STORAGE TANK EMISSIONS PILOT PROJECT (STEPP): FUGITIVE ORGANIC COMPOUND EMISSIONS FROM LIQUID STORAGE TANKS IN THE UINTA BASIN

Final Report to
The Utah State Legislature
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EXECUTIVE SUMMARY

Between August and October 2016, we visited approximately 400 natural gas and oil well pads in Duchesne and Uintah Counties, and used an infrared imaging camera to detect emissions of hydrocarbon gases to the atmosphere from liquid storage tanks on the well pads. Even though these tanks were equipped with emissions controls, we were able to detect one or more infrared-visible emission plumes at 39% of the well pads.

The emissions control devices are designed to capture hydrocarbon gases before they can be emitted to the atmosphere and either convert them by combustion to carbon dioxide or recover them. Most of the plumes we observed were emitted before they reached the control device. Therefore, the problem is not so much a failure of the control devices themselves but a failure to adequately deliver escaping gases to the control devices.

I. INTRODUCTION

The Utah Division of Air Quality (UDAQ) and the TriCounty Health Department (Daggett, Duchesne, and Uintah Counties) are actively engaged in understanding and improving winter ozone pollution in the Uinta Basin of Eastern Utah. UDAQ recently surveyed atmospheric emissions from the natural gas and oil production industry in the Basin. This survey is being used to create a new emissions inventory, the Utah Air Agencies 2014 Emissions Inventory, in which it has been assumed that storage tanks with emissions controls were 98% controlled. Using funds provided by the Utah State Legislature in 2016, UDAQ, TriCounty Health, and the Bingham Research Center at Utah State University Uintah Basin (USU) collaborated on the Storage Tank Emissions Pilot Project (STEPP), using infrared imaging of fugitive organic compound emissions from storage tanks at well pads. This report has been prepared by USU personnel to convey our findings to UDAQ, TriCounty Health and other stakeholders in the Basin.

The STEPP study was a fact-finding endeavor, not intended to regulate emissions by the industry. There was never an intention to issue citations or assess penalties if emissions were found. Therefore, the locations and the owners of emitting tanks will not become part of the public record, and this report contains only de-identified statistical data. Company-specific results were shared with the companies themselves, but not among the companies nor with the public. Companies were also given the opportunity to review this document prior to its release.

In July, 2017, UDAQ will launch the ULend program, to allow oil and gas producers to borrow infrared camera equipment and receive training in its use. Interested parties are encouraged to contact Whitney Oswald of UDAQ (woswald@utah.gov) for details.

II. BACKGROUND

A. Storage Tank Technology

Oil, water, and gas phases from a well are directed first to a separator, which separates the three phases gravimetrically. The gas phase is then transported off-site via pipeline, while the oil and water phases are directed to storage tanks prior to off-loading by tanker trucks. Often, storage tanks are located on the pad adjacent to the well, or they may be located in "tank batteries" that collect fluids from a number of wells. Natural gas wells also produce liquid petroleum (e.g., condensate) so storage tanks are usually present at gas well pads. Uinta Basin tanks for storage of waxy crude are heated year-round, to keep the crude above its pour point, and condensate tanks are usually heated during winter months.

To avoid exceeding the pressure rating of the atmospheric tanks, storage tanks are typically designed and operated not to exceed about 1 pound per square inch (psi, about 1/15 of a standard atmosphere) above atmospheric pressure, commonly referred to as gauge pressure and expressed as "psig." However, separators are pressurized. When a liquid mixture containing components of varying volatility undergoes a sudden pressure drop, some of its more volatile components are released as vapor. These "flashing" events can occur whenever product is dumped from the separator to the tank, and so are intermittent, timed to the dumping cycle of the separator. "Breathing" emissions, i.e., emissions due to the expansion of vapor in the headspace of a tank and to the evaporation of liquids, and that result from changes in temperature or barometric pressure, also occur. Therefore, without functioning emissions controls, tanks continually or intermittently vent hydrocarbon vapors to the atmosphere. All atmospheric, fixed-roof tanks are equipped with a "thief" hatch that permits observation of the liquid level and extraction of oil or water samples for analysis. Excess pressure is relieved in "uncontrolled" tanks simply by venting to the atmosphere, usually with a thief hatch or a pressure-relief valve (PRV) designed to unseal automatically at or below about 1 psig, or else with a vent line open directly to the atmosphere. "Controlled" tanks maintain an internal pressure below 1 psig, but are equipped with control devices to prevent venting of hydrocarbons to the atmosphere. Three different types of control devices are commonly used: flares (open combustion), enclosed vapor combustors (enclosed combustion), or "vapor recovery" units (VRUs). To prevent over-pressurization or collapse, controlled tanks are usually equipped with a PRV, although some tanks are designed so that the thief hatch itself provides pressure relief. Thief hatches are also utilized for vacuum relief, which may occur, for example, during tank unloading or when the vapor headspace cools. The Utah Air Agencies 2014 Emissions Inventory indicates that approximately 20% of the tanks in the Uinta Basin are controlled while the remaining 80% are uncontrolled.

When a controlled tank emits from its thief hatch or its PRV, it is typically the result of an operational or maintenance issue. Some examples of such issues include: 1. An open thief hatch or blowdown valve, left open perhaps by operator error. 2. A poor seal on the thief hatch (e.g., a gasket can be easily fouled by dirt or oil, especially waxy crude, interfering with its seal). 3. Malfunction of the flare, combustor, or VRU, causing venting through the PRV. 4. Under-engineering of the flare, combustor, or VRU, i.e., the control device functions, but is unable to handle the vapor flow, especially when the separator dumps to the tank, again resulting in venting through the PRV. 5. Malfunction of the PRV.

Malfunction of the combustor may also produce emissions from the combustor stack.

B. Federal and state regulations regarding storage tanks.

The EPA New Source Performance Standard (40 CFR Part 60) Subpart OOOO (quad-O) [ecrf.gov, 2017] mandates that recently constructed tanks with a potential to emit six or more tons per year per individual tank of volatile organic compounds (VOC) be equipped with control devices with at least 95% control efficiency. Quad-O also requires storage tank owners to perform monthly "audio-visual-olfactory" (AVO) inspections (i.e., listen, look, and smell for emissions). In their recent inventory of oil and gas (O&G) emissions in the basin (Utah Air Agencies 2014 Oil and Gas Emission Inventory), UDAQ requested that operators provide the percentage "control efficiency" they assume with their controlled tanks. For all facilities on state jurisdiction this control efficiency was reported as 98%, and the reported emissions in the inventory accounted for this control rate.

"Control efficiency" refers to the efficiency with which a control device removes a certain percentage of compounds from the exhaust stream it receives. It should be contrasted with "capture efficiency," which reflects losses before the exhaust stream reaches the control device. Most common control devices have a rated control efficiency for VOCs of at least 95%. But 100% capture efficiency is also difficult to achieve. Operators and regulators account for capture efficiency by including "fugitive emissions" from components such as valves and thief hatches. Furthermore, quad-O does not require O&G operators to meet or demonstrate a certain level of capture efficiency, but instead relies upon general design and inspection requirements: "You must design and operate a closed vent system with no detectable emissions, as determined using olfactory, visual and auditory inspections." [40 CFR 60.5411a(c)(2)] The Utah Air Agencies 2014 Inventory accounted for fugitive emissions, i.e., for capture efficiency, from components that included: "connectors, flanges, open ended lines, pump seals, valves, compressor seals, pressure relief valves, dump level arms, polished rod pumps, and thief hatches." Thus "capture efficiency" was accounted for in the inventory by tabulating fugitive emissions, while "control efficiency" was accounted for when operators assumed 98% efficiency. -

Starting in 2014, Best Available Control Technology (BACT) for New Source Review permitting in Utah required that VOC emissions be controlled for tank batteries emitting greater than 4 tons per year. Current BACT also requires the control of oil loading emissions if the site is equipped with a combustor, as well as monthly thief hatch inspections on tank gaskets [deq.utah.gov, 2014].

C. Summary of Emissions Inventories and Other Studies

According to several emissions inventories, storage tanks are responsible for about 17 to 34% of all Uinta Basin VOC emissions, see Table 1. The WRAP-III 2012 projection and the UDAQ 2014 triennial were both developed by projecting the WRAP-III 2006 baseline into the future. They were scaled by the change in production and facility count that occurred during the intervening years rather than using new surveys. This probably explains why all three arrive at a contribution of about 30%. The Utah Air Agencies 2014 Oil and Gas Inventory is not yet published and based on data from O&G companies collected by UDAQ, EPA, and the Ute Tribe. (Because it is unpublished, its results are still subject to change.) The 2006 WRAP III inventory was created with a much less detailed dataset than was available for the creation of the Utah Air Agencies 2014 inventory. While there have been changes in production technology between 2006 and 2014, as well as improvements in emissions control technology, the difference in emissions estimates are most likely the result of better and more complete information about the production facilities in 2014.

Table 1. According to several emissions inventories, storage tanks are important contributors to the total oil and gas VOC emission in the Uinta Basin. (Results of the Utah Air Agencies inventory are still subject to change.)

INVENTORY	Total VOC, ton/yr	VOC Emissions from tanks, ton/yr	Tank contribution
WRAP-III 2006 Baseline Emissions[a]	72,000	21,000	29%
WRAP-III 2012 Projected Emissions[b]	127,000	42,000	33%
UDAQ 2014 triennial inventory[c]	156,000	52,000	34%
Utah Air Agencies 2014 Oil and Gas Inventory[d]	73,000	13,000	17%

[[a]wrapair.org, 2009, Baseline; [b]wrapair.org, 2009, Projection; [c]deq.utah.gov, 2016; [d]P. Barickman & W. Oswald, private communication]

Lyon et al. [2016] performed a helicopter survey of well pads in a number of basins, including about 1500 in the Uinta Basin, looking for emissions with an infrared camera. In their survey, out of all well pads in the Uinta Basin at which an emission was visible, 81% came from a storage tank. It is not known how many of those tanks were controlled, so their results cannot be used to assess the effectiveness of tank controls. The EPA asserts that storage tank emissions controls nationwide are under-performing, and in September 2015 issued a compliance alert on the subject [epa.gov, 2015].

D. Methanol storage tanks

Although the STEPP study focused on oil, condensate and produced water storage tanks, USU personnel reported all IR-visible emissions that they encountered. Many well pads in the basin are equipped with methanol storage tanks. These also operate at atmospheric pressure, and are not equipped with emission controls. All observed methanol vents are exempt from regulation.

E. Infrared Camera Technology

In this study, we used an OpGal EyeCGas® infrared camera designed to detect emissions of organic compounds. Matter interacts with infrared light in two different ways, as discussed in the following paragraphs.

First, all objects emit a "thermal glow" over a spectral range that is determined by their temperature. The thermal glow of objects near 300 K occurs in the infrared and is a strong function of temperature, so that temperature differences between objects can be detected by infrared imaging. This property is exploited with night-vision goggles. But we were unable to see the emission from a hot-air gun, suggesting that unless they are extremely hot or dense, the thermal glow of gases is invisible to these cameras. (This also causes us to question the explanation that some of the plumes we observed were actually heat signatures from tank heaters.)

Second, infrared light excites molecular vibrations at certain resonant frequencies. A gas is partially opaque at the wavelengths corresponding to these frequencies. The spectral range of the EyeCGas® camera is 3 to 4 μm [eyecgas.com, 2016], meaning that it is tuned to the excitation wavelengths of C-H bond-stretching vibrations in organic molecules. Backlighting at these wavelengths is absorbed when it passes through an organic gas plume. The contrast between infrared light passing directly through the plume relative to that passing to the side is detectable by the camera.

Other gases in the air, including H_2O and CO_2, are also partially opaque at these wavelengths, suggesting a possible mechanism for false-positive identifications. However, as long as there are comparable concentrations of H_2O or CO_2 in and out of the plume, they do not contribute to the contrast between the plume and its background. The other major components of air, O_2, N_2, and Ar, are transparent in the infrared.

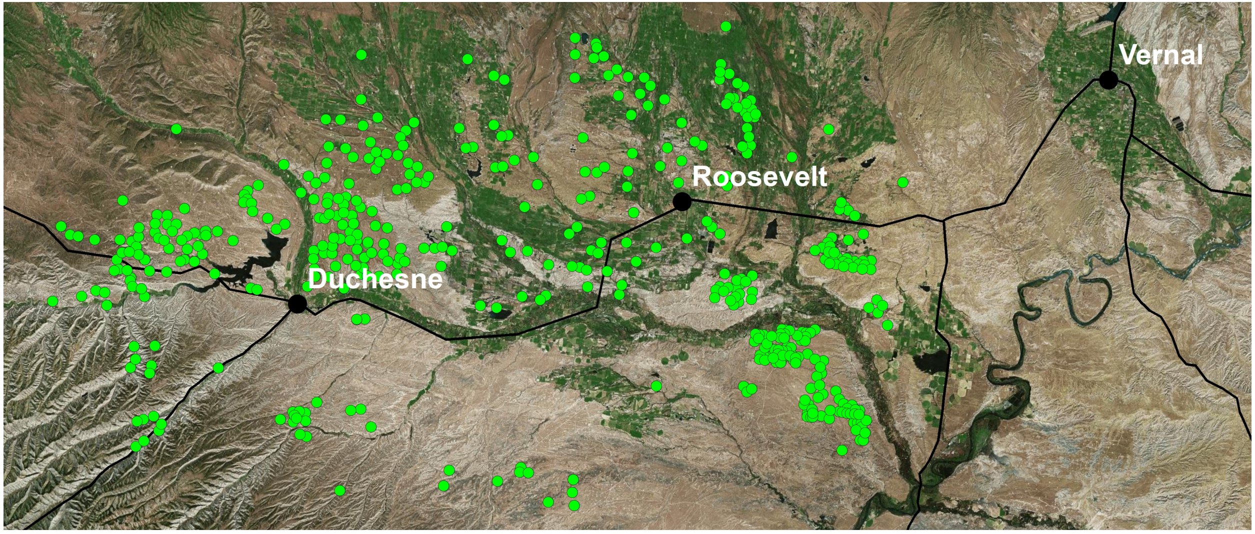
Many factors influence the image of the plume. These include the orientation of the plume relative to the line of sight; the distance to the plume; the wind speed, which has a diluting effect on the plume; and the composition of the plume, since each individual organic compound has a unique infrared absorption profile. The spectral characteristics of the backlighting depend on its origin (blue sky, clouds, snow cover, the ground, etc.) and on the presence of IR-absorbing molecules, such as water vapor. All of these will cause plumes of organic compounds to be perceived differently. For such reasons, the camera is non-quantitative, incapable of determining organic compound compositions, concentrations, or the emission rate of a leak.

III. PROCEDURE

A. Selection of wells to be surveyed.

UDAQ generated a list of 474 well pads consisting of all well pads with controlled tanks in Uintah and Duchesne Counties under state jurisdiction. (Tribal wells were not included.) This list was generated from surveys completed by O&G operators in connection with the Utah Air Agencies 2014 Emissions Inventory. Staff from the Bingham Research Center at USU visited each well pad and observed it with an infrared camera, and reported on any emission plumes detected. Figure 1 displays the locations of the well pads visited.

Figure 1. Map of well pads visited during this study.



B. Kick-off meeting.

A kick-off meeting for the STEPP study occurred on September 1, 2016 in Vernal. Present were UDAQ and TriCounty Health personnel, industry representatives, state and county governmental officials, and USU personnel. UDAQ and USU personnel explained the goals of the project.

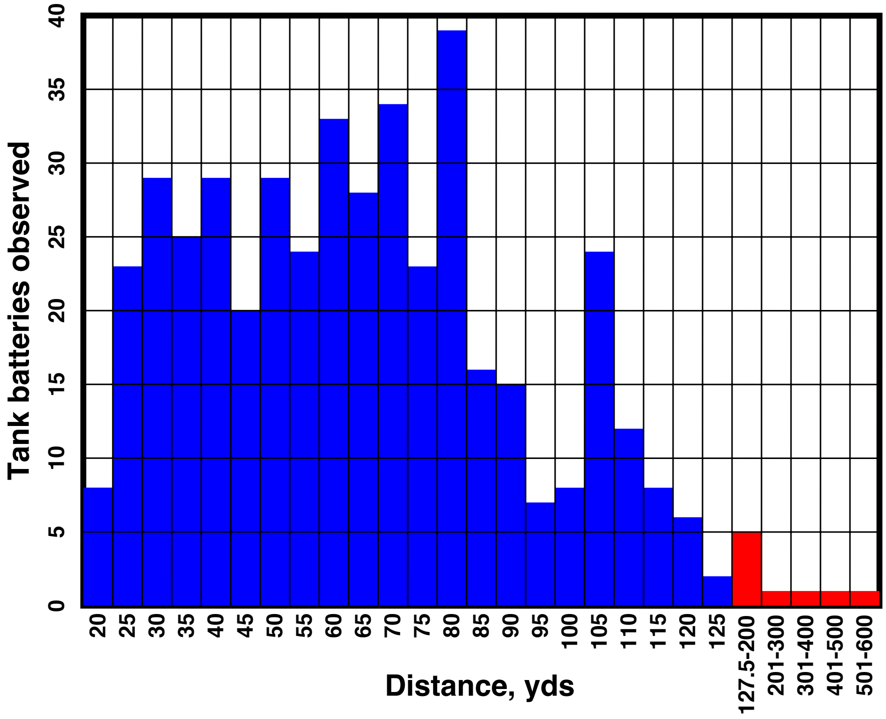
C. Infrared imaging of wells.

USU personnel attempted to visit and image all 474 well pads identified by UDAQ. These visits occurred between August 2 and October 31, 2016. For one of the following reasons, 20 well pads were not imaged:

- Site access was blocked, with no good observation points outside the gate.
- No tanks were found at the site.
- A work-over was in progress at the site.
- No well pad was found, probably because of erroneous GIS coordinates.

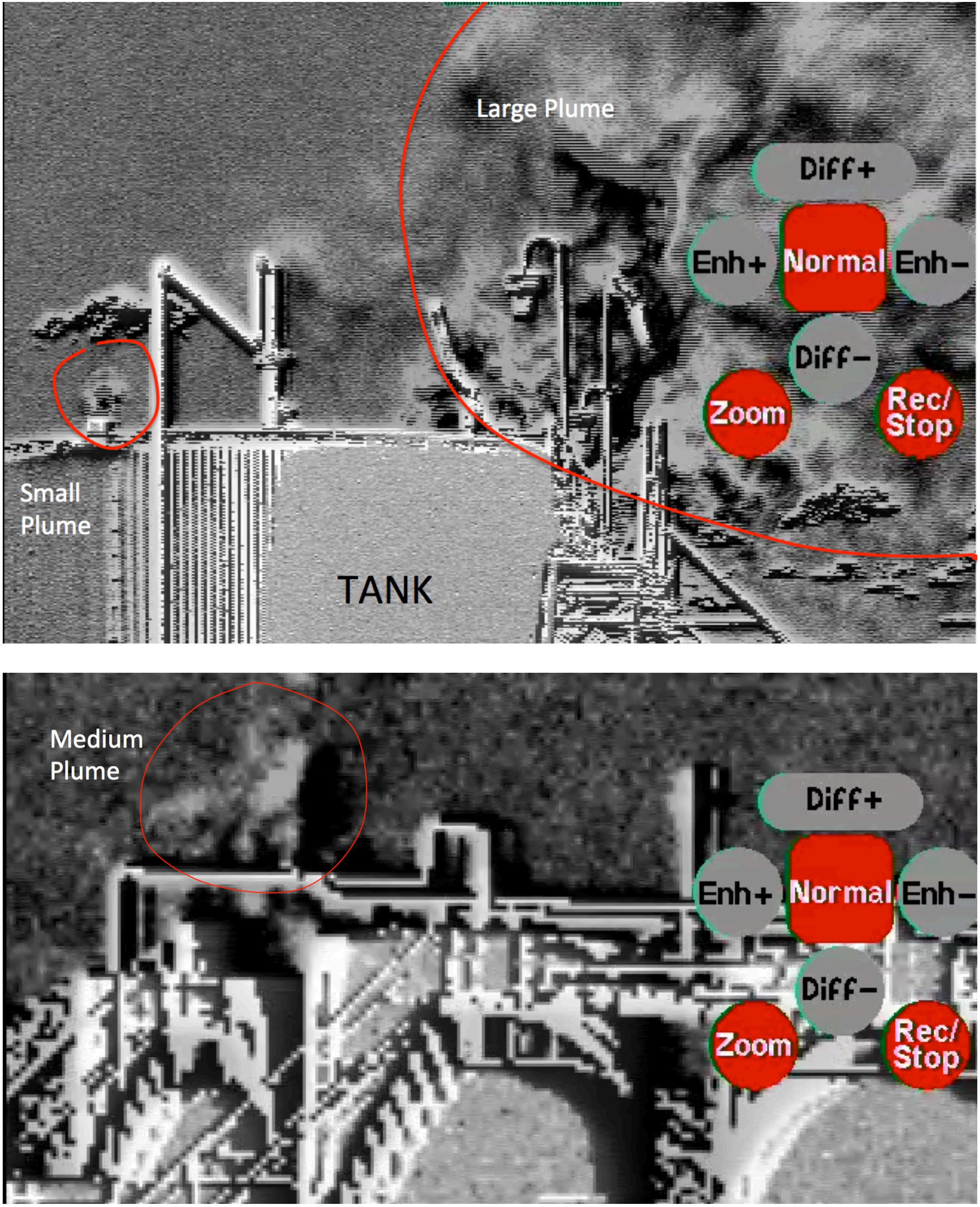
An EyeCGas® hand-held camera with video recording capabilities was employed [eyecgas.com, 2016]. For obvious safety and liability reasons, survey personnel did not climb on the tanks, thus the optimal position for observing emissions is usually some distance away. (The operator needs to stand far enough back that the tank does not completely fill the view screen.) Other factors, such as gated access, also influenced the location chosen for viewing the tanks. The observation distance was measured with a Nikon laser range finder. Figure 2 displays a histogram of the distances at which observations were made. The average distance was 68 yards. We typically viewed tanks for about 2 minutes before concluding that they were not emitting. Because tank plumes may appear only intermittently, coinciding with the dump cycle of the separator, we may have missed plumes from wells that have a long dump cycle.

FIGURE 2: Histogram of the number of tank batteries observed at a given distance.



As already mentioned, the camera is unable to provide a quantitative characterization of the emission. Nevertheless, emissions were subjectively categorized as small, medium, or large. Almost all observations were performed by the same individual, so there is very little observer bias in the small/medium/large designations. Figures 3 and 4 display representative snapshots of small, medium, and large plumes. These still photos are not as informative as videos, since it is easier to visualize the plume and to distinguish it from other objects in the field of view when it is seen in motion. Nevertheless, these images provide an indication of the approximate sizes of plumes that received the small, medium, or large designations.

Figures 3 and 4. Infrared camera views of small, medium, and large plumes.



Whenever a plume was detected with the infrared camera, an effort was made to determine its source. Since climbing on the tanks was out of the question, it was often impossible to determine the source of the plume with absolute certainty. In such cases the camera operators made a determination, based on prior knowledge and experience, of what they believed to be the most probable source of the leak. Conditions that made it difficult to ascertain the source include:

- The view of the plume source was blocked by other equipment,
- The plume source at the top of a tank was not visible from ground level,
- The observation had to occur from too great a distance.

When their prior knowledge and experience failed them, and the uncertainty in source determination was simply too high, the source was noted as unknown.

As already mentioned, even though the focus of the study was oil, condensate and produced water storage tanks, camera operators noted all emissions visible at the well pad.

The camera manufacturer provides training in use of the camera. Our operators were trained by UDAQ employees who had received manufacturer training.

D. Communication of findings to storage tank owners.

Password-protected video footage and camera operator logs and notebooks were provided to all storage tank owner/operators in the study. Data were redacted so that owner/operators had access only to data on their own facilities. Follow-up discussions were solicited and encouraged, during which time tank owner/operators were able to respond to the study, offer clarifications, and describe any corrective action taken. Some, but not all, of the companies engaged in follow-up discussions. These discussions occurred in January and February 2017.

E. Controlled propane releases.

As already mentioned, the infrared camera is not capable of quantitative, objective measurements of flux magnitudes. To obtain some notion of the detection limit of the camera and of the order of magnitude of observed emissions, we imaged controlled releases of propane with the infrared camera on December 22, 2016 and February 3, 2017. Propane was chosen because it often constitutes one of the major components of emissions from storage tanks and because of its commercial availability. The observations were performed at distances of 25 or 50 yards, by the same camera operator and using the same camera as in the field observations. The sky was overcast on December 22 and clear on February 3. We did not monitor wind speed on December 22, but wind speed at the Vernal Airport (at a distance of 3 mi from the test site) was reported as 0 m/s at the same hour as the test. Mean wind speed during the February 3 measurement was 1.4 m/s. Commercial-grade propane was discharged through a vertically mounted steel pipe of diameter three inches and length six feet. The flow rate of the propane was adjusted by manipulating the regulator on the propane tank, and was measured using a Fox Model FT3 mass flow meter. With this apparatus, we were able to produce fluxes as large as 2.0 to 2.5 g/s.

IV. RESULTS

A. Controlled propane releases.

Figure 5 displays results of the controlled propane release measurements. A total of 13 plumes were imaged. Two of these were barely detectable and taken as the detection limit of the procedure. Three plumes were judged to be at the borderline between the small and medium designation, and all remaining plumes were designated as small. The detection limit in our procedure is therefore < 0.3 g/s at 25 yards, and about 0.5 g/s at 50 yards. The transition from small to medium plumes occurs at around 1 to 2 g/s at 25 yards, and at > 2 g/s at 50 yards. This procedure is unable to produce larger plumes, so we are unable to provide any quantification for the transition from medium to large plumes. Since our camera operator saw plumes at the boundary between small and medium at 25 yards but not at 50, these measurements indicate that a subjective estimate of the size of a plume depends on distance to the source. The visual perception of the plume depends on two separate but correlated factors, one, its spatial extent, and two, its contrast relative to background. The small/medium/large categorization depends mainly on spatial extent of the plume, and so does not completely characterize the plume. For example, we can imagine a large plume that has poor contrast and which is therefore at the detection limit of the camera.

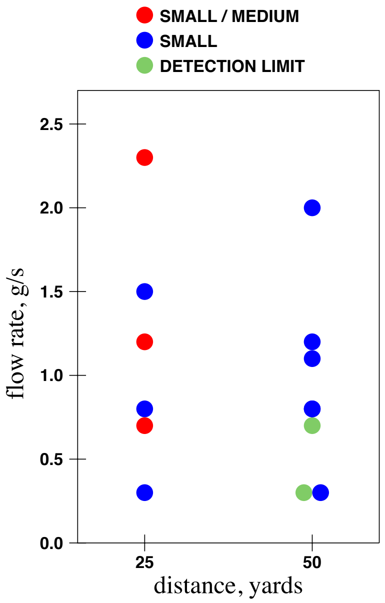


Figure 5. Symbols represent controlled-release propane plumes that were imaged by the infrared camera with the indicated flow rate and sighted from the indicated distance. Color-coding indicates the camera operator's judgment of the size of the plume.

B. Well pad emissions.

As explained above, 454 well pads with controlled tanks were visited, and any detectable emissions were recorded. A total of 196 plumes, or 0.43 plumes per pad, were observed. Emissions were detectable at 178 (39%) of the well pads. Tables 2 and 3 summarize the results. Each well pad is assigned to one of four classes, N (no detectable emissions), S (small), M (medium), and L (large), defined as the size of the largest plume observed at the pad.

Table 2. Statistics on observed plumes.

Small	46	23%
Medium	74	38%
Large	76	39%
TOTAL	196	100%

Table 3. Statistics on imaged well pads.

N	276	61%
S	42	9%
M	65	14%
L	71	16%
Total	454	100%

Table 4 demonstrates a correlation between the ability to perceive a plume and the observation distance. For example, the fraction of well pads assigned to class N (no observable emissions) increases from about 40% to almost 70% as the observation distance increases. Small and medium-sized plumes apparently are more difficult to perceive at larger distances. This is consistent with the findings on controlled-release propane plumes that indicated that the detection limit varies with observation distance.

Table 4. Correlation between observation distance and perception of plumes.

Distance range	Well pads in each class (N, S, M, L)	Percentage (N, S, M, L)
18 to 37.5 yards	34, 14, 24, 13	40%, 16%, 28%, 15%
37.5 to 62.5 yards	81, 14, 19, 21	60%, 10%, 14%, 16%
62.5 to 87.5 yards	94, 9, 14, 23	67%, 6%, 10%, 16%
87.5 to 112.5 yards	44, 6, 9, 7	67%, 9%, 14%, 11%
112.5 to 137.5 yards	13, 0, 0, 6	69%, 0%, 0%, 31%

Table 5 summarizes probable sources of the emissions found at the 178 well pads that were observed to have emissions. As already mentioned, it was difficult to definitively identify the source of the emission, so the data in this table should be regarded as tentative. The total number of leaks recorded, 196, is greater than 178 because some pads had more than one plume.

Table 5. Statistics on probable sources of emissions. Note that methanol tanks do not have control requirements but are included to provide a complete picture of the IR camera survey.

Probable source category	Small	Med	Large	TOTAL	%
Thief hatches	8	41	44	93	47%
Pressure relief valves	19	19	15	53	27%
Tank vent pipes	0	7	5	12	6%
Methanol tanks	6	0	0	6	3%
Ball valves	2	3	0	5	2.6%
Combustors	1	2	0	3	1.5%
Pressure relief piping or ports	2	0	1	3	1.5%
Flare stack	0	0	1	1	0.5%
Possible hole in tank	0	1	0	1	0.5%
Shack on site	1	0	0	1	0.5%
Internal valve	1	0	0	1	0.5%
Unidentified sources	6	1	10	17	9%
TOTAL	46	74	76	196	100%

Plumes from thief hatches tend to run medium to large in designated size. Plumes from pressure relief valves tend to run small to medium, although they can also be large. Together, thief hatches and pressure relief valves account for 74% of all observed plumes.

A few small methanol emissions were observed from methanol storage tanks. As expected, these are correlated with ambient temperature. The median temperature at which such vents were seen was 79°F, while the median temperature across all observations was 68°F.

Well pads with large or medium emissions had more oil production reported for 2014, on average, than well pads with small or no observed emissions (Figure 6). This may be because separators at wells with higher production dump to the tank more often. Well pads with large or medium observed emissions also had higher inventoried organic compound emissions in the unpublished Utah Air Agencies 2014 Inventory (0.25 ± 0.08 tons per year; mean ± 90% confidence interval) than wells with small or no observed emissions (0.16 ± 0.03 tons per year). This is likely because wells with higher rates of oil production are assumed in the inventory to have higher emissions.

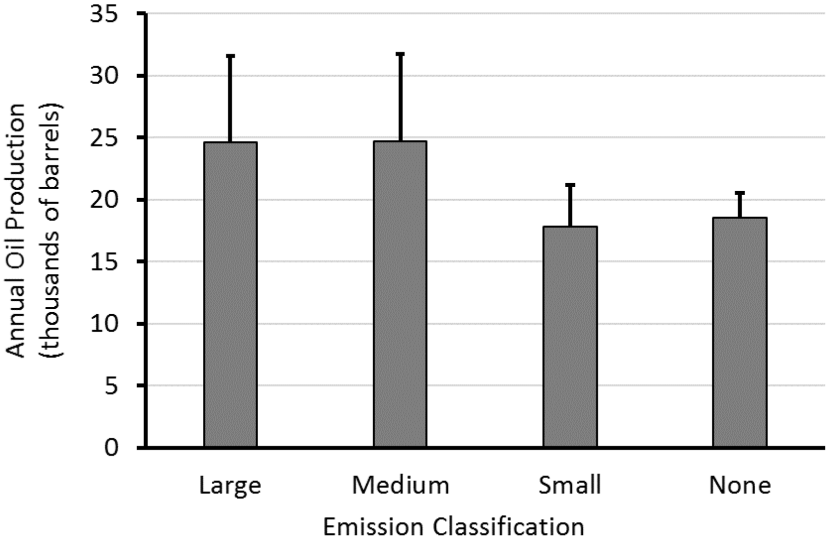


Figure 6. Annual oil production versus emission classification. Whiskers represent 90% confidence intervals.

Some companies tended to have higher emissions than others. We do not disclose company names in this report, but Table 6 shows de-identified data.

Table 6. Emissions data by company (de-identified). Average severity score was assigned according to the following weights: S = 1, M = 2, L = 3.

Company	Plumes /pad	Severity Score
A	0.27	2.2
B	0.36	2.4
C	0.36	2.2
D	0.38	2.6
E	0.55	1.8
F	0.60	2.2
AVERAGE	0.43	2.2

Trends by age of the facility are not present because tank controls have come into use only recently. Leak presence and leak severity were not correlated with wind speed. Only two of the wells were gas wells, so differences between gas and oil wells could not be established.

C. Feedback from well pad owner/operators.

Video footage and the camera operator logs and Excel notebooks were shared with the owner/operators of the well pads. They were then invited to meet with personnel from TriCounty Health, UDAQ, and USU, to discuss any concerns about the project and report any repairs made to their tanks. Some, but not all, of the six owners met with us in January or February 2017.

In all, we heard back on 48 of the 178 well pads at which we had observed emissions. In a large majority of cases, the owners agreed that the tanks in question had been emitting. Of these 48, repairs had been performed or scheduled on 44, while owners reported they had found no emissions at two of the pads. Two other pads had been misidentified and did not have controlled tanks. Many of the 48 well pads had passed a recent AVO inspection, indicating, as expected, that AVO inspections are not as sensitive as infrared imaging.

The following paragraphs summarize the concerns that were voiced in these meetings.

1. The waxy crude tanks are heated to about 160°F. Therefore, it was suggested that in some cases we might have seen the heat signature of the heater rather than a hydrocarbon plume. However, see Section II.E. On the other hand, if the heater exhaust contains un-

combusted hydrocarbons, or if its CO_2 or H_2O concentration is significantly different than background, then it could be visible to the camera.

2. There are many ways in which emission control systems on tanks are under-engineered, or can fail, or require frequent repairs.

- Dust and oil spilled on the thief hatch can foul the gasket, preventing a good seal.
- Waxy crude tanks are heated. This decreases the lifetime of gaskets, seals, etc.
- Flame arrestors on combustors can easily become clogged, causing pressure back-up which must be alleviated by the PRV.
- Some tanks are designed to be blown down before opening the thief hatch. Some combustors require liquid knock-out devices to prevent liquids from entering the combustor, which must be periodically emptied. These constitute unavoidable emissions.
- Pressure surges occur whenever the separator dumps to the tank. Control devices need to be engineered to the maximum pressure, not the average.

Some owners, citing these and other challenges, asserted that controlling the emissions from tanks remains an engineering challenge and better designs are needed. They asserted that the quad-O expectation of 95% control efficiency misses the point because it does not account for capture efficiency, or the difficulty in delivering gases to the combustor.

3. Citing similar reasons, some owners requested that regulators give them time to make repairs whenever an unpermitted leak is found, rather than fining or citing them immediately.

4. Owners pointed out that the emission status of a tank can change frequently. We may have happened to visit a tank whose thief hatch is almost always closed on a rare day when the hatch had been inadvertently left open. (We duly note this concern, but respectfully point out that it is an example of faulty statistical reasoning. The counter-argument boils down to this: We also could have visited a tank whose thief hatch is almost always open and caught it on a rare day when it was actually closed. If we visit enough tanks, all this variability averages out.)

V. COMPARISON WITH LYON ET AL.

Lyon et al [2016] performed extensive helicopter-based infrared surveys of well pads in seven different basins, including about 1500 well pads in the Uinta Basin. Consistent with our results, they reported that when a well pad was observed with at least one emission, 81% of these emissions were from storage tanks. It is not known how many of the tanks observed in this survey were controlled and hence their results cannot be used to assess the effectiveness of storage tank controls. Moreover, they reported that emissions were detectable at only 6.6% of the Uinta Basin well pads in their survey. This value is to be contrasted with the nearly six-fold higher detection ratio (39%) reported above by us.

Their survey consisted of a randomly selected fraction of all active Uinta Basin well pads, including both controlled and uncontrolled tanks under both state and tribal jurisdiction. Ours consisted of all well pads under state jurisdiction with emission-controlled tanks. It seems highly unlikely that state vs. tribal jurisdiction could explain a six-fold difference, and the fact that we looked only at controlled tanks makes the discrepancy that much harder to explain. Their observation distance was approximately 50 m above ground level. As seen in Figure 2, our observation distance was highly variable, but our mean observation distance of 62 m is similar to theirs. One possible reason for the discrepancy might be that downwash from the helicopter rotor dilutes emission plumes; another might be the difference in backlighting when observed from above. They state that they videotaped each observed emission for a period of about 20 to 80 s, but they did not state how long they hovered over a well pad before concluding that it was not emitting. In our study, we found it necessary to wait about 2 min to capture intermittent emissions. They also imaged controlled release plumes and state that they obtained a detection threshold of about 1 g/s for propane or butane. As seen in Figure 5, our 50-yard detection limit is probably somewhat better. More measurements would be needed to determine if the detection limit for ground-based observation is sufficiently better to account for the six-fold discrepancy. Coordinated observations with two cameras, one ground-based and one in the air, would also be helpful in resolving the discrepancy. The paramount advantage of helicopter observations is the ability to visit many more well pads in a given time period. Taking both the 6.6% and 39% detection ratios at face value indicates that ground-based observations are more sensitive.

VI. IMPLICATIONS FOR THE UTAH AIR AGENCIES 2014 EMISSIONS INVENTORY

UDAQ surveyed O&G companies in the Uinta Basin to obtain a more accurate, up-to-date emissions inventory, the Utah Air Agencies 2014 Emissions Inventory. The results are still under review and should be considered tentative. The inventory estimates the VOC emission from all storage tanks in the basin, both controlled and uncontrolled, at about 13,000 tons/yr. Based on information provided by the operators, approximately 20% of the storage tanks in the Uintah Basin are controlled. The inventory assumed 95% to 98% control efficiency at all storage tanks with emissions controls. It also accounted for capture efficiency through fugitive emissions estimates for these same tanks.

An important question is whether emission factors for the category of "fugitive emissions" should be modified in light of the results reported here. Many of the emissions tabulated in Table 5 involve thief hatches and valves (part of “fugitive emissions”), and it is possible that the fugitive emission rate at the wells we surveyed was higher than was reported in the 2014 inventory. However, since the IR camera we used in this study was not able to provide quantitative information about emissions, we can’t use the data collected in a direct comparison with the inventory. Additional work to quantify fugitive emissions from controlled tanks is needed to determine definitively whether adjustments to the 2014 inventory are needed.

VII. CONCLUSIONS

We visited and took infrared images at over 400 well pads with emission-controlled storage tanks under state jurisdiction in the Uinta Basin. The most important finding of this study is that we were able to detect 0.43 emission plumes per pad and that most of these were associated with the storage tanks. Close-up inspection was usually not possible, but that said, 74% of the detected plumes appeared to be emitting from the thief hatch or the pressure relief valve. We also found that 39% of all pads visited had detectable plumes.

Our observations imply that emissions from controlled storage tanks are more a problem of capture efficiency than of control efficiency, although because up-close observation was impossible it is difficult to state this with certainty. 95% control efficiency is of no use if we fail to route vapors to the combustors. The quad-O reliance on AVO inspections to monitor capture efficiency may be insufficient.

It has also been suggested that our results are inaccurate because we happened to catch some tanks "at their worst." It is probably true that we sometimes saw plumes from tanks that almost never emit. However, it is also probably true that we caught other tanks "at their best." There is no possible selection bias when we visit all well pads of a specific category (controlled tanks under state jurisdiction, in this case). Our results may have some inaccuracy because each well pad only received one visit. We could remedy that by performing several visits to each well pad over a more extended time period.

A similar effort but based on observation from a helicopter achieved a much smaller detection ratio of only 6.6% of all well pads in the basin [Lyon et al, 2016]. In Section V we suggest several possible reasons for the discrepancy, but still regard the discrepancy as unexplained. If both studies can be taken at face value, then our conclusion is that ground-based imaging is much more sensitive than imaging from helicopters. A study combining both imaging bases with two cameras would probably clear up the discrepancy.

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