



Opportunity for a Healthy Life

**Leak Inspection and Repair at Oil and Gas Well Sites
Boulder County Voluntary Inspection Program Results 2014–2016**

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Abstract

Public concern has grown in Boulder County regarding the health and safety implications of emissions from oil and gas activity. Boulder County has implemented a voluntary oil and gas inspection program in order to respond to this concern. The program resulted in nearly 500 inspections at 145 production sites across the county from 2014 to 2016. Gas leaks were detected at 65% of inspected sites, and 31% of the sites with leaks experienced them in multiple calendar years. Most leaks were detected at storage tanks, separators, and wellheads. Across equipment categories, many leaks involved malfunctioning pneumatic controllers. Once reported to operators by the Boulder County oil and gas inspector, 99% of the leaks were resolved, and half of the leaks were resolved within five days. Given that almost all of the observed and resolved leaks were detected with the aid of an infrared (IR) camera, increasing the frequency of required IR inspections is necessary to improve leak detection and repair and to reduce emissions from oil and gas production sites on the Front Range.

Introduction

In recent years, oil and gas development in Colorado has increased sharply due to advances in drilling and well stimulation technologies, including horizontal drilling and hydraulic fracturing (Figure 1a). While production volumes have generally decreased in Boulder County since 2008 (Figure 1b), oil and gas have been produced in the county for over a century.¹ Here and in neighboring counties, oil and gas development increasingly takes place near residential areas, which has prompted public, scientific, and local governmental concern about emissions from oil and gas facilities from a health and safety perspective.²⁻⁴ Concurrently, oil and gas emissions have come under scrutiny as an exacerbating factor in Front Range ozone nonattainment status. Volatile organic compounds (VOCs) and nitrogen oxides (NO_x) released from oil and gas facilities are ozone precursors.⁵ Oil and gas development produces approximately 44% of the VOC inventory along the Denver Front Range,⁶ and measured VOC concentrations across northeastern Colorado indicate that oil and gas operations are a significant source of ozone precursors in the region.⁷ Furthermore, the oil and gas industry is the largest emitter of methane – a potent greenhouse gas that contributes to climate change – in the United States.⁸

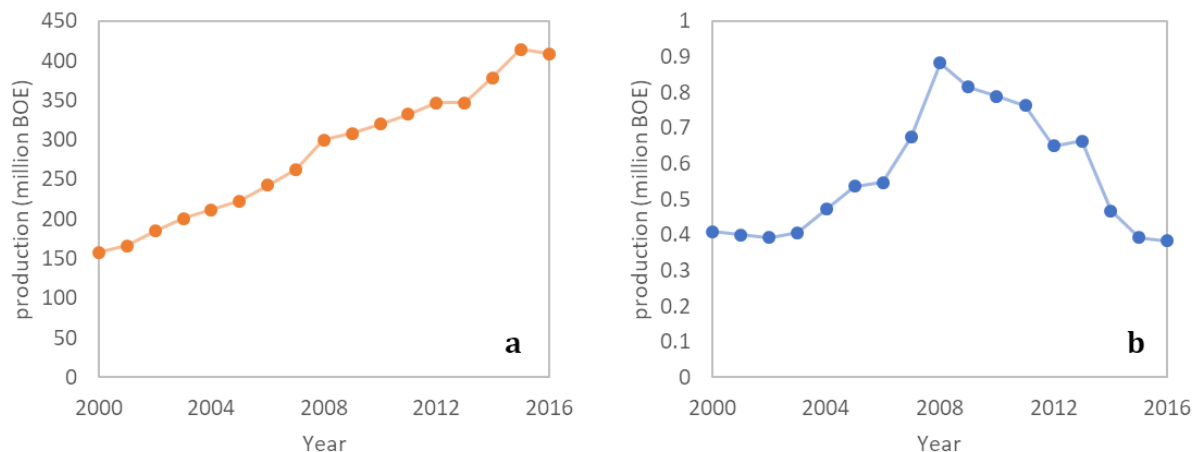


Figure 1. Annual oil and natural gas production in (a) the state of Colorado and (b) Boulder County from 2000 to 2016.⁹ Production volumes are expressed in millions of barrels of oil equivalent (BOE), where 5,800 ft³ of natural gas is equivalent to 1 bbl of oil.

Previous research suggests that particular processes and pieces of equipment at oil and gas facilities are implicated in hydrocarbon emissions. Pétron et al. reported that air masses above the Denver-Julesburg Basin in Colorado are likely impacted by venting of raw natural gas and flash emissions from condensate storage tanks.¹⁰ At the Platteville Atmospheric Observatory in northeastern Colorado, Halliday et al. detected elevated concentrations of benzene and identified emissions from condensate tanks as one probable source.¹¹ The Air Pollution Control Division (APCD) of the Colorado Department of Public Health and Environment (CDPHE) reported that three quarters of gas leaks and venting at production facilities were from liquid hydrocarbon storage tanks.¹² An air quality study in Fort Worth, Texas, indicated that the most common sources of emissions were tank thief hatches and pneumatic valve controllers. Its authors suggested that improved inspections and maintenance of equipment could greatly reduce or eliminate preventable emissions from oil and gas facilities, especially for sites where increased emissions are attributable to equipment malfunctions.¹³ Allen et al. similarly note that many high-emitting pneumatic controllers do not behave according to the manufacturer’s specifications.¹⁴

Boulder County’s voluntary inspection program was instituted in 2014 to evaluate the field conditions of active oil and gas facilities and to supplement inspections by the Colorado Oil and Gas Conservation Commission (COGCC) and the APCD of CDPHE. Well sites are inspected by the COGCC under its risk-based inspection program. A routine COGCC inspection evaluates the condition of thief hatches, emission control devices, and other production equipment.¹⁵ The COGCC also requires operators to inspect

valves, pipes, and fittings at regular intervals.¹⁶ Most oil and gas production facilities in Boulder County require monthly audio, visual, olfactory (AVO) inspections, which are mandated by State Regulation 7 and performed by operators. Additionally, most of these facilities emit between 0 and 6 tons of VOCs per year and are, therefore, only required to be inspected one time in the life of the facility under Regulation 7 XVII.F.4.c per the Approved Instrument Monitoring Method (AIMM) requirement.¹⁷

In contrast to the suite of required inspections, the Boulder County inspector conducts inspections on a voluntary basis. Boulder County's intention is to address community concerns regarding air quality issues related to oil and gas operations. 10 Boulder County operators have participated in this program since 2014 (Appendix A).

The goal of the first year of the inspection program (2014) was to access and inventory as many sites as possible while conducting AVO and IR camera inspections. In 2015 and 2016, the focus of the program was to conduct more detailed leak detection and repair (LDAR) inspections and to ascertain – through follow-up inspections and correspondence with the operators – if, how, and when gas leaks were resolved. Reports and presentations of these inspection data have been used by the Boulder County Board of County Commissioners (BOCC) in establishing local oil and gas policies.

Objectives

This analysis aims to determine the number of gaseous leaks, the source of the leaks, and the time required to resolve the leaks.

Methods

The goal of the inspection program is to visit each facility (hereafter referred to as a "site," which may contain more than one well) in Boulder County at least twice per year – one AVO visit and one visit with an IR camera. During every site visit the Boulder County oil and gas inspector (referred to hereafter as "inspector" unless otherwise indicated) completes a checklist of items that can be inspected visually (Appendix B). These items are drawn from COGCC and CDPHE requirements, and the checklists are similar to those used by state inspectors. In February 2014, the inspector became certified to use an optical gas imaging camera (FLIR GF-320 thermal infrared camera) owned by the Regional Air Quality Council (RAQC) to detect gaseous leaks. This IR camera can detect emissions of methane, ethane, and VOCs from equipment at oil and gas sites.

During visits with the IR camera, the inspector follows a standard operating procedure, which can be found in Appendix C, to take safety precautions and to survey the site for leaks. The inspector first uses the camera in high sensitivity mode (HSM) to perform an initial scan of any large gas leaks from wellheads, tanks, separation equipment, emission control devices (ECDs), or equipment below the ground surface (e.g., flowlines). The camera is then switched to its automatic mode to pinpoint and confirm the sources of any detected leaks. Sample images collected by the inspector can be found in Appendix D. Hydrocarbons may be emitted with varying compositions and magnitudes across different categories of equipment at oil and gas sites.¹⁸ However, the IR cameras used in this inspection program cannot speciate the gas or quantify the rate at which it is released.

After each visit, the inspector notifies the operator via email of general inspection findings and of the location of any observed leaks, including from equipment that the operator has already tagged as needing repairs. The inspector then tracks the date of the operator's response and the date of leak resolution reported by the operator. When possible, the inspector will return to the site with the IR camera to confirm that leaks have been resolved as described by the operator.

In analyzing the inspection data, the following state definition of a leak was used: "For infra-red camera and AVO monitoring...a leak is any detectable emissions not associated with normal equipment operation."¹⁷ Therefore, the inspector's descriptions of leaks and correspondence between the county and the operator were manually reviewed to determine if detected emissions were associated with normal equipment operation. If so, the emissions were not considered a leak and were excluded from this analysis. From 2014 to 2016, the inspector notified operators of only 6 possible leaks that were later determined to be associated with normal equipment operation.

For the analysis, each leak was defined as either single or recurrent. If a leak was observed from the same equipment component unchanged across consecutive inspections without documentation of repair between inspections, it was defined as a single leak. If documentation showed that a repair had been made or the leak had ceased between consecutive inspections, then the leak was defined as recurrent and counted as a new leak in the analysis.

In 2015 and 2016, the inspector also evaluated whether leaks were associated with pneumatic controllers. In Regulation 7 XVIII.B.7, CDPHE defines a "pneumatic controller"

as “an instrument that is actuated using pressured gas and used to control or monitor process parameters such as liquid level, gas level, pressure, valve position, liquid flow, gas flow and temperature.”¹⁷ Pneumatic controllers are found within a variety of equipment categories found at active oil and gas sites. In Boulder County’s inspection program, leaks involving pneumatic controllers have been identified at the wellhead, on separation equipment, and on emission control devices.

The Boulder County inspector employs a two-step procedure to aid in identifying pneumatic controllers that were not operating as intended. Per the county’s standard operating procedures for IR camera inspections (Appendix C), the camera is first used to identify visible emissions from any pneumatic controller(s) at the site. After making a note of these controller(s) where emissions were detected, performing a full inspection of the site with the IR camera, and completing paperwork for approximately 15 to 20 minutes, the inspector returns to the controller(s) where emissions were noted. If the inspector detects continued emissions from the controller(s) with the IR camera, the emissions are reported to the operator. At this point, the operator is responsible for determining whether the controller(s) are operating normally.

Results

Numbers of Visits and Leaks

From 2014 to 2016, Boulder County Public Health conducted 489 visits to 145 different oil and gas sites (about 3.4 visits per site) (Table 1); 67% of the visits involved an IR camera inspection, while 33% involved an AVO inspection only, and 118 sites (81%) were inspected in multiple calendar years.

Table 1. Numbers of visits and leaks by inspection type and by year of Boulder County’s voluntary inspection program

	2014	2015	2016	Total
Visits	243	94	152	489
IR visits	142	74	111	327
AVO visits	101	20	41	162
Leaks	84	55	80	219
IR leaks	83	55	77	215
AVO leaks	1	0	3	4

A total of 219 leaks were detected, and 94 sites (65%) in Boulder County experienced at least 1 leak during the 3-year period (Table 2; Figure 2). Furthermore, 29 of these 94

sites (31%) experienced leaks in multiple calendar years. For the sites at which at least 1 leak occurred, a single leak occurred at 45% of sites, while 24% of sites experienced 4 or more leaks – or more than 1 leak per year of the inspection program, from 2014 to 2016 (Figure 3).

Table 2. Number of sites and percentage of sites experiencing leaks by year of Boulder County’s voluntary inspection program

	2014	2015	2016	Overall
Sites visited	131	80	111	145
Sites with leak(s)	52	30	44	94
Sites with leak(s) as a percentage of sites visited	40%	38%	40%	65%

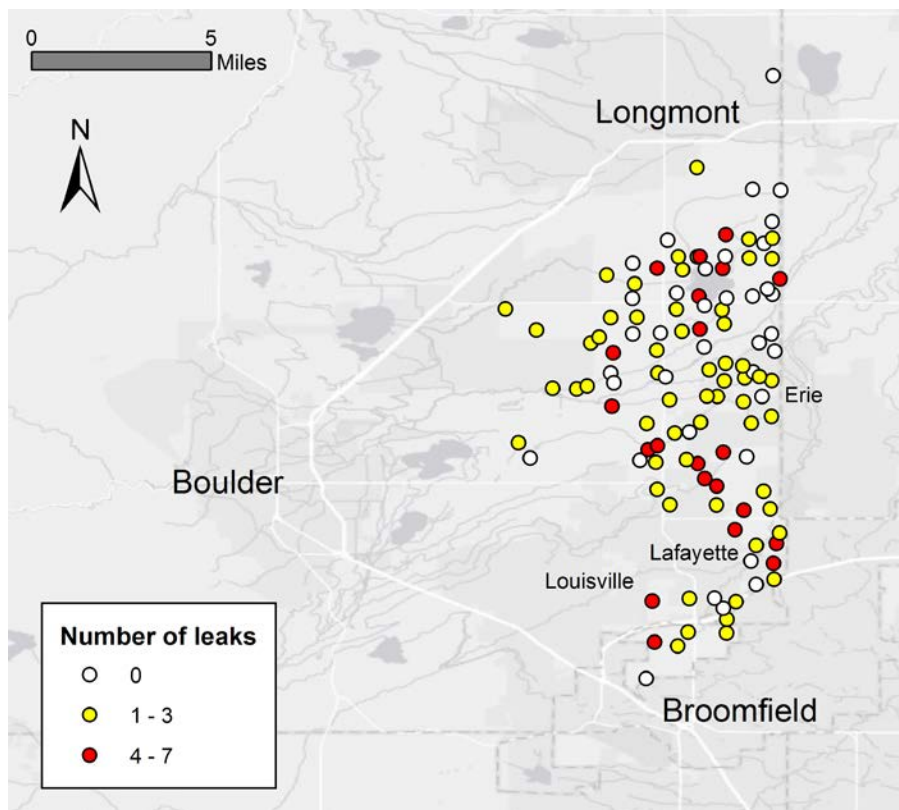


Figure 2. Locations of oil and gas production sites and numbers of leaks

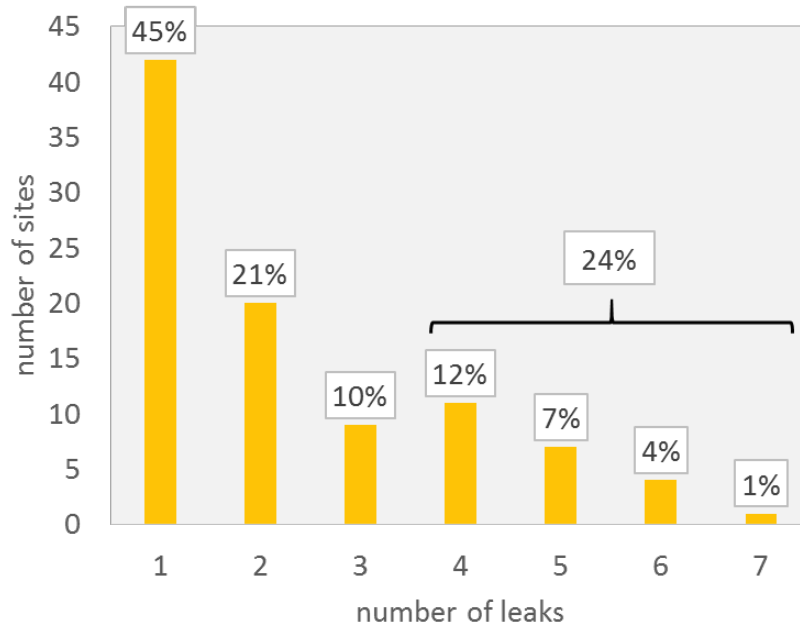


Figure 3. The numbers of sites in Boulder County that experienced one or more leaks from 2014 to 2016

Return Visits and Recurrent Leaks

The inspector returned to oil and gas sites 190 times to conduct IR camera inspections, often to confirm that an earlier leak had been resolved. During 82 of these return visits (43%), the inspector detected 1 or more new leaks at the site. During three return visits (2%), the inspector observed a new leak that was recurrent from a previous visit.

Leak Characteristics

The most common pieces of equipment that experienced leaks at oil and gas facilities were separators, tanks, and wellheads (Figure 4). Leaks were less frequently observed from ECDs, flowlines, and pipelines. In 2015 and 2016 – years in which more detailed data about leaking equipment were available – 42 leaks (31%) involved a malfunctioning pneumatic controller based on correspondence between the inspector and operators.

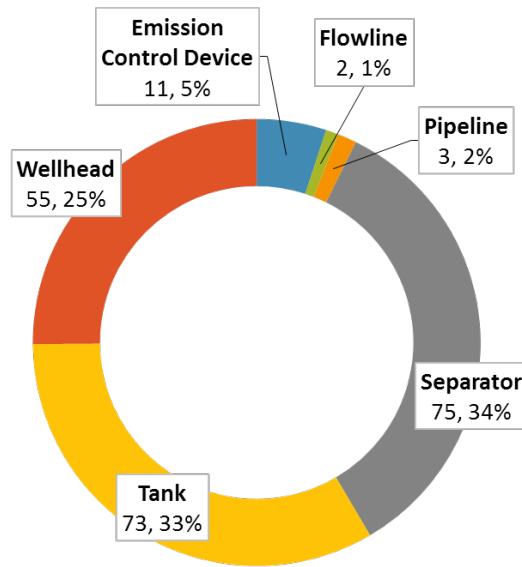


Figure 4. Equipment experiencing leaks at oil and gas sites

Time to Leak Resolution

Operators resolved 218 of 219 leaks (>99%) after notification from the inspector. The vast majority of leaks were resolved with equipment repairs, but operators reported that 13 leaks were stopped by shutting in a well (temporarily halting production) at the site. Of the resolutions reported by operators, 87 (40%) were subsequently confirmed by an IR camera inspection during a return visit by the Boulder County inspector.

For 91% of the resolved leaks (n = 199), notification dates and repair dates were available to analyze the time required for leak resolution. The average resolution time was 18 days; however, the data were strongly skewed toward faster resolution times, resulting in a median resolution time of 5 days. 90% of leaks were resolved in approximately 45 days or less.

All 42 leaks from pneumatic controllers in 2015 and 2016 were repaired, indicating that the controllers were not operating as intended when the inspector observed the emissions. Examples of these repairs as they were reported by operators are available in Appendix E.

Discussion

The overwhelming majority of leaks (98%) were detected during IR camera inspections. By contrast, AVO visits rarely resulted in leak detection. Regardless of how they were detected, leaks were common among oil and gas facilities in Boulder County from 2014

to 2016. Two-thirds of inspected sites experienced at least one leak over the three-year period. Furthermore, leaks can occur regularly at these sites; about one quarter of sites experienced more than one leak per year.

Only three leaks recurred across multiple inspections, which suggests that operators were responsive to notifications of leaks submitted to them by the inspector. During the three-year period of the inspection program, operators were successful at resolving leaks through well shut-ins or equipment repairs, and resolved leaks rarely recurred after they were resolved.

As similarly noted by Pétron et al.; Halliday et al.; Eastern Research Group, Inc.; and APCD, storage tanks appear to be a significant source of hydrocarbon leaks from well sites.¹⁰⁻¹³ Based on the number of leaks detected from wellheads and separators in this analysis, malfunctions of these pieces of equipment may also have negative implications for regional air quality.

Pneumatic controllers, which are used to control the production process on multiple types of equipment, were implicated in 31% of the leaks observed in 2015 and 2016. Repairing and maintaining malfunctioning pneumatic controllers or using zero emission technologies, then, would potentially provide emissions reductions.

About half of leaks were resolved in five days or less from the date the operator was notified of the leak by the inspector. Compared to the lengthy resolution times for soil or groundwater remediation, this rapid resolution of leaks suggests that equipment repairs can usually be accomplished in a straightforward manner.

In its two-year pilot project involving IR camera inspections across the state of Colorado, APCD observed a marked decrease in the percentage of oil and gas well production facilities that experienced leaks. Leaks or venting were found at 42% of facilities at the beginning of the project in the third quarter of 2013, while only 9% of facilities experienced leaks or venting at the end of the project in the second quarter of 2015.¹² By contrast, Boulder County's analysis indicates that the percentage of sites experiencing leaks in the county remained stable (approximately 40% of sites per year of the voluntary inspection program). At the time of this analysis, the available data were insufficient to discern the reason for the divergence between the results. The divergence may be due to differences between oil and gas sites in Boulder County and

those elsewhere in Colorado (e.g., production volumes per site or ages of equipment at each site).

Conclusions

Leaks are common among oil and gas sites in Boulder County, and these sites often experienced multiple leaks during the three-year inspection period. Therefore, the one-time AIMM inspection requirement is inadequate to identify and initiate the repair of leaks from malfunctioning equipment. By increasing the frequency of required inspections, leaks would be discovered sooner, which would aid in curtailing regional emissions of methane and VOCs from oil and gas operations.

Inspections and maintenance should target separators, storage tanks, wellheads, and pneumatic controllers across equipment categories in order to reduce the number of leaks at oil and gas facilities. Furthermore, inspections should be conducted with IR cameras whenever possible. In this analysis, IR camera inspections were much more likely to detect leaks than AVO inspections. Since leak detection is a prerequisite for leak resolution, and because an inspection program is limited by the time required for an inspector to visit individual well sites and conduct inspections, IR camera inspections may be the most efficient strategy for reducing leaks from oil and gas facilities.

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Appendix A: Participating Operators

Table A1. Operators who have taken part in Boulder County's voluntary oil and gas inspection program

Operator	Years Participated
Anadarko Petroleum (Kerr McGee oil and Gas Onshore L.P.)	2014–present
CDM Oil and Gas	2014–present
Crestone Peak Resources	2016–present
Encana Corporation	2014–2016
Extraction Oil and Gas (8 North LLC)	2015–present
Noble Energy	2014–2015
PDC Energy	2014–present
Smith Oil Properties Inc.	2016–present
Synergy Resources	2015–2016
Top Operating Company	2016–present

Appendix B: Site Inspection Checklist

Site Visit Checklist

Date: _____ Time: _____

Company: _____

Location name: _____

Site Location: _____

AIRS ID on/by tanks? (#) _____

Access: _____

Site Inventory:

Tank Battery:

- Is thief hatch closed?
- Is there air pollution control equipment?
- AIRS ID on equipment?
- Type of control (flare, VRU, other):
- Is flare pilot on?
- Is fuel gas valve position open?
- Is flare enclosed?
- Is flare free of visible emissions?
- Can observer visually observe proper operation?
- Does flare have auto-igniter?

Site Condition:

- Are there waterways or surface waters nearby?
- What is the condition and type of containment?
- Is there proper signage?
- Is there unused equipment or debris on site?
- What is the condition of the access road?
- What BMP's are in place for stormwater management?
- Are there signs of spills or leaks?
- Is the site in close proximity to schools or residential areas?
- Type of produced water storage?
- Anchoring in place?
- Have baseline water tests been conducted?
- Acceptable noise levels?
- Visual impacts?

Appendix C: Standard Operating Procedures for Infrared Camera Inspections

Boulder County Voluntary Oil and Gas Inspection Program Using Optical Gas Imaging (Infrared) Camera for Leak Detection - Standard Operating Procedures

Boulder County's voluntary oil and gas inspection program aims to visit each facility at least twice each year; one visit with the infrared (IR) camera and one audio, visual, olfactory (AVO) visit. During the visits, the inspector follows these procedures:

1. Arrives on-site with proper personal protective equipment (PPE): fire-resistant clothing (FRC) outer layer, hard hat, protective glasses, steel-toed shoes, 4-gas monitor.
2. Parks the vehicle facing out, in case of emergency.
3. As a safety precaution, uses the camera in high sensitivity mode (HSM) to perform an initial scan of the facility, looking for any large gas releases from tanks, ground, separation equipment, and emission control devices (ECD).
 - a. All equipment is viewed in both auto and HSM modes to identify any releases. Auto is used to pinpoint and confirm the source of release.
4. Scans the facility and observe the pressure relief valves (PRV) on any tanks. If venting is observed, makes a note and checks the PRV again when the entire facility has been inspected in order to determine if the PRVs are operating correctly or still malfunctioning.
5. Moves through the facility, generally starting with the storage tanks, to observe all PRVs, thief hatches, piping that is viewable from the ground, and the ground where the dump lines and flash gas lines enter.
6. Observes the ground between the tanks and separation equipment to check for any gas that may be coming out of the ground.
7. Observes the separation equipment and any ECDs. If any releases are seen at pneumatic devices, makes a note to recheck before leaving. Checks the separator's doghouse (without opening the door) for any gas coming through spaces in the door or ventilation holes.
8. Checks all areas where lines are entering or coming out of the ground.
9. Checks any pipeline equipment that is exposed with the camera.
 - Views all equipment from several different angles to avoid any issues with shadows, wind, etc. and potentially getting a false detect. The wellheads, associated piping, and accessory equipment are viewed from as many angles as possible.
10. After going through the entire facility, completes the inspection paperwork.

11. After completing the paperwork, rechecks any pneumatic devices or PRVs that were noted with the camera. If the equipment still has an observable release, it is then considered to be malfunctioning and is reported to the operator.
12. Reports all findings, including a short summary of the facility that was visited and any identified releases, by email to the operator, usually within one business day.
13. Tracks the operator's response and repair timing. Keeps the description of the repair provided by the operator.
14. When possible, returns to the facility to confirm all repairs are made and conduct another scan of the facility equipment to identify any additional releases.

Appendix D: Infrared Camera Images

The following still images were recorded at oil and gas facilities by the Boulder County oil and gas inspector using a FLIR GF-320 thermal infrared camera.

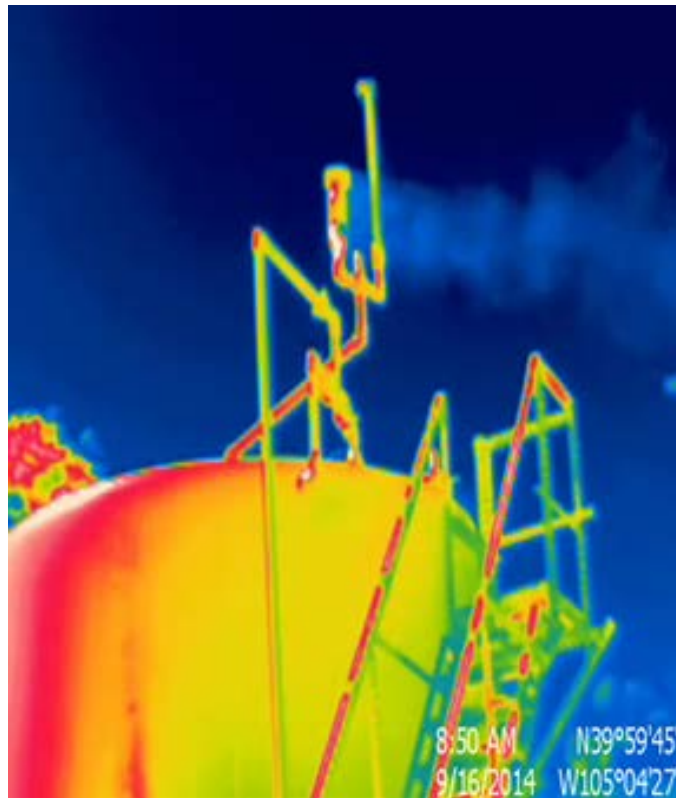


Figure D1. Emissions from pressure relief valve on crude oil tank

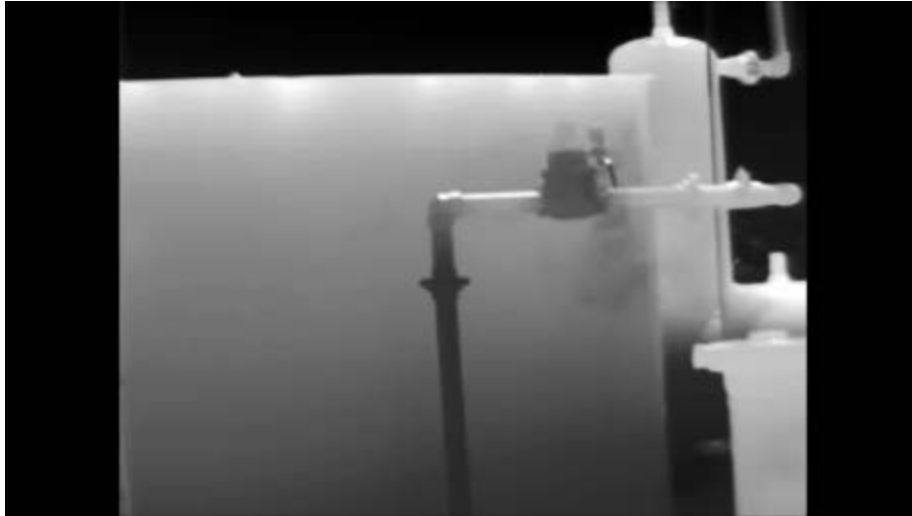


Figure D2. Emissions from back pressure Kimray valve on separator

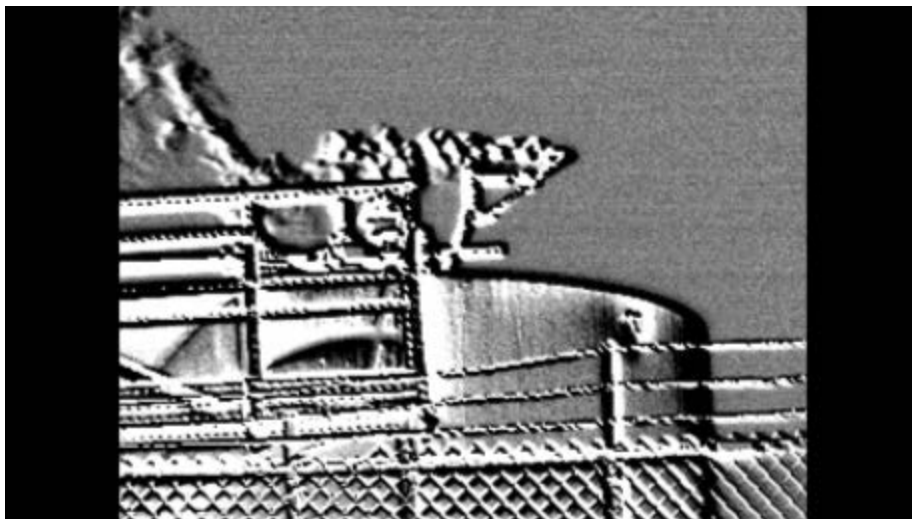


Figure D3. Emissions from blowdown valve on condensate tank viewed in high sensitivity mode (HSM)



Figure D4. Emissions from crude oil tank



Figure D5. Emissions from tubing hanger on wellhead

Appendix E: Examples of Reported Repairs to Pneumatic Controllers

Examples of repairs to leaking pneumatic controllers (as reported to Boulder County inspector by operators):

- Actuator (rebuilt)
- Belgas regulator to telemetry system at well (replaced), hi/lo controller on separator (tightened), pressure gauge on supply gas line for horizontal gas run (tightened) on separator
- Combustor (replaced supply gas tubing and fittings)
- Connections jam nut (tightened)
- Controller (rebuilt)
- Controller-hi lo (replaced)
- Controller-hi-lo (replaced)
- Controller-level (replaced mizer assembly)
- Controllers (tightened operator on both)
- Kimray (repaired)
- Kimray (replaced)
- Kimray bolts (tightened)
- Kimray BPR, Fittings (tightened)
- Kimray valve (tightened bolts)
- Mizer-top dump (rebuilt)
- Regulator (replaced diaphragms)
- Regulator (tightened fittings)
- Regulator (tightened fittings on both inlet and outlet of operator)
- Regulator (took apart, cleaned, adjusted)
- Regulator , ECD (repaired)
- Regulator on supply line (replaced) and connections on supply gas line (replaced)
- Separator (fixed on site)
- T12 (adjusted), Pressure release Valve (waiting for parts)
- T12 temperature controller (replaced)
- T12-bottom (rebuilt with new O-ring)
- T12-top (rebuilt with new O-ring)
- Valve (repaired)