

The Application of a Laser Based Open-Path Spectrometer for the Measurement of Fugitive Emissions and Process Control.

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ABSTRACT

In this paper examples of field operations are presented explaining the application of a new laser based spectrometer and incorporating real-time dispersion modeling techniques to measure fugitive emissions from land fills, gas processing facilities, chemical plants, aluminium smelters, etc.

Whilst open-path FTIR spectrometers can measure a variety of gases, they suffer from the drawbacks of being large, expensive and of limited range. Also, uncertainty in results caused by spectral overlap has been a matter of concern to regulatory organizations. The laser spectrometer described in this paper is a small(5kg), portable device based on readily available telecommunications technology. Accuracy is determined by an on board reference cell whose calibration is traceable to NIST standards. The instrument is tuned to a unique absorption line for a specific gas (CH₄, H₂S, CO₂, HF, HCN, NH₃), and as a result is immune from line competition. Typical detection sensitivity of <1ppm over path lengths in excess of several hundred metres is observed.

Descriptions in the use of dispersion modeling techniques and tracer gases, in conjunction with the laser spectrometer, hereafter referred to as a GasFinder, are given in order to estimate the fugitive emission rates from various sources.

INTRODUCTION

Before emissions can be managed, they have to be measured. Most fugitive emissions are evaluated by measuring a sample from the area being measured. At a gas processing plant a percentage of the valves are checked for leaks and the resulting value extrapolated for the whole plant. In a refinery with a large number of valves, glands, open tanks etc., this can lead to a final number which is at best an educated guess.

At a landfill site, spot measurements may underestimate because of missing places with large methane emissions, or conversely overestimate because of measuring in areas with high gas concentrations. Using an open path system, the plume of gas coming downwind from the source is averaged and if necessary background values subtracted. The resulting concentration is then compared to a modeled source. The ratio of the two concentrations is calculated and gives a value for the total emissions.

Process engineers are required to monitor emissions but are often hampered by the lack of real time information or have to use a point source sensing system which may not detect a toxic plume outside the sensor's boundaries. Open path spectrometry averages a path over a specified distance and displays the output in real time.

SPECIFIC EXAMPLES

Fugitive Methane Emissions from a Gas Processing Plant.

Large processing plants have many kilometres of pipeline and hundreds of valves. Detecting a leak is a logistical nightmare as is its quantification. Using open path spectrometry, leaks can be detected in a few hours. Turbine inefficiency and blow-by can be evaluated by monitoring exhaust stacks.

Procedure

The setup is different depending on whether the requirement is for emission rates or just concentrations measurements for leak detection. If concentrations are all that are required, the equipment is set up downwind of the source to be investigated and readings taken of the gas concentration. This is a direct reading in real time and the equipment can usually be set up within 10min. The only equipment required is the GasFinder, tripod and battery at one end of the designated path and a retro-reflector at the other end. The length of path will determine the size of the reflector. Path length can be up to 1km, though the average is about 100m. A series of readings with the path in a grid pattern can often quickly locate the source of a leak. Figure 1. shows two paths upwind and downwind of a source.

If emissions rates are required, then meteorological equipment is needed. Upwind measurements are made to establish a concentration level for background methane. The global average is 1.7ppm but values will vary from 0.5ppm to 5.0ppm depending on location. A path is then set up downwind of the area or facility under investigation. The height of the path is usually about 1.5m above the ground, but this will vary with the local topography and the source type. The path length can be up to 1km long depending on the size of the retroreflector, with the average length being 100-300m. The distance of the path from the source is chosen to be at least ten times the source height wherever possible. This is to comply with the modeling requirements. Readings are taken every 3 seconds of methane concentrations, wind speed and direction, temperature and pressure. These are averaged over 1min. and 5 min. intervals. A topographic survey is made of the layout of the facility and its relationship to the laser position and path. Measurements are also made of the building heights as well as the land contours. This can be undertaken while the gas concentration and meteorological readings are being logged. The logging should continue as long as time permits within the limits of the emission survey, one hour at least for meaningful results and preferably longer. Some interesting anomalies can often be seen over a 24hr. period which the operators were not aware of. On a cautionary note, to extrapolate the data collected for one hour to a yearly total is merely playing with figures.

The physical characteristics of the site, together with the meteorological data, are then fed into the EPA's Industrial Source Complex Model Short Term (ISCST3) program and the output, based on a nominal input of 1gm/sec, is compared to the actual concentration readings¹. The resulting ratio gives a measure of the methane emission rate for the facility under investigation. A summary of the procedure is shown below.

1. If necessary record the background levels of the gas under investigation.
2. Record meteorological data at the site.
3. Record path-averaged gas concentrations at a location predominantly "down-wind" of the site.
4. Use the meteorological data to compute a "model plume" using the EPA's ISCST3 model, normalized to an emission rate of one gram per second.
5. Calculate the modeled concentration along a path representative of the actual path.
6. Numerically integrate this concentration profile to obtain a *modeled* path averaged concentration.
7. Scale the model emission rate to coincide with the *measured* path averaged concentration.

Figure 2. shows the different values of emissions coming from a compressor station with six banks each having six turbine compressor units.

As can be seen, compressors #1 and #5 are in good condition, whereas #2, #3 & #4 have various amounts of gas leaking. #6 was not operating although some of the piping was pressurised. Further monitoring would locate the source of the leaks and differentiate between leaking valves and pipes, and the exhaust from the compressors. As has been stated previously, it is highly suspect to extrapolate one hour of data to a year, though it does give an indication of what that rate of leak would add up to.

Measurements of Methane from Landfills.

Landfill gas is generated from the anaerobic decomposition of municipal waste in landfills. Landfill gas consists predominantly of methane and carbon dioxide (approximately 55% and 45% respectively). Methane is explosive (lower explosive limit of 4.5% in air) and is also a potent greenhouse gas. Therefore the need for effective monitoring of fugitive methane emissions from landfills is important from both a safety and an environmental point of view.

Procedure

Methane concentrations are taken using multiple path measurements across the entire landfill. Measurements upwind of the landfill are also made to locate any other influencing methane sources and to measure the local ambient methane levels. An overall 'picture' of surface emissions is mapped. Hotspots (areas with high concentration gradients) are located. If necessary, the flux (overall emissions) from the hotspots can then be measured. Onsite employees are often the best source of information as to where the leaks are. They may remember poorly capped areas and places that smell worse than usual.

Figure 3. Summary of 17 paths taken across a landfill. Background (ambient) concentrations were measured at 2.6ppm.

Figure 4. A plot using the values in Figure 3. A 'hot spot' can be seen between paths 9 and 4

As discussed earlier in this paper, dispersion modeling can be carried out to estimate the total emission from a point or area source. The theory behind the use of dispersion modeling assumes that the actual meteorological and geographical conditions can be accurately reproduced in the model. On many landfills, this is simply not possible. Irregular terrain and highly variable wind conditions reduce the accuracy of the modeled conditions and subsequently the estimation of emissions.

A located source of methane can be estimated without the use of computer modeling but using compressed methane as a tracer gas. Upwind concentrations of methane (C^{up}) are measured and then readings are taken downwind of the landfill source under investigation (C^{down}). The tracer gas is then released at a measured rate (R^{tracer}) from the same point as the landfill source. The combined concentration (C^{comb}) of the three sources is measured on the identical downwind path at the same time. The emission rate is then calculated as shown below.

$$R^{land} = [(C^{down} - C^{up}) / (C^{comb} - C^{down})] \times R^{tracer}$$

where

R^{land} = rate of landfill methane in kg/hr

C^{down} = concentration of landfill and upwind methane in ppm

C^{up} = concentration of methane upwind in ppm

C^{comb} = concentration of landfill, upwind and tracer methane in ppm

R^{tracer} = rate of tracer gas in kg/hr

Using values taken from an actual survey, (see figure 5) with a tracer gas emission rate of 14.3 kg.hr⁻¹, the emission rate of the unknown source of methane is calculated as follows:

$$\begin{aligned}\text{Methane emission rate} &= (20 \text{ PPM}-5 \text{ PPM}) / (37 \text{ PPM}-20 \text{ PPM}) \times 14.3 \text{ kg.hr}^{-1} \\ &\Rightarrow 15 \text{ PPM} / 17 \text{ PPM} \times 14.3 \text{ kg.hr}^{-1} \\ &\Rightarrow 12.6 \text{ kg hr}^{-1}\end{aligned}$$

The estimated emission rate from the area of landfill monitored is 12.6 kg/hr.

The tracer gas bottles were weighed on a small, mid-range digital scale (5kg), and were emptied during the release. Usually about 300g of 80% methane (240g of CH₄) in a minute, a relatively slow flow rate. Scale increments were 5g, giving an accuracy within +/- 5%.

Measurements of Hydrogen Fluoride in Aluminium Smelters.

Hydrogen fluoride gas (HF) is emitted from the reduction cells in the aluminium smelting process. Most of this gas is collected and treated, however some fugitive emissions escape through the roof vents of smelting buildings (potrooms). The quantification of the untreated emissions is important as HF gas is potentially deadly.

The potrooms in aluminium smelters can be up to 1000m in length, and current monitoring techniques involve the use of labour intensive cassette sampling along the length of the apex of the roof. In a study in NSW, Australia², a Boreal Laser GasFinder used in comparison trials obtained results within 10% of standard cassette sampling methods. Similar results have also been obtained in Europe.

Procedure

A path is set up over the pot lines in the roof of the building. The usual length is about 300m with the temperature approaching 50⁰c. The dust and fumes are more akin to Dante's Inferno than the pristine look of aluminium. Under these conditions the visible aiming laser is invaluable for the initial alignment. For long term operation in a fixed location, both the instrument and retro-reflector need to be housed in an enclosure that will keep dust from obscuring the windows and mirrors. A vortex cooler has been used successfully to cool the instrument enclosure, although this necessitates a supply of compressed air. It has the added advantage of keeping the enclosure dust free. Instrument alignment can be a problem due to the movement of a metal building with temperature extremes and care must be taken to minimise any movement of the mounting. Allowance can be made for building movement by placing the retro mirrors in a wide array such that the laser beam can move onto a new set of retros. A real time data feed from the instrument can be routed to a process control room SCADA system with a 4-20mA loop or an RS232 line via a fibre optic link or radio modem. The use of the GasFinder for monitoring emissions can give the process engineers a real time tool to enhance the pot line efficiency by keeping the emissions low and thus increase the economic viability of the process. This has a secondary advantage of reducing noxious emissions into the environment. A win - win situation.

Figure 6. shows the concentration of Hydrogen fluoride in the pot room ceiling of an aluminium smelter over a 12 hour period. Each point represents a reading averaged over 80 sec using 1sec data.

Airborne Applications

Checking for leaks in a gas pipeline.

In North America alone there are thousands of kilometres of pipeline often in remote areas. Leak detection presents a difficult logistical problem that can be reduced by using an airborne system.

Procedure

A modified GasFinder system is carried in a helicopter with a fibre optic link to and from a mirror assembly which is mounted underneath the helicopter between the skids. The system takes 3 readings of methane concentrations every second. The helicopter flies slightly downwind of the pipeline at a height of 30m to 50m depending on terrain. A forward speed of at least 100kph ensures that rotor downwash does not affect the readings. This speed gives a value of the methane concentration above the pipeline every 7.5m. A GPS receiver gives a position concurrent with the gas concentration at that location, and all data is logged using a laptop computer. The pilot has a remote control which allows him to monitor the operation, and an audio alarm signal indicates when a high concentration of gas has been detected (greater than 10ppm). This can be verified by returning to the same place and flying over the suspected leak.

On receipt of the computer disc containing the flight data, a three-dimensional plot can be made showing latitude, longitude and gas concentration. This method of surveying pipelines is a fast and effective method of checking for methane leaks and is used by TransCanada Pipelines in its Alberta gas transmission operations.

Figure 7. A 3D map of the measured gas concentration plotted against simultaneous GPS co-ordinates.

Fenceline monitoring.

These installations are often in locations where the refinery or chemical plant is upwind of a community, or they are decreed by government regulations, which attempt to limit the amount of emissions emanating from a plant.

Procedure

A GasFinder is set up at one end of the fenceline to be monitored and aimed at a retroreflector at the other end. Data is collected by a data logger or sent to a control room. Path lengths are up to 1km and as the equipment is subject to weather extremes, it needs to be protected with an enclosure. A mirror system is available to operate between two lines, thus enabling one instrument to be used on two adjacent fence lines, and avoiding the cost of two instruments. The long-term alignment stability of instruments is important and foundations for the mounts need to be engineered to comply with the local conditions.

CONCLUSIONS

The use of an open path spectrometer to detect and measure gas levels brings a new tool to industry and regulatory bodies. Engineers now have a real time display of concentration levels, which can be directly correlated to the process making the gas. Authorities now have a portable, calibrated detection system, traceable to NIST standards, to quantify emissions.

References.

1. Bauer,J; Tulip,J; Kain,P; Paulson,M; Ondrack,J. "Results of the Application of a New Laser Based Open-Path Spectrometer for the Measurement of Fugitive Emissions from Gas Processing Plants", Proc. of an International Specialty Conference, Dallas, Texas, 1996
2. Whitely,K. "Continuous Long Path Gaseous HF Monitoring in a Potroom Vent", Proc. 6th Al Smelting Workshop, 1998.

Figure 1. An example of two paths upwind and downwind of a source of gas. Narrowing the distance between the paths will locate the source.

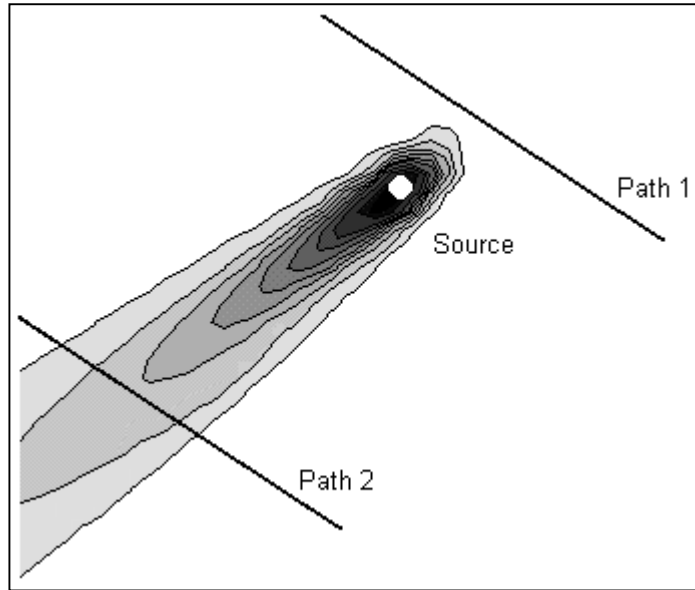


Figure 2. Displays the different downwind concentrations and emissions from five turbine compressor units. #2 and #4 are very poor, #1 and #5 are good and #6 is not operating.

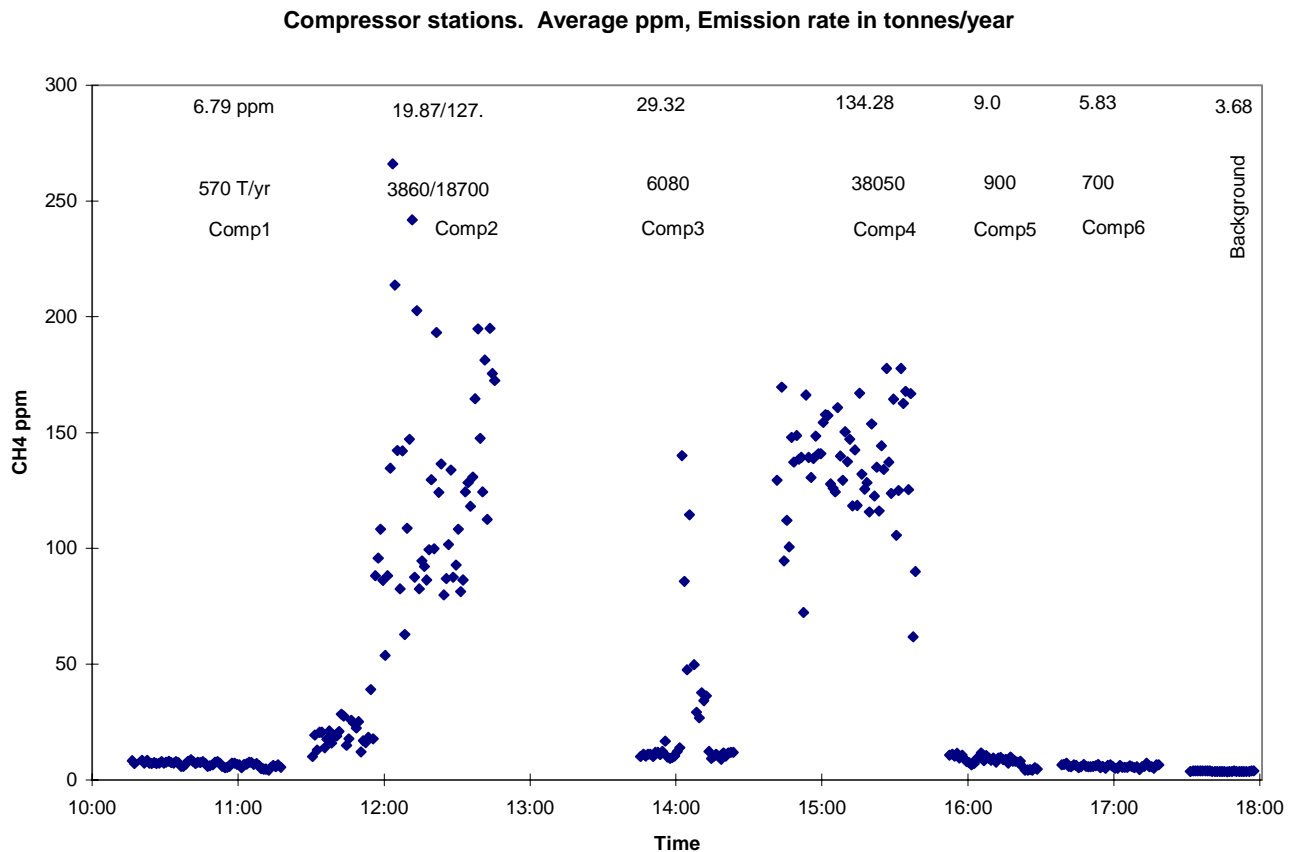


Figure 3. A table listing the paths and corresponding concentration levels at a landfill site

Path Details		Methane Levels	
Path ID	Length (m)	Average	Max (ppm)
1	100	4.7	6.1
2	100	8.9	11.3
3	100	6.3	9.3
4	100	12.7	20.1
5	100	4.6	5.9
6	120	3.7	4.7
7	100	5.6	7.0
8	100	3.4	4.2
9	100	2.9	3.8
10	90	3.2	3.9
11	100	4.0	5.2
12	100	3.4	4.2
13	100	2.7	3.5
14	90	3.1	3.9
15	100	7.8	10.1
16	100	15.7	23.4
17	80	8.4	11.9

Figure 4. A plot displaying four of the values in Figure 3. Between paths 4 and 9 there is a source of gas.

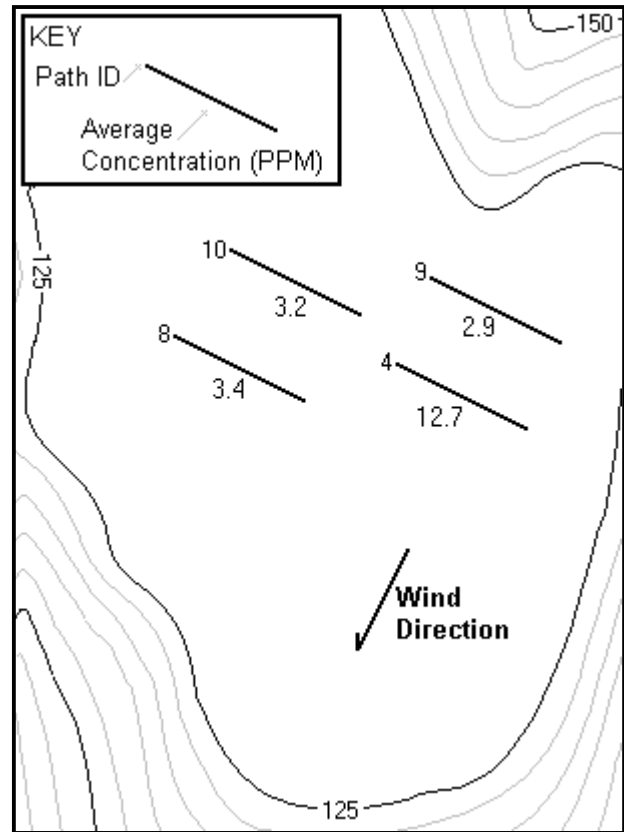


Figure 5. A survey of a landfill using tracer gas. A_m is the ambient or background value of methane and G_m is the average gas concentration downwind. T_m is the value when the tracer gas is introduced.

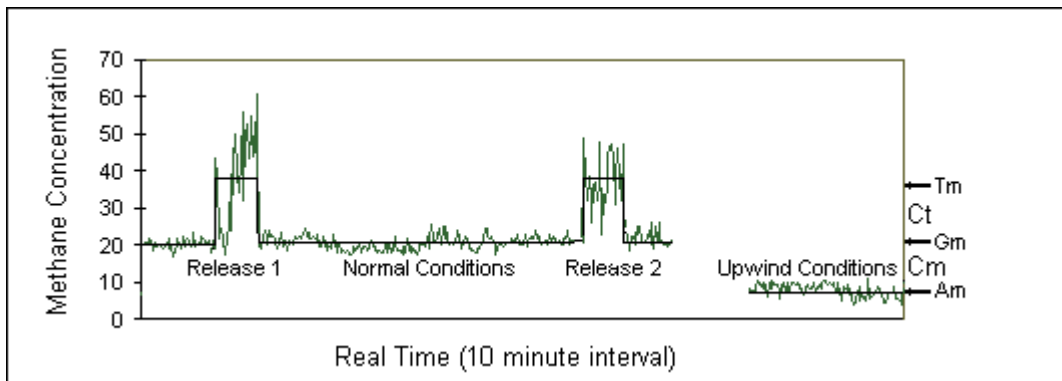


Figure 6. The concentration of Hydrogen fluoride gas in the ceiling of an aluminium smelter over a 12 hour period. From 14:20 to 16:35 some anodes were being changed; however, the tea break at 16:00 can easily be seen.

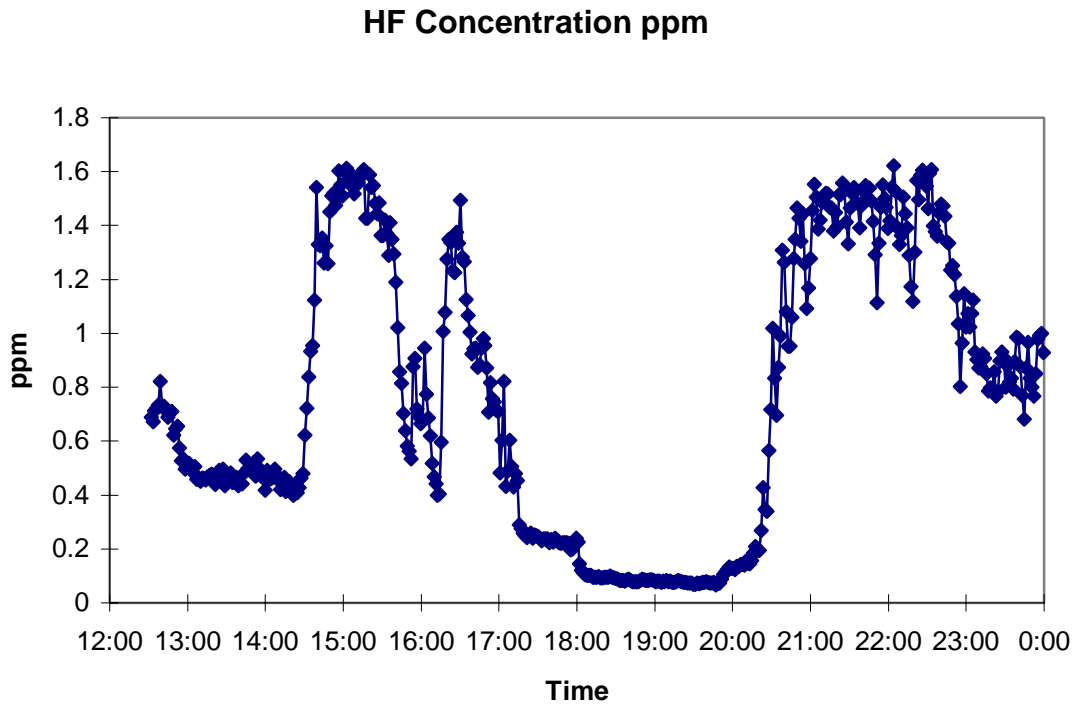
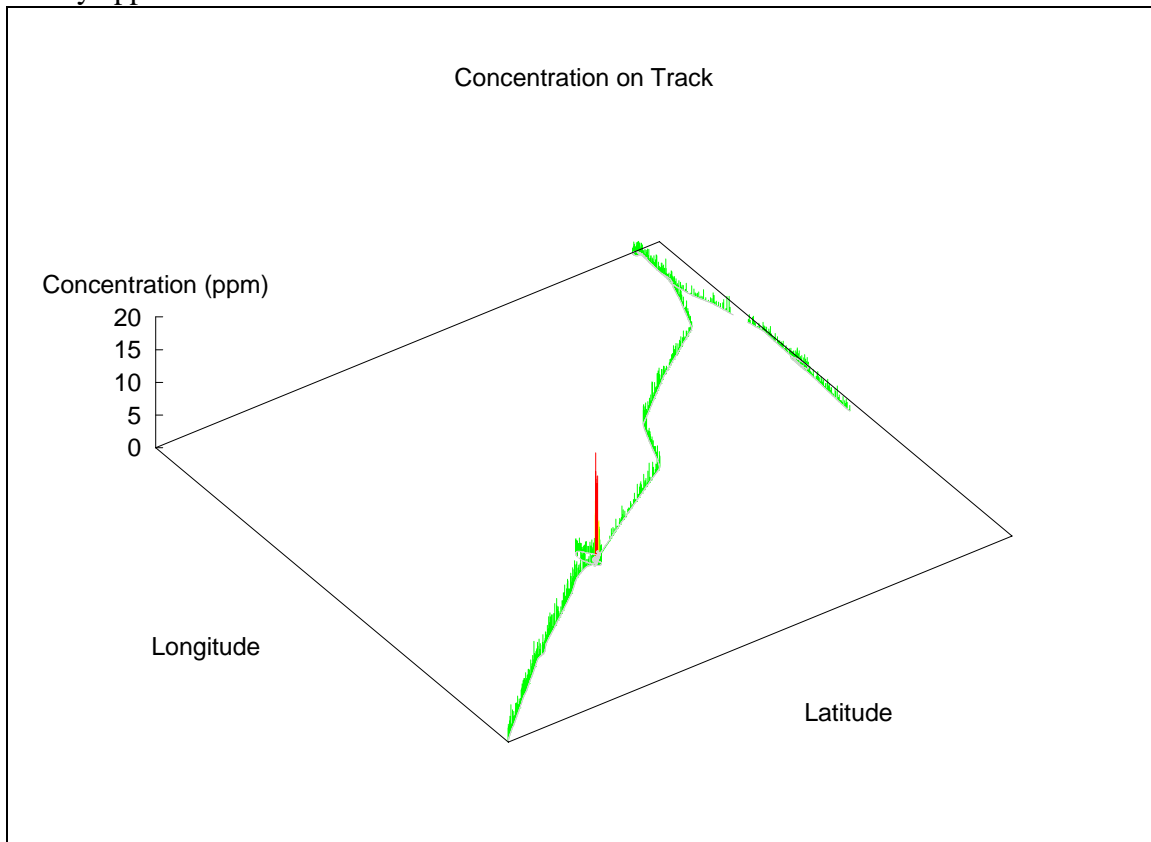


Figure 7. A 3D map of gas concentration plotted on a map grid. The track length is 233km. Concentrations from 0 to 5ppm are plotted in green, 5 to 10 are yellow and over 10 are in red. Lat. and Long. values have been removed to preserve confidentiality. The leak, in this case a valve station, is clearly apparent.



Instrumentation used

I - Gas Detector System

- Boreal Laser "GasFinder 2.0"
- Opticon 2" Hexagonal Retroreflector (5x Array)
- Tripods

II - Meteorological/Data Logging System

- Campbell Scientific CR10X datalogger
- Campbell Scientific #107 Temperature Probe
- R.M. Young 05103-10 Wind Monitor
- Vaisala PTB101 Barometric Pressure Sensor

Keywords

Tunable Diode Laser, Gas detection, Spectrometer, Open path, Dispersion modeling, Environmental monitoring.