DIAL Measurements of Fugitive Emissions from Natural Gas Plants and the Comparison with Emission Factor Estimates

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ABSTRACT

Natural gas processing is a major industry in Alberta, Canada, and a significant source of fugitive emissions of both methane and volatile organic hydrocarbon (VOCs). This project investigated fugitive emissions at natural gas processing plants in Alberta using two complementary optical measurement methods. At five gas plants, the fugitive emissions of methane and hydrocarbons ethane and larger (C_{2+} hydrocarbons) were measured and quantified using Differential Absorption Lidar (DIAL). The DIAL was also used to measure emissions from process flares at two of the gas plants. At two of the plants, a gas leak imaging camera was used to locate individual hydrocarbon leaks.

For the five gas plants surveyed in Alberta, DIAL measured methane emissions ranged from 100 to 146 kg/hr and C2+ hydrocarbon emissions ranged from 38 to 342 kg/hr. Compressors and condensate storage tanks were two significant emission sources at all of the gas plants. Process flares operating on pilot were typically responsible for 10 to 15% of the total methane emissions.

At two gas plants the DIAL measured emissions of methane, VOCs and benzene were compared with values calculated using emission factor methods. Measured emissions of methane and VOCs were four to eight times higher than the emission factor estimates. The largest differences between measured values and estimates were for the flares and storage tanks. DIAL measured values gave a more realistic evaluation of revenue lost as fugitives than the industry accepted estimation methods, leading to an increased incentive to improve leak detection and repair.

INTRODUCTION

Fugitive emissions of methane from the natural gas industry in Canada may account for over 3% of the national total of greenhouse gas emissions[1]. Currently the quantity of fugitive emissions from gas processing plants are estimated using emission factor methods based on guidelines published by the Canadian Association of Petroleum Producers[2]. The natural gas industry in Alberta is exploring better methods to characterize fugitive emissions losses and to locate sources of fugitive emissions.

Differential Absorption Light Detection and Ranging (DIAL) is a laser-based optical method that can remotely measure the concentration of gases in the atmosphere up to several hundred meters distant with detection limits in the order of parts per billion. Spectrasyne Ltd., UK, has commercially operated a mobile DIAL system in Europe for over 15 years to measure fugitive emissions of hydrocarbons from oil and gas processing and storage facilities, emissions from flares, hydrocarbon emissions from airports, benzene emissions from petrochemical facilities and NO emissions from flares.

During a four week period in 2003 and again in 2004, the Spectrasyne Ltd. equipment was demonstrated in Alberta in projects jointly funded by government and industry[3,4]. The test program included:

- tracking of SO_2 plumes from tail gas incinerator stacks at two gas processing plants and a sour gas well test flare,
- demonstration of accuracy of SO_2 mass flux measurement in the plume from a tail gas incinerator,
- measurement of fugitive emissions of methane and C_{2+} hydrocarbons at five gas processing plants,
- measurement of the combustion efficiency of a well test flare and two solution gas flares, and
- measurement of the efficiency of conversion of H_2S to SO_2 in sour gas flares.

Currently, the majority of fugitive emissions of greenhouse gas (GHG) and criteria air contaminant (CAC) reported for inclusion in emission(s) inventories are estimates, generated through use of emission factors based on equipment installed and operating at a site. In Canada, most large industries must annually report their emissions of CAC's to the National Pollutant Release Inventory and their emissions of greenhouse gases to the Canadian Greenhouse Gas Inventory. Both industry and government are interested in independent verification of the accuracy of these emission estimates.

EXPERIMENTAL METHODS

Differential Absorption Lidar

DIAL is a laser-based optical method that can measure the concentration of a gas species at a remote point in the atmosphere. The DIAL method uses a pulsed laser operating at two wavelengths, one strongly absorbed by the gas species of interest and one weakly absorbed. A system of mirrors and lenses is used to direct the laser pulses toward the target gas volume and collect light back-scattered from particles and aerosols in the atmosphere. The pulse time and light absorption information from the return signals enables calculation of a gas concentration distribution along the length of the light path. With a scanning telescope/mirror system, the unit can quickly scan an area downwind of a facility. The Spectrasyne DIAL unit contains two DIAL systems, one operating in the infra-red wavelength range and one operating in the ultra-violet range.

Measurement of fugitives with the DIAL unit relies on wind carrying the volatile hydrocarbons through a vertical plane downwind of the area of interest. DIAL is then used to scan through this plume and measure a two dimensional profile of the gas concentration of interest that, when combined with wind speed measurement, enables the calculation of the mass rate of the species moving through the vertical plane. The DIAL equipment can be tuned to measure specific hydrocarbon species, such as benzene or methane, or can be tuned to measure a class of species, such as C_{2+} alkanes. When a class of species is measured, such as C_{2+}, sorption tubes are mounted on a tower and placed in the plume to collect a sample for later analysis of the detailed hydrocarbon composition and calculation of an average molecular weight.

Spectrasyne Ltd. has over 15 years of experience performing fugitive emission surveys using their DIAL instrument. At operating industrial sites, variation in fugitive emissions occurs as a result of operational and meteorological changes. To average out these changes, DIAL measurements at a given location are collected for sufficient time to average out these variations. Time weighted mean (TWM) emission values are calculated for each series of individual scans. The mobile unit includes a 14.5 meter tower for wind speed and direction measurements and also includes remote towers that can be set up in the plume to measure wind properties and to collect gas samples from the plume for later analysis. Quantifying emissions from specific areas of a plant require either a wind direction that provides uncontaminated upwind regions or the ability to take DIAL measurements upwind and subtract this from the total downwind amount. Measurements taken under a variety of wind directions improve the ability to allocate emissions to certain areas of the plant without the need for upwind measurements and subtractions.

When performing an emission survey, the Spectrasyne DIAL truck is located optimally about 50 meters from the closest area to be measured and approximately orthogonal to the wind direction. Ideally, the truck position relative to the plant and wind direction enables measurement of emissions from the plant area of interest with minimal contamination from other areas of the plant. In most cases, the DIAL unit can complete the emissions measurements from outside any hazardous areas in the plant. Figure 1 is a photograph of the DIAL unit measuring fugitive emissions at a gas processing plant in Alberta.

Figure 1: Spectrasyne DIAL unit measuring fugitive emissions at a gas plant in Alberta.

Figure 2 and Figure 3 are example concentration profiles of fugitive emissions from gas processing plants in Alberta. Figure 2 shows the distribution of C_{2+} hydrocarbons downwind of the compressor and process buildings from ground level to an elevation of 30 meters and at a distance from 50 to 200 meters from the location of the DIAL. The concentration profile clearly shows C_{2+} emissions were predominantly from the process building. C_{2+} concentrations in the plume were as high as 20 mg/m^3. Figure 3 shows the distribution of benzene in the emission plume along the same scan plane, with most originating from the process building.

Figure 2 Concentration map of C_{2+} emissions from the compressors and process building.

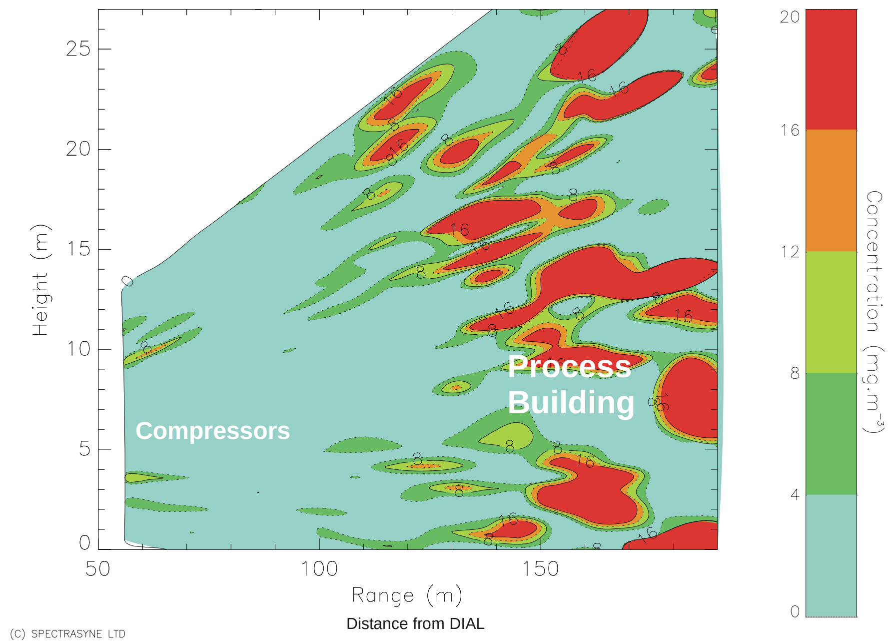
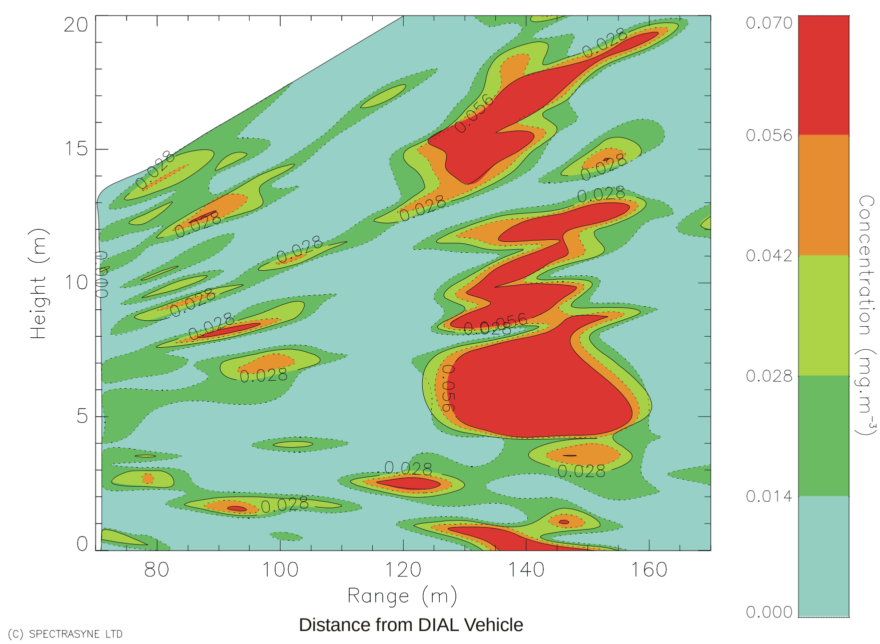


Figure 3 Concentration map of benzene emissions.



The DIAL method of measuring mass emissions has been validated in several studies in Europe and two studies in Alberta. DIAL mass flux measurements in the European validation studies ranged from 3 to 12% below the known emissions source. One European study compared DIAL measurements of vent emissions from a loading barge with independent measurement of the emissions[5]. In the two validation studies in Alberta the mass flux of a gas determined from DIAL measurements was compared to the mass flux determined from in-stack measurements of gas concentration and flow rate. One source was a sulphur dioxide (SO_2) plume from a tail gas incinerator stack at a gas processing facility while the other was a nitric oxide (NO) plume from a gas turbine power plant. In the two Alberta studies, the DIAL measured flux rate was within -11% to +1% of the flux rate determined by in-stack monitoring. The information in Table 1 demonstrates the accuracy of the DIAL method when measuring a relatively constant source.

Table 1: Comparison of DIAL measured mass flux with stack monitoring.

Source	Stack Monitor (kg/h)	DIAL (kg/h)	difference (%)
SO_2 plume from tail gas incinerator	340	304	-11
NO plume from a gas turbine power plant	66.5	67.1	+1

Gas Leak Imaging

Infra-red (IR) cameras were originally developed for thermal imaging inspection of equipment. Methane and other hydrocarbon gases absorb in a wavelength within the range of modern infrared cameras. With filters in the appropriate wavelengths, an infrared camera can be modified to produce an image of hydrocarbon gas plumes. Although these cameras cannot discriminate between hydrocarbon species or measure the mass emissions of the leak, they can be used to efficiently locate leaks. These cameras can improve the efficiency and effectiveness of locating leaking equipment in gas processing plants and enable remote leak detection in areas that are difficult or unsafe for routine access. Leak Surveys Inc., Texas, (www.leaksurveysinc.com) was contracted to perform leak surveys at two gas processing plants in Alberta. At one of the gas processing plants, a DIAL survey measured fugitive emissions both before and after the leak camera survey and the resultant focused leak repair.

RESULTS OF DIAL TESTING IN ALBERTA

Fugitive emission surveys were completed at five gas processing plants in Alberta. Two plants processed sweet gas, containing no hydrogen sulfide, and three plants processed sour gas. The plants ranged in processing capacity from 1.45×10^6 to 10×10^6 Sm^3/d of natural gas. Survey time at each site was limited to two to three days. Although this was less time at each plant than most surveys that Spectrasyne performs in Europe, the Alberta sites were relatively small and upwind interferences were generally not a problem, allowing reasonable proportioning of emissions to different parts of each facility. The location of the DIAL unit was usually moved once or twice during a typical day to access different areas of the plant. At all of the plants, surveys were completed for CH_4 and C_{2+}. At two of the gas plants, fugitive emissions of benzene were also measured. At two of the gas plants, separate measurements were also completed of CH_4 and C_{2+} hydrocarbons in the plumes originating from the process flares.

Table 2 summarizes the overall measured fugitive emissions from the five gas plants. Measured methane emissions ranged from 100 to 146 kg/hr and C_{2+} hydrocarbon emissions ranged from 38 to 342 kg/hr. In all cases the flow of fugitive emissions was less than 0.2% of the plant throughput of natural gas. At a natural gas price of CAN$5/GJ, a fugitive loss of 100 kg/hr represents CAN$237,000 per year of lost natural gas. Gas Plants B to E had fugitive losses of hydrocarbons that represent several hundred thousand dollars per year of lost product.

Table 2: Fugitive emissions at Alberta gas plants measured with DIAL.

Plant	Plant Flow Rate ($x10^6$ Sm^3/d)	CH_4 Emissions (kg/h)	C_{2+} Emissions (kg/h)	benzene (kg/h)
A	1.45	-	38	-
B	3.5	104 (450)[1]	42	-
C	10	146	342	0.24
D	6	124	86	-
E	-	144	41	0.06

[1)] increased emissions during intermittent leak

At Plant B a single intermittent leak from a pressure relief valve was located that increased site methane emissions from 104 kg/hr to 450 kg/hr. One of the DIAL scans indicating this leak is shown in Figure 4. The DIAL scans quantified this leak in the order of 200 kg/h, equivalent to several hundred thousand dollars per year of lost product. The source of the leak was clearly about 10 meters above ground level, at the same elevation as the pressure relief valve vent. The source of the leak was further confirmed with the Leak Surveys Inc. gas leak imaging camera. A still from the video of the leak is shown in Figure 5.

Figure 4: Concentration profile of methane leak at gas plant B.

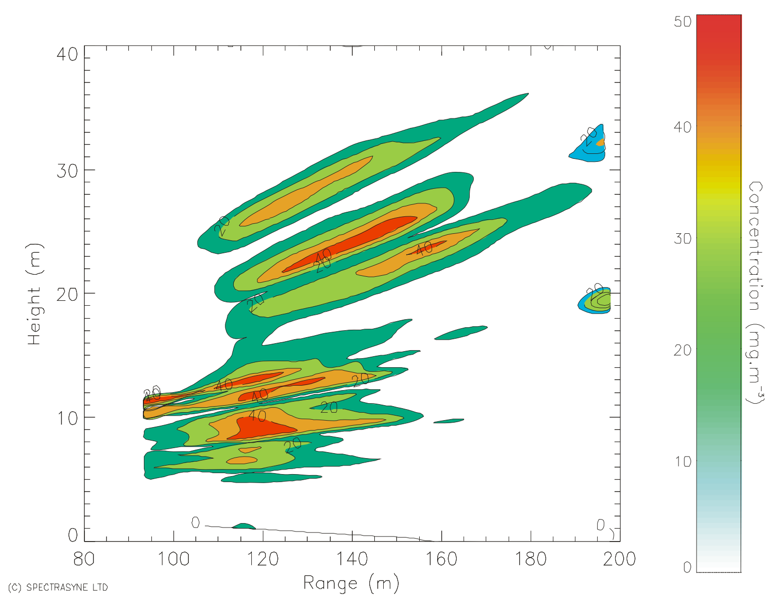
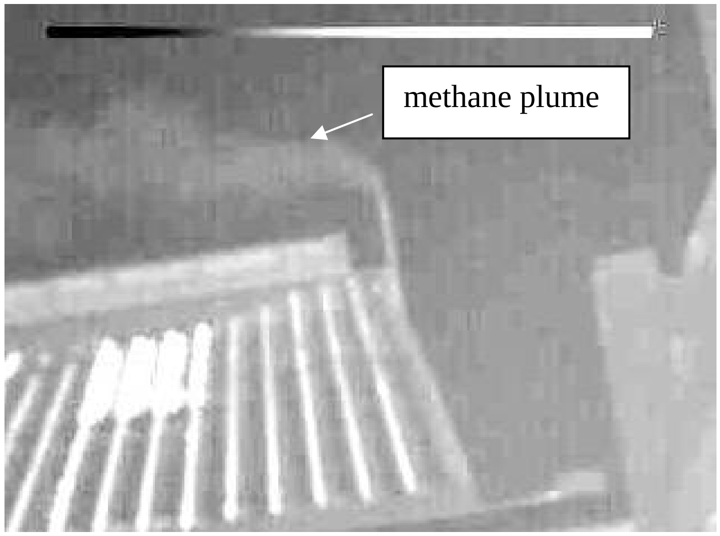


Figure 5: Visual indication of methane leak at gas plant B.
(FSI Hawk System operated by Maverick Inspection Ltd., Sherwood Park, AB)



The detailed DIAL scans were used to apportion fugitive emissions to areas of the plant. Table 3 summarizes the results for Plant B. At this facility the compressor building was the main source of both CH_4 and C_{2+} hydrocarbon emissions. Compressors and condensate storage tanks were two significant emission sources at all of the five plants. Process flares operating on pilot were another significant source of emissions of hydrocarbons. Emissions from process flares operating on pilot accounted for 10 to 20% of the total gas plant fugitive emissions of methane.

Table 3: Details of emissions from gas plant B.

plant location	**CH_4 (kg/h)**	**C_{2+} (kg/h)**
battery and wellsite	2.5	9.7
condensate tanks	30.0	9.5
compressors and bullets	53.2	16.4
process areas	18.4	6.7
flare 1	11.5	-
flare 2	15.6	-
Site Total	**131.2**	**42.3**

Reducing Fugitive Emissions

Using the DIAL and gas leak imaging camera results, Plant C performed a focused leak repair project combined with a before and after DIAL survey. Between 2003 and 2004 the site made efforts to track down and repair individual leaks, including a survey in the spring of 2004 using the Hawk gas-leak imaging camera. The gas leak imaging camera survey in 2004 identified 33 leaks, primarily in the deep cut area of the plant. After the leak repair, a follow up survey with the camera in 2005 identified only seven leaks in the plant.

Table 4 gives a summary of the emissions recorded in both 2003 and 2004 for the sour gas plant, excluding emissions from the flares on site. Between 2003 and 2004, the methane and C_{2+} hydrocarbons emissions from the deep cut area were reduced by 50% and 93%, respectively. This reduction was partly offset by an increase in hydrocarbon emissions from the condensate storage tanks. Even with the increased tank emissions, at a gas price of CAN$5/GJ, the 309 kg/h reduction in hydrocarbon emissions between 2003 and 2004 represents increased revenue on the order of $730,000 per year.

Table 4: Reduction of fugitive emissions by focused leak repair.

	2003 Survey (kg/h)		**2004 Survey (kg/h)**	
Area	**CH_4**	**C_2+**	**CH_4**	**C_{2+}**
Deepcut Plant	91	167	30.9	14.5
Sulphur Plant	23	140	26.5	7.6
Total Process	**114**	**307**	**57.4**	**22.1**
Condensate Tanks	16	24.7	42.6	35.3
Ponds		4.7	0.41	0.93
Total Site	**130**	**337**	**100**	**58.4**

COMPARISON OF DIAL MEASUREMENTS AND EMISSION FACTOR ESTIMATES

Emissions estimate calculations predict the annual fugitive emissions from a facility. DIAL measurements of emissions for this study were typically completed over a two or three day period. Measurements of a single area of the plant were typically time weighted average of a few hours of scans. To calculate annual emissions from the DIAL measurements, several important assumptions were made, including:

- DIAL short term measurements represent annual average emissions,
- gas plant operation continuously at full throughput for 52 weeks of the year,
- C_{2+} emissions represent VOC emissions,
- no gas plant upsets or atypical venting during the DIAL measurement period that would have affected emissions,
- DIAL tank measurements represent average tank emissions.

These assumptions and their potential impact on calculated total annual emissions based on the DIAL measurements must be kept in mind when comparing the DIAL measurements with estimated emissions.

Table 5 compares the hydrocarbon fugitive emissions measured with the DIAL to the estimated fugitive emissions calculated from detailed emission factor methods recommended by the Canadian Association of Petroleum Producers (CAPP). The DIAL measured emissions of methane and VOCs were four to eight times higher than the CAPP detailed estimates. The largest differences between measured emissions and estimates were for the flares and storage tanks. Flares and storage tanks were significantly higher sources of both methane and C_{2+} hydrocarbon emissions than suggested by emission estimation methods.

Table 5: Comparison of DIAL measurements and CAPP method estimates.

Plant	Methane (t/y)	
	Estimated	**DIAL Measured**
Sweet Gas Plant E	188	1264
Sour Gas Plant C	251	1020
	VOCs (t/y)	
	Estimated	**DIAL Measured**
Sweet Gas Plant E	14.9	129
Sour Gas Plant C	94.4	545
	Benzene (t/y)	
	Estimated	**DIAL Measured**
Sweet Gas Plant E	0.45	0.52
Sour Gas Plant C	0.39	2.10

CONCLUSIONS AND RECOMMENDATIONS

The mobile DIAL unit, as operated by Spectrasyne Ltd., was an effective method for quantifying fugitive emissions of hydrocarbons from gas processing plants and the gas leak imaging camera was an effective means for finding leaks. For the five gas processing plants surveyed in Alberta, fugitive emissions of CH_4 ranged from 104 to 146 kg/h and C_{2+} hydrocarbon emissions ranged from 38 to 342 kg/h. With the value of fugitive losses identified, these plants now have an increased incentive to improve leak detection and repair.

The DIAL measured values gave a more realistic evaluation of revenue lost as fugitives than the industry accepted estimation methods as well as improved information on which areas of the plant contributed most to fugitive emissions. Adoption of leak imaging cameras as a tool for leak detection is recommended combined with periodic DIAL surveys to measure the quantity and value losses due to fugitive emissions of hydrocarbons.

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KEY WORDS

DIAL, fugitive emissions, methane emissions, VOC, gas leak imaging, Differential absorption Lidar, benzene, emission inventories, estimated emissions