational Safety and Health Administration, and worker training.

References

Volatile Organic Carbon (VOC) Exposures During Tank Gauging Operations

Todd Jordan, MSPH, CIH
OSHA Health Response Team
Acknowledgements

• OSHA Health Response Team
  – Phil Smith, PhD, CIH
  – Jedd Hill, MS
  – Stan Smith

• OSHA Salt Lake Technical Center
  – Daren Pearce, Chemist

• Region 8 OSHA Staff
  – Bismarck AO
  – Regional Office
Accuracy of Bakken Volatility Tests Face More Challenges

Industry, Canadian Officials Fear That Explosive Risk of North Dakota Oil Is Understated

By CHESTER DAVISON and RUSSELL GOLD

Nov. 12, 2014 8:11 p.m. ET

Regulators set to decide on crude-by-rail shipping rules are relying on testing methods that may understated the explosive risk of the crude, according to a growing chorus of industry and Canadian officials.

The tests' accuracy is central to addressing the safety of growing crude-by-rail shipments across the continent: whether Bakken crude contains potentially dangerous levels of dissolved gases. Several trains carrying Bakken crude have exploded after derailing, including a fiery accident last year that killed 47 people in a small town in Quebec.

The North Dakota Industrial Commission is expected to rule Thursday on what steps, if any, producers must take to strip volatile gases out of crude oil before loading it into railroad tank cars.

The regulator's decision will be based, at least in part, on the testimony of a half-dozen oil executives who urged the state to consider the conclusions of a study by the North Dakota Petroleum Council, a lobbying group for energy producers. That study found Bakken crude was no more volatile than other so-called light crudes commonplace in Texas and elsewhere.

But that finding may reflect a problem with the methodology, which could have allowed flammable gases, or light ends, to escape in the process of collecting and handling the crude samples. This means that tests aimed at determining how explosive crude is within a tank car might be significantly underestimating the risk of combustion.

Concern about the validity of those results prompted Canadian federal authorities to commission new tests, to be carried out later this year and in early 2016, that will use newer methods designed to prevent light ends from escaping.

The U.S. government recently tested the same North Dakota crude using both the older and newer methods to compare the results.
Preliminary Field Studies on Worker Exposures to Volatile Chemicals during Oil and Gas Extraction Flowback and Production Testing Operations

Categories: Oil and Gas

August 21st, 2014 10:00 am ET - Eric J. Forsman, MSPH, CH, John Snowdon, PhD, DAST, Bradley Klop, MPH, CH, Michael Breitenstein, BS, and Marita Alexander-Scott, DVR, MS, MPH.

Flowback Operations
Flowback refers to process fluids that return from the well bore and are collected on the surface after hydraulic fracturing. In addition to the mixture originally injected, returning process fluids contain a number of naturally occurring materials originating from within the earth, including hydrocarbons such as benzene. After separation, flowback fluids are typically stored temporarily in tanks or surface impoundments (silted pond) and recovered oil is pumped to production tanks, which are fixed systems at the well pad. Figure 1 shows two separators (white), six flowback tanks (tan), and multiple water tanks (yellow) arranged in a typical side-by-side manner in the background of the photo. Workers periodically gauge the fluid levels in both flowback and production tanks with hand-held gauges (sticks and tapes) through access hatches at the top of the tank (Figure 2).

Initial Exposure Assessments during Flowback and Production Testing Operations
NIOSH exposure assessments included short-term and full-shift personal breathing zone and area air sampling for benzene and other hydrocarbons using standard methods and analyses listed in the NIOSH Manual of Analytical Methods.[9] Real-time, direct reading instruments were also used to characterize peak and short-term exposures to workers and various workplace areas for volatile organic compounds, benzene, carbon monoxide, hydrogen sulfide, and flammables/combustible atmospheres. We conducted biological monitoring by collecting pre- and post-shift urine samples from flowback workers to evaluate exposure to benzene. Benzene metabolites found in a worker's urine indicate some level of exposure during the work shift. Benzene is an exposure concern because the Department of Health and Human Services’ National Toxicology Program has determined that it is a known carcinogen (i.e., can cause cancer).[10] The International Agency for Cancer Research and the FDA have also determined that benzene is carcinogenic to humans.[11,12]

Findings
Flowback tanks can be exposed to recommended levels of benzene due to its presence in the returning process fluids. In addition, a number of volatile organic compounds were measured above the threshold limit value (TLVs) and personal and area air sampling for these compounds were also collected. The composition of the returning process fluids may change during the process of returning fluids to the production tanks, which may result in shifts of benzene concentrations, as well as other compounds. Finally, benzene levels may also vary during the day as flowback fluid levels change and work activities are conducted.
OSHA Problem Solving Initiative (PSI)

• Examine serious S&H hazards in Oil and Gas
  – Tank Gauging and Similar Operations
    • Hydrocarbon exposures compared to Short Term Exposure Limits (STEL), Ceilings (C), and Immediately Dangerous to Life and Health (IDLH)
    • \( O_2 \) deficiency
    • Combustible Vapors/Gas
Example Hydrocarbon Production Tanks
Exposure Activities
Phase 1 Sampling
Bulk Crude Oil Sample Composition
<table>
<thead>
<tr>
<th>Substance</th>
<th>OSHA 8-hr TWA (ppm)</th>
<th>OSHA Ceiling (ppm)</th>
<th>OSHA Max Peak above Ceiling for 8-hr Shift (ppm)</th>
<th>NIOSH IDLH (ppm)</th>
<th>Cal/OSHA PEL (ppm)</th>
<th>NIOSH REL (ppm)</th>
<th>ACGIH® 2014 TLV® (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>10</td>
<td>25</td>
<td>50 (10 min)</td>
<td>500</td>
<td>1 5 (ST)</td>
<td>0.1 1 (ST)</td>
<td>0.5 2.5 (ST)</td>
</tr>
<tr>
<td>Butane</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>1900*</td>
<td>800</td>
<td>800</td>
<td>1000 (ST)</td>
</tr>
<tr>
<td>Cyclohexane</td>
<td>300</td>
<td>None</td>
<td>None</td>
<td>1300</td>
<td>300</td>
<td>300</td>
<td>100</td>
</tr>
<tr>
<td>Ethyl Benzene</td>
<td>100</td>
<td>None</td>
<td>None</td>
<td>800</td>
<td>100 125 (ST)</td>
<td>100 125 (ST)</td>
<td>20</td>
</tr>
<tr>
<td>Heptane</td>
<td>500</td>
<td>None</td>
<td>None</td>
<td>750</td>
<td>400 500 (ST)</td>
<td>85 440 (ST, 15min)</td>
<td>400 500 (ST)</td>
</tr>
<tr>
<td>N-Hexane</td>
<td>500</td>
<td>None</td>
<td>None</td>
<td>1100</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Pentane</td>
<td>1000</td>
<td>None</td>
<td>None</td>
<td>1500*</td>
<td>1000</td>
<td>120 610 (C, 15min)</td>
<td>1000</td>
</tr>
<tr>
<td>Propane</td>
<td>1000</td>
<td>None</td>
<td>None</td>
<td>2100</td>
<td>1000</td>
<td>1000</td>
<td>Appx. F TLV Book</td>
</tr>
<tr>
<td>Toluene</td>
<td>200</td>
<td>300</td>
<td>500 (10 min)</td>
<td>500</td>
<td>10 150 (ST)</td>
<td>100 150 (ST)</td>
<td>20</td>
</tr>
<tr>
<td>Xylene</td>
<td>100</td>
<td>None</td>
<td>None</td>
<td>900</td>
<td>100 150 (ST)</td>
<td>100 150 (ST)</td>
<td>100 150 (ST)</td>
</tr>
</tbody>
</table>
Anesthetic Properties of Light Hydrocarbon Gases and Vapors

- Methane and ethane have anesthetic properties only when $O_2$ is diluted <18% (simple asphyxiants)
- $C_3$ and higher hydrocarbons may induce anesthesia at lower concentrations (close to IDLH values for $C_3$ and $C_4$)
- Concentration needed to produce anesthesia decreases with carbon number: oil/air partition coefficient used to predict anesthetic potency (Meyer 1899, Overton 1901)
  - $CH_4 = 0.89$
  - $C_4H_{10} = 17$
  - $C_6H_{14} = 87$
Initial Solution for IDLH/Peak Sampling

Collect breathing zone “grab” sample at time of greatest exposure potential

Stabilize VOC analytes on sorbent media for lab analysis using validated methods
Laboratory Analysis

CT Front Section

CT Back Section

Retention Time (min)
Phase 1: Laboratory Analysis
Breathing zone grab samples from gauging, stabilized on sorbent tubes

<table>
<thead>
<tr>
<th>Analyte</th>
<th>Concentration Range</th>
<th>Short-Duration Standard (or IDLH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>n-Pentane</td>
<td>9.6 – 623 ppm</td>
<td>1,500 ppm (IDLH)</td>
</tr>
<tr>
<td>2-Methylbutane</td>
<td>2.6 – 408</td>
<td>None</td>
</tr>
<tr>
<td>Benzene</td>
<td>1.6 – 4.0</td>
<td>50 (Z-2, Peak)</td>
</tr>
<tr>
<td>Cyclohexane</td>
<td>7.2 – 15.6</td>
<td>2,000 (IDLH)</td>
</tr>
<tr>
<td>Methyl cyclohexane</td>
<td>5.3 – 14.8</td>
<td>1,200 (IDLH)</td>
</tr>
<tr>
<td>n-Hexane</td>
<td>29.2 – 143</td>
<td>1,100 (IDLH)</td>
</tr>
<tr>
<td>n-Heptane</td>
<td>9.5 – 16.0</td>
<td>750 (IDLH)</td>
</tr>
<tr>
<td><strong>Total Hydrocarbons</strong></td>
<td>212 – 1,460</td>
<td>None</td>
</tr>
</tbody>
</table>

^ Does not include C\textsubscript{3} and C\textsubscript{4} hydrocarbons
Field Analysis Data

- To avoid the loss of light hydrocarbon gases, breathing zone samples were immediately collected onto a tri-bed needle trap for analysis by field-portable GC-MS.
Phase 2: Breathing Zone and Area
Grab Sampling Train
Phase 2 Laboratory Results
(preliminary and conservative estimates)
Area grab samples ~1.5’ above hatch opening during gauging

<table>
<thead>
<tr>
<th>Analyte</th>
<th>Concentration Range</th>
<th>IDLH (ppm)</th>
<th>Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propane</td>
<td>Pending (~1%), 10,000 ppm</td>
<td>2,100</td>
<td>~5x</td>
</tr>
<tr>
<td>Hexane</td>
<td>Pending</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Butane</td>
<td>S1=5.3%, 53,000 ppm S2=9.1%, 91,000 ppm</td>
<td>1,900</td>
<td>28-48x</td>
</tr>
<tr>
<td>Isopentane</td>
<td>S1=1.2%, 12,000 ppm S2=0.9%, 9,000 ppm</td>
<td>1,400</td>
<td>6-9x</td>
</tr>
<tr>
<td>Pentane</td>
<td>S1=1.7%, 17,000 ppm S2=1.0%, 10,000 ppm</td>
<td>1,500</td>
<td>7-11x</td>
</tr>
<tr>
<td>C₄+C₅ (Total)</td>
<td>S1=8.2%, 82,000 ppm S2=11%, 110,000 ppm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Observations and Findings
Vapor Emissions

• Infrared photo demonstrating vapor emissions upon opening tank hatch
Flowback
Configuration Matters
Vapor Emissions During Hatch Openings
Findings

Supplied-air respiratory protection is typically used where \( \text{H}_2\text{S} \) exposure is possible, although incorrect supply hose combinations are being used (not NIOSH-certified when parts are substituted)
Flammability Hazards
Findings

• During interviews all employees described cases where chemical exposures caused light-headedness and weakness of knees requiring the need to sit down and rest until symptoms disappeared.
  – Increased incidents when hatches are “fluttering” due to higher gas pressures
Findings

• Potential to exceed OELs and IDLH for VOCs, particularly lighter hydrocarbons (C$_3$-C$_6$)
• Potential for O$_2$ deficient atmospheres
• Flammability hazards
  – Correct use of meters for vapor exposures and O$_2$ deficient atmospheres. Generally only using H$_2$S meters
Recommendations

• Conduct additional chemical exposure assessments of tank gauging, tank opening and flow-back operations
  – Solo operations (drivers)
  – Pumpers (gauging multiple tanks)
  – Effects of environmental conditions
• Examine and implement engineering controls
• Develop administrative and work practice controls
  – SOPs for hatch opening to reduce exposures and potential for flash fires
• Assess adequacy of PPE, particularly Respiratory Protection
Questions?

Todd Jordan, MSPH, CIH
OSHA Health Response Team

jordan.todd@dol.gov
801-233-4916