Detection Limits of Optical Gas Imaging for Natural Gas Leak Detection in Realistic Controlled Conditions

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INTRODUCTION

With the growth of natural gas production accompanying expansion of shale and tight gas production plays, the available quantity of natural gas in the U.S. has grown and the cost of gas has fallen. As a result, a substantial fraction of electric power generation has been converted or replaced with natural gas fired units, with natural gas surpassing coal to become the largest fuel source for electricity production in 2017.[1] While natural gas produces lower combustion CO2 emissions than coal, methane, the primary constituent of natural gas, has a global warming potential ≈84 times higher than CO2 for a 20-year time horizon. Interest in reducing natural gas emissions has led to an increased interest in technologies for detecting natural gas leaks. This study presents recent tests of the detection efficacy of one of the most popular leak detection technologies used in mid- and up-stream sectors of the natural gas industry: *optical gas imaging* (OGI). OGI has been extensively utilized in recent studies of natural gas emissions on production[2–5], gathering,[6,7] transmission,[8,9] and distribution systems[10].

OGI primarily utilizes video cameras filtered to mid-IR wavelengths overlapped with an absorption band of methane. Normally invisible gas plumes show up as darker than surroundings if the plume is colder than the background and absorbing thermal energy, or as light plumes if the plume reverse is true – i.e. the plum is hotter than the background of the view. To enhance the sensitivity and reduce the noise in the video image, state-of-the-art OGI cameras utilize sensors and optical paths cooled to low temperatures. As a result, the cameras are expensive ($50,000 or more) and relatively bulky compared with visible light cameras of similar resolution;

typical OGI cameras operate at a resolution of 240x320 pixels, a far lower resolution than most current visible light cameras.

In practice, OGI camera technology is deployed in a wide range of field conditions by operators who vary in training and experience. A typical deployment has an operator image all components at a facility – piping valves, major equipment, etc. –by slowly scanning across the equipment, looking for a visible plume representing an emission. The emission may be either an undesired emission (‘a leak’) or a planned emission (‘venting’).

Several studies have assessed the ability of current OGI cameras to visualize natural gas plumes in laboratory and field conditions.[11] These studies have tested cameras, typically tripod-mounted, under a range of conditions and leak sizes. Few studies have quantified the leak detection capabilities of the combined camera-operator system in realistic conditions. No studies have been completed in fully controlled conditions where leak locations and rates were precisely known on realistic equipment.

The data presented here is the result of an extended, single-blind test of the performance of the operator and OGI camera. In this test, experienced operators used OGI to detect leaks in a simulated upstream natural gas facility with a wide selection of controlled emission locations.

METHODS

All testing was performed at the *Methane Emissions Technology Evaluation Center* (METEC) at Colorado State University (CSU) in Fort Collins, Colorado, U.S.A., pictured in Figure 1. The center emulates the above-ground equipment for five wet- and dry-gas production pads ranging in size and complexity, which were grouped into three test pads for this study, as shown in the figure.

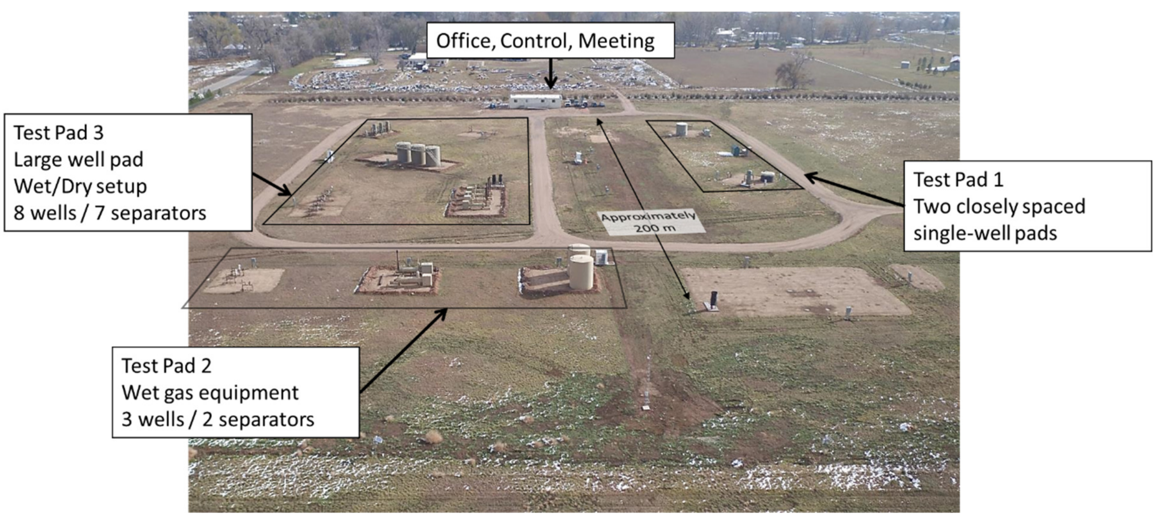

Figure 1: METEC facility as deployed for study

All oil and gas production equipment on the site is built of decommissioned equipment from operating gas production basins, donated by industry advisory board members for the center. The equipment was reassembled at METEC and augmented with gas supply equipment to simulate leaks. Where possible, gas delivery tubing is hidden from view, or routed in existing small-diameter piping already attached to the equipment in normal field service – for example, gas delivery lines for pneumatic controllers and actuators. Gas flow is remotely controlled using valves installed in series with precision orifices. Mass flow rates are measured using mass flow meters. After setup, emission rates at any emission point can be remotely controlled.

The resulting equipment closely resembles functioning field equipment in most ways. Emission points are in locations, and leak at rates and in patterns, similar to what is seen in field conditions. The routing of gas from the supply tanks to emission points is fully hidden on most pads, resembling the functional behavior of leaks seen in the field. However, there are several important differences between the configuration of METEC for this study and conditions that would normally be encountered in an oil & gas (O&G) production basin. First, no equipment is heated; in field conditions, separators may be heated for process reasons. Second, in some field conditions leaking gas may be emitted at high pressure and velocity, forming a small jet near the point of the leak. At METEC, gas is always emitted at slow velocities and near atmospheric pressure. Finally, to avoid 'tipping off' operators to the presence of an emission source, industrial-grade, unodorized, methane, was utilized for the test. In contrast, field conditions gas may have volatile organics heavier than methane that are also detected by OGI camera, and in many fields with significant oil or condensate production, produced gas has a noticeable odor.

The test data presented here was collected in tests performed between February and September, 2018. Additional testing was completed in October and November, which is not included in this presentation. CSU research staff recruited camera operators from O&G operators, leak detection contractors ('contractors'), and regulatory bodies to participate in the study. Each operator brought their own OGI camera (all FLIR™ GF320® cameras) and performed the survey using their normal protocol. The study intentionally allowed the leak detection protocols to vary between teams; the intent was for operators to perform the survey *as in their normal practice,* thus capturing actual performance of working survey teams.

Teams arrived at METEC with their equipment in the morning and received safety and project methodology briefings. They were then tasked with finding leaks on the METEC equipment, in the following sequence: First, a leak pattern was initiated on all the three well pads shown in Figure 1. Operators did not know the location, size, or emission pattern of the leaks. Leak patterns included tests where one or more pads had no leaks. Second, operators were instructed to circulate through the facility to scan with their camera and detect leaks. When multiple operators were screening for leaks simultaneously, they were kept separated from each other and did not communicate while working. Operators recorded each leak found, including location, viewing positions, and other information. Some operators were accompanied by an assistant who helped record the data. Third, when an operator finished with one leak pattern, they returned to the control center, finalized their reporting log, and submitted it to the METEC operator. Finally, when all operators completed leak detection on one leak pattern, METEC staff reset the leak pattern and again dispatched operators to detect leaks.

Using this method, each operator completed 1-4 rounds of the three test pads during each day of testing. For this study, we refer to each visit of an operator to a well pad as a "test." Therefore, each test represents one leak pattern, on one well pad, screened by one operator. In total 1125 tests were performed by operator, contractor, and regulatory teams; tests by amateur teams and manufacturers are excluded from this analysis.

Detection sheets from operators were analyzed by METEC personnel and coded into a single data table. There were four possible results for each test: A leak was present and was detected (true positive or TP) or was not detected (false negative – FN), and a leak was not present but was indicated in detection logs (false positive – FP) or was not detected (true negative – TN). For the analysis presented here we consider only detection efficacy when leaks were present – i.e. true positives and false negatives.

Detection efficacy was analyzed using a logistic regression. Figure 2 illustrates detection curves for the range of gas release rates, stratified by wind speed. The x axis indicates the gas release rate during the test, and the y axis the probability of detection. Each test included in the wind speed bins is marked with a point – 0 equals a false negative and 1 equals a true positive. Curves represent the result of the logistic regression, without bootstrapping; higher curves indicate higher detection probabilities for a given gas release rate.

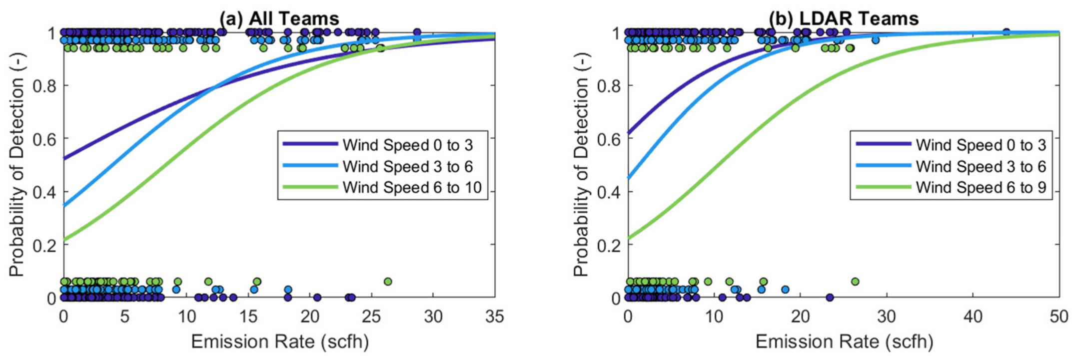

Figure 2: Detection curves by wind speed. Panel (a) shows detection curves for both compliance and LDAR teams, while panel (b) focuses on LDAR teams only – the largest group of tests, with the most consistent protocols. LDAR data shows a clear drop in detection probability with wind speed, as expected.

As expected, wind speed decreases detection probability for small leaks. However, including all teams, the impact of wind speed decreases with increasing leak size. Although data is sparse above 20 scfh, detection probabilities above 15 scfh are relatively independent of wind speed. Considering the 702 tests conducted by LDAR teams – operators and contractors – there is a clear decrease in detection as wind speed increases. For winds below 6 m/s, detection probabilities are similar for leaks larger than ≈ 10 scfh. Above that wind speed, detection probability is substantially reduced.

In contrast, there is little change in detection probability with temperatures, as illustrated in Figure 3. Considering both subsets discussed in Figure 2, there is little change in detection probability across a range of temperatures.

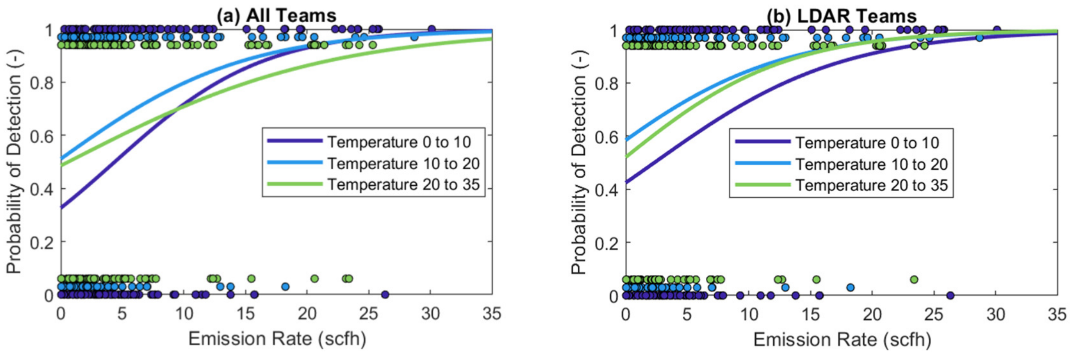

Figure 3: Detection curves by temperature. Panels represent the same subsets as the previous figure. For all teams, and LDAR teams, ambient temperature in °C has little impact on detection probabilities.

SUMMARY

While additional analysis is required, preliminary analysis indicates that variables expected to impact leak detection probabilities have a range of effects. Wind speed impacts detection probabilities substantially, particularly when comparing a consistent subset of data – i.e. professional leak detection teams employed directly by O&G operators or by their contractors. This is consistent with previous studies of leak detection, using cameras or other leak detection methods – wind disperses gases faster, making leaks harder to detect.

Given the thermal imaging characteristics of OGI cameras, it would be expected that ambient temperature would have also have an impact on leak detection. In contrast, no difference was seen. At METEC, gas released from leak points is close to the temperature of equipment at the time of release, since it is flowing through tubing in, or attached to, the equipment. Differences in apparent temperature seen by the camera are therefore likely to be similar at different ambient temperatures, and would likely depend more on sun angle, solar heating of equipment, and similar factors, rather than the ambient air temperature.

Future work will include analysis of other variables, including location of leaks, time of day effects, and experience level of operators.

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