



Society of Petroleum Engineers

**SPE-184452-MS**

## **Working Together to Prevent Worker Exposures during Gauging and Sampling Activities**

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This paper was prepared for presentation at the SPE Health, Safety, Security, Environment, & Social Responsibility Conference - North America held in New Orleans, Louisiana, USA, 18–20 April 2017.

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### **Abstract**

**Background:** Workers responsible for manually gauging or collecting fluid samples from oilfield production tanks can be exposed to lethal doses of hydrocarbon gases and vapors as well as oxygen deficient environments. Nine worker deaths related to gauging and sampling were identified during 2010–2014 (Harrison et al., 2016) and, since 2015, a campaign to increase awareness of this hazard has reached thousands of workers and companies. Despite this, many oilfield companies continue to require workers to open tank hatches to gauge tanks and collect fluid samples. Continuing this practice could be due to the perceived costs or measurement inaccuracies of implementing alternative methods, regulatory barriers, or because it has historically been conducted in this manner. In response, the American Petroleum Institute released a new safety standard (API MPMS 18.2) describing alternative methods for measuring crude oil without opening tank hatches, and some companies have proactively implemented safer technologies and practices to eliminate the hazard. **Methods:** This paper will cover five case studies featuring companies that have examined their workers' exposures and implemented safer methods for gauging and sampling. Unanticipated benefits as well as challenges are also covered. **Conclusions:** The types of approaches featured in these case studies have the potential to nearly eliminate manual tank gauging and sampling in their operations. These companies demonstrate that using alternative methods is not only safer, but a wise investment for a company's bottom line. **Novel Information:** This paper contains the first report of how companies successfully implemented alternative methods to reduce hydrocarbon gas and vapor exposures associated with opening tank hatches, and how they addressed cost and regulatory barriers.

*The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health.*

### **Introduction**

Previous reports indicate that at least nine workers died during 2010–2014 while working around open tank hatches ("thief hatches") at crude oil production tanks. It is believed that exposure to hydrocarbon gases and vapors and associated oxygen deficiency was either a primary or contributory factor in these

deaths (Harrison et al., 2016; NIOSH, 2016). Workers traditionally open hatches to gauge the level of fluid in the tank or to collect a sample to test the quality of the fluid prior to sale (i.e., custody transfer). Exposure assessments completed by OSHA and NIOSH have revealed the potential for acute overexposures of gases and vapors to workers during flowback operations and while gauging and sampling production tanks (Esswein et al., 2014; Jordan 2015). Additionally, the volume of hydrocarbon gas and vapor released is such that workers may also be in an oxygen-deficient atmosphere. Companies have responded to this newly recognized hazard by implementing a variety of controls to eliminate or reduce the number of times a hatch is opened by workers to complete these tasks. In addition, the American Petroleum Institute (API) issued a new standard in their Manual of Petroleum Measurement Standards (MPMS), Chapter 18.2 "Custody Transfer of Crude Oil from Lease Tanks Using Alternative Methods" that describes the methods and equipment needed for gauging using alternative methods (API, 2016). Subsequently, the Bureau of Land Management (BLM) updated their measurement rules for oil and gas leases on federal and tribal land to include API's 18.2 standard (BLM, 2016). These policy changes may help to reduce manual gauging and sampling in the future.

Despite this well known hazard, some oilfield companies continue to require workers to open tank hatches to gauge tanks and collect fluid samples. This could be due to perceived measurement inaccuracies, cost of implementing alternative methods, or concern with regulatory barriers. Some companies also report that manual methods are "just the way it has always been done". The following case studies will highlight five companies' initiatives at evaluating and implementing different controls and the results achieved towards reducing exposure to hydrocarbon gases and vapors for their employees. Each case study was provided by the company safety and health representative and features at least one aspect of each company's efforts to reduce or eliminate exposure during tank gauging and sampling. The case reports do not provide a comprehensive description of the companies' employee protection and exposure prevention programs.

## Case Studies

### Case Study 1: BHP Billiton, Implementing Automatic Tank Gauging and Other Controls

**Summary.** This case study describes the measures taken to prevent possible inhalation exposures to this petroleum exploration and production (E&P) company's workers involved in manual tank gauging, sampling, and fluid transfer activities at oil and gas well sites. The activities described below have resulted in a 98% reduction in the number of tank hatch openings, from over 15,000 openings to approximately 260 openings (with appropriate controls) per month. The company was able to implement engineering controls immediately without additional expenditure when the dangers of opening a thief hatch were recognized.

**Background.** In the summer of 2014, following a routine industrial hygiene exposure evaluation, it was found that some of the operation and measurement technicians in the Permian Production Unit (PPU) field experienced benzene exposures that approached or exceeded company requirements. Additionally, field personnel reported that when opening thief hatches (Figure 1) to gauge tanks, sometimes the gas pressure would blow their hard hat off or result in dizziness. At the time, no connection had been established with thief hatch opening and serious injury or death. Following industry standards at the time (API MPMS 18.1, 2002), each tank was manually gauged and sampled (thieved) for each load. Company wide, the number of measurements taken at open thief hatches exceeded 15,000 per month.



Figure 1—Open thief hatch

To address exposure concerns resulting from this activity, a task force called the Thief Hatch Group, comprised of company staff from marketing, operations, engineering, risk, technology, instrumentation and automation, and safety, was formed. In an effort to decrease the risk to workers from this hazard, an engineering solution, Automated Tank Gauging (ATG), was identified and implemented. The use of ATG reduced the number of times manual tank gauging was needed, reduced operating costs, and improved productivity. ATG was instituted at well sites across the PPU and policies implemented that prohibited workers from opening thief hatches without authorization. Only Instrumentation and Automation teams were allowed to measure tanks, with a buddy system and with appropriate respiratory protection. Visits to trucking companies were made to discuss the options for transfer of fluids without opening a thief hatch. All of the trucking companies had existing capability for obtaining a sample as part of their hydrogen sulfide exposure safety procedures. These companies also agreed to retrofit their truck load lines to measure volumes from the ground (not at the thief hatch) in preparation for the new API 18.2 measurement standard.

At an industry health and safety conference in December 2014, attendees discussed the potential link between worker deaths and tank gases and vapors. In at least one of the fatalities, low oxygen levels were a probable factor. The Thief Hatch Group initiated a project to characterize the risk of low oxygen levels (in addition to hydrocarbon gases) when opening a thief hatch.

**Methods.** In May 2015, the company performed a time and motion study in the field. The goals of the study were to further characterize hazards at open tank hatches. Oxygen and lower explosive limit (LEL) levels were measured when the thief hatch was opened as well as the length of time it took for vapors to disperse. Experts from four-gas monitor and respiratory protection supply companies participated in the study and evaluated different methods of opening hatches. For example, the team analyzed if a difference in risk existed by opening the thief hatch quickly (e.g., flipping it open) or slowly. Finally, the team worked to replicate the data at multiple well sites with similar production.

**Results.** Table 1 represents the most significant data gathered from the workers' four-gas monitors. Some of the findings were:

- Oxygen deficiency was present regardless of the method used to open the thief hatch (quick open vs. slow open).
- Knowledge and understanding of wind speed and direction and taking appropriate action to remain upwind was crucial.
- There is significant pressure in the tank when the thief hatch is opened even if blanket gas are set low at two ounces/square inch of pressure (0.125 PSI).
- In areas where a worker would be present, LEL levels exceeded 100% when the hatch was opened and remained so for at least 200-410 seconds in every test, thus the worker could be in an explosive atmosphere for up to 7 minutes after the hatch was opened.

**Table 1—Oxygen and LEL levels at thief hatch after opening**

Test	Location			
	Well Site 1	Well Site 1	Well Site 2	Well Site 2
	Quick open	Slow open	Quick open	Slow open
Oxygen level after opening hatch*	16.3% for 83 seconds	13.8% for 50 seconds	14.9% for 98 seconds	19.4% for 1 second
LEL level after opening hatch**	100% for 280 seconds	100% for 410 seconds	100% for 230 seconds	100% for 320 seconds

As a result of the study findings, the company took the following actions:

- Updated the thief hatch respiratory program to include requirements for a self-contained breathing apparatus (SCBA) when tank opening is necessary.
- Tanks with supplied air hose lines were mounted on workers' trucks.
- Respiratory fit testing, medical/respiratory assessments were performed along with training.

Also, administrative efforts were employed to further reduce the potential for exposure:

- Restrictions were placed on catwalks requiring authorization.
- Barriers and signage were placed on the cat walks prohibiting access (Figure 2).
- Standard operating procedures for opening thief hatches were developed and communicated to workers.



**Figure 2—Restricted Catwalk**

**Conclusions.** The Thief Hatch Group's efforts reduced the risk to workers associated with exposures during tank gauging more than 98 percent by implementing the use of automatic tank gauging, reducing the number of potential exposures per month from 15,000 to 260. This was achieved by applying the hierarchy of controls, a widely accepted system that emphasizes the most effective controls (elimination, substitution, and engineering) as a first consideration (NIOSH), supplemented by industrial hygiene exposure data, and supported by an internal education and awareness program.

Importantly, there has been a significant outreach program to other companies and regulators from the Measurement Team who have shared their knowledge and participated in the writing of the new API 18.2 measurement standard.

Currently, the company continues to test engineering solutions and work closely with regulatory agencies to minimize the opening of thief hatches as the primary means for oil measurement. Opening a thief hatch today requires authorization, personal protective equipment (PPE), certification, and strict adherence to the standard operating procedure. The company's employees continue to work with supplied air when opening a thief hatch or working on an open tank. Oil haulers are prohibited from opening thief hatches. Most

importantly, the company's engineers and measurement team continue to search for ways to reduce potential exposures.

## **Case Study 2: Noble Energy, ATLAS – Advancing Alternative Methods for Traditional Tank Gauging**

**Background.** Developing unconventional shale plays has created worker safety, health, and environmental emission hazards when traditional manual tank measurement practices are utilized. The production and storage of this unconventional shale oil has led to an increased release of hydrocarbon gas and vapors during the standard practice of manual tank gauging and sampling for crude oil custody transfer. During this process, the hydrocarbon gas and vapors would be released into the atmosphere and potentially expose fluid haulers to hydrocarbons exceeding Immediately Dangerous to Life and Health (IDLH) concentrations, and a potential low oxygen environment. As a leader of the industry, this operator sanctioned a multi-disciplinary team to engineer out the hazards and reduce air emissions, while maintaining measurement accuracy, with crude oil truck sales.

As part of a continual effort to improve safety, health, and reduce emissions in the U.S. onshore oil and gas industry, this Exploration & Production (E&P) company developed, tested, and implemented the ATLAS (Alternative Truck Loading Anson System). ATLAS is an innovative industry safety standard for crude oil truck transportation that eliminates manual gauging and sampling operations on crude oil storage tanks across a wide variety of production equipment. The company's ATLAS process is endorsed by a variety of external stakeholders and contributed to the development of a new API standard in July 2016 (API MPMS 18.2).

**Methods.** The ATLAS program is a combination of 1) a new engineering control for quality determination, 2) automated tank gauging (ATG) for quantity determination, and 3) maintenance procedures. First, the ATLAS's engineering control was the development of a patent pending mixing/sampling device designed to be portable and easy to use for the quality testing aspect of tank gauging custody transfer. The device was lab tested for mixing performance and sampling accuracy before being introduced for field testing. Second, the company tested and vetted our existing automated tank gauging (ATG) technology which was currently installed (but not consistently used) on most of our locations, as well as existing truck-based automation technology. Data from over 400 truck loads of crude oil was examined, comparing quantity and quality measurements from traditional manual methods (API MPMS 18.1) to the proposed ATLAS method. Third, by treating ATGs as custody transfer devices, maintenance procedures were developed and implemented to ensure the accuracy, repeatability, and performance of the ATGs.

**Challenges.** Measurement certainty and crude oil truck driver acceptance were significant hurdles. At the time of development and testing, it was unknown if these automated technologies would meet custody transfer standards for crude oil quantity and quality transactions. There were also several concerns with training and other procedures that affected acceptance among the crude oil truck drivers. Conventional (manual) crude oil truck measurement practices, known as API 18.1, were deeply rooted over several decades amongst external stakeholders, U.S. onshore producers, and the crude oil trucking industry. Comprehensive training programs and external stakeholder communications were required to achieve acceptance of the new procedures. The ATLAS process had to deliver measurement certainty that was improved over conventional methods at a relatively low cost in order to be scalable to all production facilities and the trucking industry.

**Results.** With the execution of the second phase of the ATLAS, the operator only opens thief hatches for maintenance activities and verification of levels when ATGs are not present. Collectively, the ATLAS method allows the company's haulers to perform all necessary functions from the ground, near the controls of the truck. As a result, this method eliminates the need to ascend or descend stairs or open a thief hatch, thus

mitigating the risks of slips, trips, and falls, as well as significantly reducing the potential for exposure to hydrocarbon gases and vapors. These results were achieved through the mutual objectives and concise focus on a common goal to lead safety and health improvements across the industry. The team was comprised of a diverse group of support members from Production, Corporate Measurement, Legal, Land, Transportation Industry, Marketing, EHSR (environment, health and safety, and social responsibility), and Measurement Consultants. The team defined success with the following:

- Zero truckers on top of tanks across operator holdings.
- Scalability to all types of locations (legacy, horizontal completions) across multiple business units.
- Externally endorsed by API, BLM, State of Colorado, and Industry.
- Peer oil and gas companies requesting support from operator to develop their own version.

**Forward-looking Vision.** The ATLAS process has been included in an API Standard that will be utilized to reduce safety and health hazards at the operator and across the entire oil and gas industry.

### **Case Study 3: Bonanza Creek Energy, Mounting Lease Automate Custody Transfer (LACT) Meters on Oil Transport Trucks**

**Summary.** This independent E&P Company worked with its primary oil hauling marketing company and their primary oil hauler to implement technology that eliminates the need for oil haulers to open thief hatches and access tank batteries. The technology implemented entailed the addition of lease automated custody transfer (LACT) meters that are mounted on oil transport trucks. The use of mobile truck-mounted LACT units eliminates the need for oil haulers to access the tank batteries and open thief hatches. The technology also allows for API approved custody transfer of oil from sites that are not currently equipped with permanent or skid mounted LACT units. Use of mobile truck mounted LACT units is not currently universally used throughout the company's operations; the technology was piloted in 2015 and expanded to a total of four units operating on the company's leases. The use of mobile LACT units has resulted in a substantial reduction of exposure risk to oil haulers, reductions in air emissions, and more stable facility operations due to consistent vapor pressures in storage tank systems. This innovation addresses the issues of worker safety and health, protects the environment and the community through reduced air emissions, and improves operational efficiency.

**Methods.** The mobile LACT unit is new to the industry in the Denver-Julesburg Basin (i.e., DJ Basin) in Northeast Colorado but has been utilized in the Bakken oil fields. The primary oil hauler utilizes the technology for select operators in the Bakken and offered to pilot the program in the DJ Basin upon the company's request. A truck mounted LACT unit utilizes a Coriolis meter to measure the volume of oil as it is being delivered to the tanker. The Coriolis meters are mounted on the truck (Figure 3) along with a delivery system that meets API MPMS 18.1 specifications.



Figure 3—Mobile LACT Unit

**Results.** Over the course of twelve months, this E&P Company hauled oil from approximately 175 tank batteries. Three of the company's newest facilities are equipped with permanent LACT units but the remaining 172 are not. Approximately 172 locations require oil hauling operations and thus have the potential for some worker exposure to hydrocarbon vapors and oxygen deficiency from manual gauging and sampling. On any given day in the company's Wattenberg fields, there are approximately 60–70 haul trucks and haul truck drivers. Conversion of four of the trucks to mobile LACT units represents greater than a 12% reduction in potential hydrocarbon and oxygen deficiency exposures by haul truck drivers. Additionally, the company focuses these truck routes on those locations that are considered to have the highest potential for emissions (e.g., large batteries). Expansion of the use of mobile LACT units would continue to increase the benefits to our hauler workforce and adoption by other operators could eventually eliminate exposures from working around open thief hatches as an oil field hazard.

**Environmental Protection and Community Relations Improvements.** Every time an oil hauler opens a thief hatch there is a release of volatile organic compounds (VOCs), and lower molecular weight hydrocarbon gases such as methane. VOCs are classified as ozone pre-cursor compounds and methane is one of the most potent greenhouse gases. It is important for oil and gas operations to minimize VOC and methane emissions to decrease its contribution to ozone non-attainment and climate change. The ozone standard is a health-based standard and is important for protecting the health and welfare of the communities in which E&P companies operate. The Environmental Protection Agency (EPA) recently lowered the ozone standard to 70 parts per billion from 75 parts per billion, causing the Denver Front Range to be categorized as moderate non-attainment (as opposed to marginal) (EPA, 2015). This categorization triggers requirements for the state of Colorado that require planning and analysis to define specific measureable means to reduce ozone precursors.

The use of mobile truck mounted LACT decreases the amount of VOC emissions because the thief hatch is not required to be opened during loadout and the tank storage system does not have to be depressurized. The calculated emissions reduction from this change in activity for each tank is 298 pounds of VOC. The company estimates that 12% of its oil was hauled in this manner during the course of the last twelve months, which resulted in an estimated reduction in VOC emissions of 356 tons and methane emissions by 3.2 tons. As a result of this innovation, the company was the recipient of a state association's Operator of the Year Award.

#### **Case Study 4: Range Resources, a Description of Alternative Methods for Gauging Gas Busters during Flowback**

**Background.** The process of allowing fluids to flow from a well following well stimulations, such as hydraulic fracturing, is referred to as flowback. Flowback fluids may contain water, brine (salts), proppant (sand, ceramic, etc.), other solids (sediment, plug pieces), dissolved solids, natural gas, and other

hydrocarbon compounds. The flowback process begins with filtering the solids from the fluid and then entering a separator(s). Separators may be two phase (gas/liquid) or three phase (gas/petroleum/water). Initially, operators may divert fluids from the separator and flow fluids directly into a "gas buster" until gas is detected. The "gas buster" is a tank used to remove entrained natural gas and hydrocarbons in the water. After the gas buster, fluids are retained in a storage tank for either reuse or disposal. Natural gas during flowback is permitted by the Environmental Protection Agency (EPA) to be flared until substantial gas is produced which then must be sent to the sales line. A flowback/gas-buster tank is depicted in Figure 4.



Figure 4—Flowback/Gas-Buster Tank

The gas buster is a vessel containing a series of baffles that discharges the water from the bottom of the vessel releasing the entrained gas, so as not to accumulate in the water storage tank. The vessel may have an open or closed top. Water is pumped to the storage tank(s) from the bottom of the gas buster. Fluid retention in the gas buster is important to ensure as much entrained gas as possible is released from the water before being pumped into the storage tank(s). The longer the retention (accumulation of fluid), the more entrained gas and hydrocarbons will be released. To prevent overfilling the gas buster, the water level must be routinely gauged. If the well contains hydrocarbons (e.g., condensate), the hydrocarbons will separate in the gas buster. To prevent hydrocarbons from being pumped to the water storage tanks, the level of hydrocarbons must also be routinely gauged.

**Methods and Results.** Manually gauging the water/hydrocarbon level in the gas buster is one gauging method; however, this can result in worker exposure to hydrocarbon gases and vapors when the hatch is opened. Alternative methods have been explored and those with promise are utilized. One initial method to gauge liquid levels in the gas buster is with the use of infrared (IR) cameras. IR cameras are able to scrutinize between solids, water, hydrocarbons, and gas/vapor layers in the tank (Figure 5). These cameras are not very costly but are not intrinsically safe. From a distance outside an exclusion zone, the cameras do lose their ability for sharp attenuation. In order to gauge the tank using IR cameras, the outside of the gas buster must be marked. Accuracy in gauging liquid levels in the tank with an IR camera is approximately two inches.

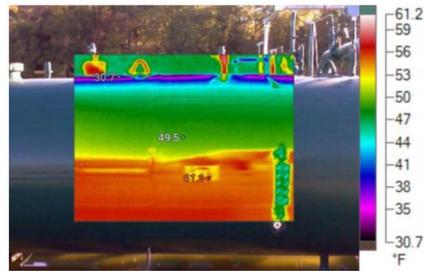


Figure 5—Fluid Levels using Infrared Camera

Another gauging method that was tested was ultrasonic level sensors (not pictured). Ultrasonic sensors are non-contact sensors where the sensor emits high frequency acoustic waves that are reflected back to and detected by the emitting transducer. One drawback of this technology is that ultrasonic sensors are affected by moisture, temperature, and pressures. This drawback primarily impacts flowback operations and not closed top tanks and single phase fluids where the sensors function well. The ultrasonic sensors that were tested detected multi-phase fluids but required calibration of the upper phase so as to measure the upper phase quantity. During flowback, initially there is no upper phase and so a calibration of the sensor would have to be accomplished after hydrocarbons have accumulated in the gas buster. Accuracy of the sensor is based on the calibration and is within 0.2%.

The most promising gauging method to date is guided wave radar. This sensor can be intrinsically safe and is easy to attach to the gas buster (Figure 6). Calibration does not require a predesignated fluid level, accuracy is within 0.08 inches, and operating temperatures are  $-320^{\circ}\text{F}$  to  $840^{\circ}\text{F}$ . The sensor can measure tanks up to 148 feet deep. The distance from the reference point to the product surface is measured. High-frequency pulses are injected to a probe and led along the probe. The pulses are reflected by the product surface, received by the electronic evaluation unit and converted into level information. When the high-frequency pulses hit the surface of the medium, only a percentage of the transmission pulse is reflected. The pulse is reflected once more at the interface point to a second medium. What makes this technology attractive is fluid levels may be transmitted to various communication media outside the exclusion zone (Figure 7).



Figure 6—Guided Wave Radar



Figure 7—Guided Wave Radar Communication Device

The company has successfully implemented guided wave radar and has eliminated the need for personnel to manually gauge the liquid levels in the open top gas buster during flowback.

## Case Study 5: Southwestern Energy, Protection of Workers During Non-Routine Tasks

**Background.** The best control method to control worker exposure to hydrocarbon gases and vapors in pressurized holding vessels (production tanks) is to eliminate the need for manual gauging and sampling, which requires opening tank hatches. Even though the elimination of manual tank gauging may be feasible during normal operations, there are still non-routine activities which may result in worker exposure to hazardous concentrations of hydrocarbon gases and vapors. The purpose of this case study was to 1) quantitatively evaluate the potential exposure for workers when controls are not implemented and 2) evaluate the risk reduction and worker protection when engineering and administrative controls were applied.

**Methods.** Due to the potential for acute worker exposure to hydrocarbon gases and vapors when the tank thief hatch is opened, a combination of conventional and unconventional methods were utilized to characterize and better understand exposures. These methods included area samples (collected approximately one foot directly above the tank opening) and personal breathing zone samples (PBZ), collected within 6–9 inches of the worker's nose or mouth). The equipment utilized during the data collection included:

- Nondispersive Infrared Direct Reading Personal Sampler: % Methane, % LEL, Oxygen, Carbon Monoxide
- Wheatstone Bridge – Direct Reading Personal Sampler: % LEL
- Flame Ionization Detector (FID) – Direct Reading Personal Sampler: Total VOC  $\leq 50,000$  ppm
- VeriAir Flex – Area Sampler: Total VOC
- Pre-Vac 250 mL Bottle – Area Sampler: BTEX
- 226-01 Charcoal Tube with Pump – Integrated Personal Sample: BTEX
- Photoionization Detector (PID) with 10.6 eV lamp – Non-Specific Direct Reading Personal Sampler: VOC  $\geq 5$  carbons

The tests were conducted at three production locations. These locations were chosen for this study based on the product composition, the natural air movement at the location, and the setup of the production equipment (i.e., combustors, gas processing units, flares). Over a two day period and using appropriate personal protective equipment (PPE), each location was assessed for potential exposure to atmospheric hazards during manual tank gauging *without* engineering controls (Day 1), and potential exposure to atmospheric hazards during manual tank gauging *with* a combination of engineering and administrative controls (Day 2). During each evaluation, the same sampling instrumentation and sampling media referenced above was used for exposure characterization.

**Controls.** The isolation of the production tanks occurred at either the separator or at the production tank. For production scenarios that allowed (such as on the downtime cycle on a plunger lift well), the separator was isolated to prevent fluids from being released into the production tank during gauging and sampling. For production scenarios that contained a continuous influx of fluids and isolation at the separator was not a viable option, isolation was obtained at the production tank itself. As pictured in [Figure 8](#) and [Figure 9](#), ball valves were utilized on each interconnection between the production tanks. For each ball valve that could not be readily accessed from the working surface, an extension was affixed to the valve and mounted for support ([Figure 8](#)). Also, the vent line system interconnecting the tanks was configured to allow each tank to be isolated independently without compromising safety systems.



Figure 8—Valve with Handle Extension



Figure 9—Valve on Overflow Line

### ***Results.***

#### **Day 1**

During data collection on Day 1, there was a significant increase in potential exposure to the worker when fluids were being dumped into the production tank. This fluid transfer resulted in additional emissions exiting through the thief hatch and into the breathing zone of the worker who was manually gauging the production tank. These events were primarily observed during the dumping/purging of the separator or during the plunger run. [Figure 10](#) shows an example set of data collected during these events which depicts high variability and rapid fluctuations that included methane spiking at one point to a volume concentration of 94.80% and a separate instance when the volume concentration of oxygen depleted to 9.80%. Also identified during the dump was an increased source VOC exposure of 689% when compared to the source VOCs collected during the initial opening of the tank. [Table 2](#) provides comparative values captured during the initial opening of the hatch and during the fluid transfer.

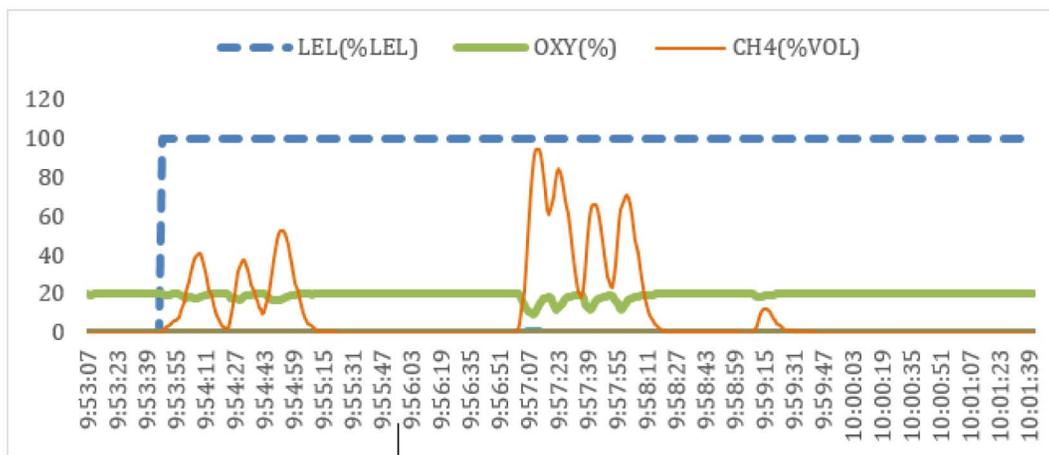


Figure 10—Multi-gas reading during fluid dump into tank

Table 2—Measurements during initial opening and when fluids were dumped into tank\*

	Monitor Location	Initial Opening	Fluid Dump
Total VOC	1 foot above hatch	76,000 ppm	600,000 ppm
FID	Breathing zone	>50,000 ppm (saturated)	>50,000 ppm (saturated)
PID	Abdomen	124 ppm	308 ppm
BTEX (226-01)	Breathing zone	Not collected	>55 ppm **
LEL	Breathing zone	100%	100%
Methane	Breathing zone	~5.0 %	94.80 %
Oxygen	Breathing zone	~19.0 %	9.80 %

\*The measurements for total VOCs, FID, PID, LEL, Methane, and Oxygen are peak measurements.

\*\*BTEX was a task based sample collected on a charcoal tube. It exceeded the 10% breakthrough limit and was a best estimation provided by the laboratory. It is a sum of ppm of benzene, toluene, ethylbenzene and toluene.

## Day 2

During the process of data collection on Day 2, there was a significant decrease in measurable hydrocarbons associated with the utilization of engineering and administrative controls. The controls and variables included 1) the isolation of production tanks at either the separator or at the production tank, depending on the production volume, and 2) variations in the amount of ventilation time allowed before the gauging process began. VOC source samples, which were collected after the production tank had been isolated and allowed to vent for 1-minute, showed a VOC reduction greater than 99% when compared to atmosphere created by the volume displacement inside of the production tank. Afterwards, the production tank was allowed an additional ventilation time of 1-minute (i.e., 2-minutes total) and VOC source samples were collected at the hatch. The values collected during both scenarios identified an additional 98% reduction in VOC after the additional ventilation time was allowed; Table 3 provides data collected during these evaluations. A comparison of the data collected between the scenarios of 1) fluids dumping while having the production tank open and 2) isolating the production tank and allowing an adequate ventilation time, showed greater than 99% reduction in the potential exposure to a hydrocarbon saturated atmosphere (Table 3).

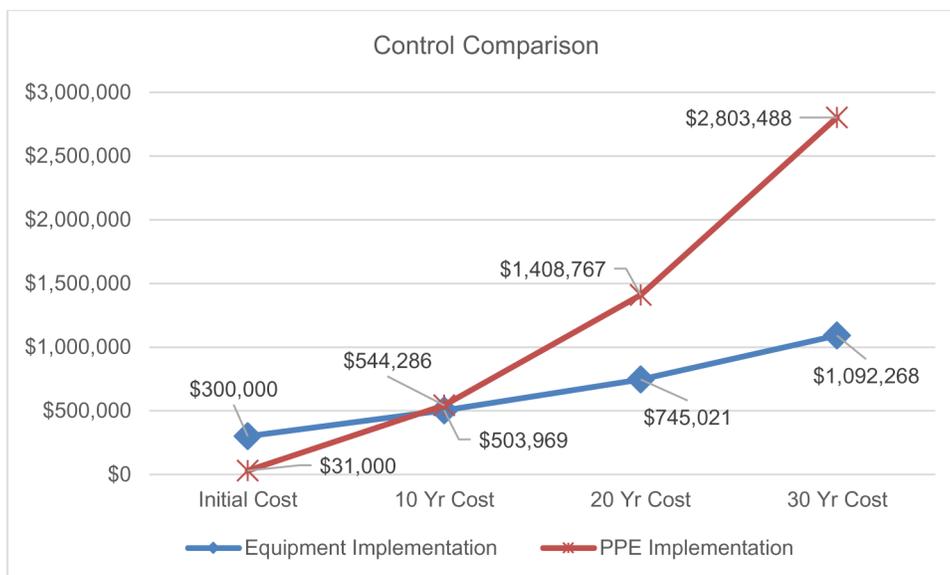
**Table 3—VOC levels during volume displacement as compared to isolation and ventilation**

	Monitor Location	Volume Displacement	After Tank Isolation and 1-Minute Ventilation	After Tank Isolation and 2-Minute Ventilation
<b>Total VOC</b>	<i>1 foot above hatch</i>	600,000 ppm	4,000 ppm	0 ppm
<b>FID</b>	<i>Breathing zone</i>	>50,000 ppm (saturated)	40 ppm	0.8 ppm
<b>BTEX (226-01)</b>	<i>Breathing zone</i>	>55 ppm *	<0.1 ppm	<0.1 ppm
<b>LEL</b>	<i>Breathing zone</i>	100 %	0.0%	0.0%
<b>Methane</b>	<i>Breathing zone</i>	94.80 %	0.0%	0.0%
<b>Oxygen</b>	<i>Breathing zone</i>	9.80 %	20.9 %	20.9%

\*The measurements for total VOCs, FID, PID, LEL, Methane, and Oxygen are peak measurements.

\*\*BTEX was a task based sample collected on a charcoal tube. It exceeded the 10% breakthrough limit and was a best estimation provided by the laboratory. It is a sum of ppm of benzene, toluene, ethylbenzene and toluene.

**Cost Benefit Analysis.** The additional cost associated with the implementation of these controls was approximately \$3,000 per location, including time, equipment, and materials. Due to the limited use of the equipment, the contents flowing through the equipment, and the probability of failure, the estimated life of the implemented controls were conservatively estimated at 15 years. The cost (time, equipment, and materials) for replacing one of the controls is estimated to be \$750. The estimated cost of these engineering controls was compared to a cost value associated with the implementation of PPE to perform manual gauging. The estimated cost associated with the PPE included an initial cost of \$3,000 per production operator for a self-contained breathing apparatus (SCBA), initial and annual medical evaluation costs (physical fitness testing, respiratory fitness tests, exam) of \$100 per operator, an annual equipment cost (maintenance, tank filling – one tank lasting 10 uses) of \$1125 per employee, and one additional man-hour due to two employees being required on-site (IDLH requirement per 1910.134(g)(3)(i)). This comparative analysis was based on an asset of 100 locations, a well lifespan of 30 years, 10 production operators that share the 100 locations, and one production tank on each location being manually gauged each month (Figure 11).



\*Based on a yearly inflation rate of 3.0%

**Figure 11—Cost benefit analysis**

In closing, the best risk reduction method is to characterize and eliminate the potential exposure of workers to the hazards associated with a task. In addition to the consideration of normal operations, non-routine operations must also be a part of the risk characterization to obtain a complete assessment. As it pertains to manual tank gauging, this study has provided an example of both engineering and administrative controls which further reduce the atmospheric hazard associated with the operation. For those using this data as a guidance to better characterize their employee's potential exposures, additional considerations should be provided to other surface equipment that has the potential to contain a similar atmosphere. Examples of this equipment may include an enclosed gas processing unit (GPU/stack pack), an enclosed separator, or vessels used to collect condensate or fluids from production lines. Measurements collected from this equipment have shown the potential to contain a similar high hydrocarbon and low oxygen atmosphere that is observed at the production tanks.

## Conclusion

Several common elements contributed to the success of each company's efforts. First was *the creation of multi-disciplinary teams* to address a common hazard. In order to achieve reduced exposures for workers, it is critical to involve personnel from engineering, operations, measurement, health and safety, and other affected divisions so that the most effective solutions can be created and collective agreement on those solutions can be obtained. Second, *placing a focus on the top layers of the hierarchy of controls* by either eliminating the hazard (not opening tanks) or by developing engineering controls to reduce potential exposures. These controls were supplemented with administrative controls, training and proper PPE to ensure the safety of workers. Third, each of these companies found that the interventions' safety and health benefits went *hand in hand with other tangible benefits*, including operational efficiencies, reductions in environmental impact, and the subsequent but increasingly essential benefit of improved corporate social responsibility to the local communities.

While exposures around production tanks have been well quantified, it is important to also evaluate other potential sources of hydrocarbon gases and associated oxygen deficiency, such as drip pots, flowback tanks, etc., as well as other operations that may pose similar hazards to workers.

This paper provides excellent examples of industry initiatives to characterize risk, implement controls, and then determine the effectiveness of the interventions to protect workers. The paper provides specific examples of controls and is a call to action for all companies in the oil and gas extraction industry to reduce or eliminate the opening of tank hatches on well sites. When hatches must be opened, it is essential to evaluate exposures and to implement methods for reducing hydrocarbon gas and vapor and other exposures. Our collective goal is to achieve a safer and healthier oilfield for the United States.

## Acknowledgements

The authors would like to acknowledge the significant contributions of Bradley King and Ryan Hill (NIOSH) in their thoughtful review and input of this manuscript as well as the Department of Health and Human Services.

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