Technical Annex: Distributed sampling with real-time analysis to detect fugitive emissions from National Grid Gas compressor stations

Contents

Objective

The aim of this project is to develop a cost effective methodology to enable National Grid Gas (NGG) to monitor and quantify fugitive emissions from above ground installations on the gas grid. The project will involve trialling a distributed sampling and real-time analysis approach over a one year period to assess its practicality, performance and cost effectiveness.

Outline of Approach

The technique trialled uses of a multiplexed, highly accurate and sensitive gas analyser to monitor at a number of locations around the boundary fence of the compressor station. In parallel, meteorological measurements of wind speed, direction and temperature were made. An air pollution dispersion model combines the concentration data with the meteorological data to highlight possible areas of emission and then quantify the likely emissions that would generate the concentrations measured. The dispersion model can be run both over long periods of time to quantify long-term fugitive emissions as well as over short time periods to quantify short-term emission events such as component failure or venting to enable preventative maintenance.

A walk over fugitive emission survey was also undertaken to allow the comparison of the modelled fugitive emissions with direct measurement and thus confirm the quantitative nature of the model.

Project Activities

WP1 Initial emission assessment + system build

Information from a previous DIfferential Adsorption Lidar (DIAL) survey (2014) of [redacted] on likely fugitive emission points and amounts were combined with wind data measured at Belfast International airport and Newcastle Airport to model likely annual concentrations at the fence-line of the site. This forward dispersion modelling was used to highlight the most appropriate locations for real-time sampling and measurement. The results of the dispersion modelling are given in Annex 1.

The site was then visited by NPL to collect relevant information from NGG to ensure a robust sampling plan was implemented and all safety considerations taken into account.

As the project was a for new measurement system, NPL purchased the components and built the system during the last quarter of 2016 and the first quarter of 2017. At the end of the project NGG will own all of the infrastructure deployed at site. The system was delivered to site in mid-March 2017.

WP2 Measurements, emission source location, emission quantification and validation

Measurements

Traditionally, boundary fence style long-term sampling methods, e.g. diffusion tubes, have been used to assess the impact of industrial processes on the local community. While these methods are low cost and well validated, they provide no useful emission quantification data due to the long-term sampling period. Over the sampling period the meteorological conditions, especially wind direction, have extreme variability meaning that the long-term samplers are not measuring source plumes directly, but are making long term averages of the concentrations at individual sampling points. This makes it impossible to differentiate between likely sources of emissions. By performing real-time sampling from different sampling locations it is possible to link measured concentrations to specific wind directions and speeds and hence determine specific emission sources or areas. To make these measurements a fast response analyser is required as the sampling time at each location will be short (<5 minutes) to ensure that all locations are sampled within a representative meteorological condition. A suitable measurement technology that delivers fast response measurements along with long-term calibration stability is Off-Axis Integrated Cavity Output

Spectroscopy (OA-ICOS). Currently there are no robust low cost real-time sensors for methane and other light hydrocarbons. OA-ICOS has the following advantages enabling it to perform highly accurate and fast measurements:

- **Parts-Per-Billion (ppb) Precision:** Does not require a sub-nanometre optical-mechanical setup enabling a robust measurement bench not susceptible to sub-nanometre alignment issues. This enables it to quickly deliver parts-per-billion precision.
- **Wide Dynamic Range:** Directly measures absorption rather than cavity decay time. Therefore, it offers a linear response over a significantly wider dynamic range than conventional Cavity Ring Down Spectroscopy (CRDS).

Figure 1 below shows a schematic of an Off-Axis Integrated Cavity Output Spectroscopy (OA-ICOS) system:

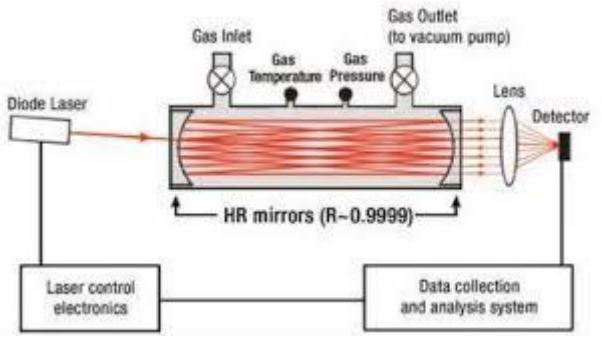

Figure 1: Schematic of an Off-Axis Integrated Cavity Output Spectroscopy (OA-ICOS) system

The OA-ICOS analyser is connected to a distributed sampling system by the use of a stream selection value. This distributed sampling system draws ambient air from up to 15 locations around the site on a continuous basis to reduce any lag time effect. The stream selection valve enables the analyser to sample from each location in addition to a calibration cylinder on a pre-programed basis.

All of the measurement infrastructure has been located on a twin axle trailer for portability and to provide a weatherproof enclosure. The trailer was delivered to the [redacted] compressor station on 13th March 2017. Over the next 3 days the sample lines were installed around the site and measurements started at midday on 17th March 2017. On 31st May 20173 one additional sample line (15) was installed at the north end of the site and on 17th July 2017 2 additional lies were installed on the vent lines from the 2 compressor cabs. Figure 2 shows the locations of the 15 sample locations and the measurement trailer.

Due to issues with power interruptions when the site's emergency generators were tested an uninterruptable power supply for the analyser was installed on 31st August.

[redacted]

Note: background image is out of date and the 2 structures to the west of the compressors are no longer there.

The blue markers indicate the location of the sampling point and the number indicates the sample identifier.

Figure 2: [redacted] sample locations and measurement trailer

Data is collected from the analyser and weather sensors on a weekly basis via a mobile phone link and the stored on NPL servers.

Emission source location

Two methods can be used to predict the location of emission sources. The simplest is by the use of pollution roses generated from the concentration data at each location, the second is by reverse dispersion modelling to find the locations whose possible emissions might contribute to the measured location at each sampling point. For both approaches the meteorological data is required.

Concentrations roses

The gas concentration measurements and wind data have been combined to produce concentration roses (polar plots) to show under which weather conditions the different gas concentrations occur. In these polar plots the colour represents the measured concentration at a specific wind direction and speed. The distance from the centre of the plot corresponds to wind speed, i.e. colours close to the origin are concentrations measured a very low wind speeds whilst colours further from the origin represent concentrations measured at higher wind speeds. The angular position represents the wind direction. As the location of the red high concentration spot moves away from the centre of the plot (increasing wind speed) it indicates that the emission source is further away and indicative of a specific emission. A red spot centred on zero wind speed indicates a build-up of emissions during stagnant (poor dispersion) conditions and is more indicative general local emissions. The white areas represent wind directions and speeds that did not occur due the period of measurement.

Figure 3 shows the concentrations roses for [redacted] for the month of June 2017.

The colour axis of each polar plot is different to highlight the range of concentrations measured. The colour range starts at blue to indicate the lowest concentrations and then moves through green, yellow, orange to red to show the highest concentrations.

Results from sampling points on the compressor cab vents (13 & 14) have not been included in the polar plots as the sampling points are placed directly next to the vents and are directly measuring the emissions.

Figure 3 Methane concentration roses overlaid on overhead image – June 2017

The plots indicate significant emissions from the northern and western parts of the NGG site as well as from the [redacted] Gas portion of the site.

Concentration roses can be used to indicate areas of the site where there are emissions, but give no quantification of the emission rate.

Reverse dispersion modelling – source location, quantification & validation

The reverse dispersion model "Airviro Receptor" from the Swedish Meteorological and Hydrological Institute (SMHI) was set up to predict the possible emission points from the [redacted] site that would lead to the concentrations measured at the sampling locations. The model runs in 2 modes:

i) Source location
ii) Source quantification

In the "source location" mode the model takes measured concentrations and met data and calculates a probability field indicating the location of sources in the model domain. In "source quantification" mode, areas of emissions are defined for the model run and then the model takes the meteorological and concentration data and calculates the emissions required to generate these concentrations. The model outputs an emission rate in g/s and an uncertainty in the emissions as a standard deviation.

Source location

Figures 4 shows how the probable emission locations can change over time. The top centre probability map shows the period 17th March to 31st May, while the 2 probability maps below this show the periods 17th March to 31st March and 1st April to 31st May.

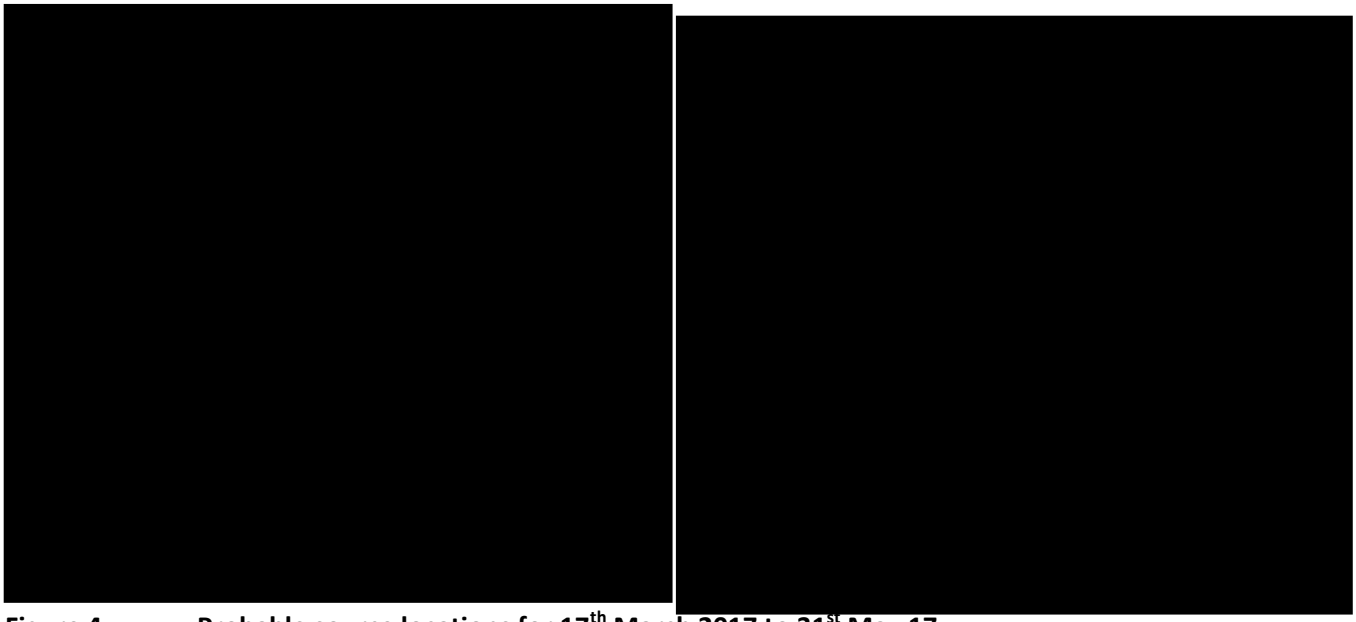

Figure 4 Probable source locations for 17th March 2017 to 31st May 17

It can be seen that over the whole period the dominant emission location changes from the NGG interconnect and western AGI areas to the [redacted] Gas AGI area at the bottom SE corner of their infrastructure. The [redacted] gas emission was later traced to a leaking valve during a walk over survey, which is discussed later.

The emission probability maps for complete monitoring period are given in Annex 1.

Source quantification

The source location mode was run over multiple time periods from 17th March to 20th June to find the probable locations of sources on the site. Five areas were identified as being the most probable sources of emission: PIG traps North (Interconnector), PIG traps West (West AGI), Compressors, [redacted] Gas valves around sample point 11 and [redacted] Gas heaters.

These locations were then fixed in the source quantification mode to calculate the emissions required to deliver the measured concentrations seen by the analyser. Figure 5 shows the locations of the 5 probable emission areas used to calculate the emission estimates. Emissions rates are calculated by the model in g/s and these have been converted to tonnes per year to give an annual equivalent emission rate.

Figure 5 Location of probable emission areas used for emission estimation

The emission rates for the source quantification model runs are given in Annex 1.

Validation

The following text comes from the Executive Summary of "Fugitive Natural Gas Emissions Survey at National Grid Compressor Station: [redacted], County Durham"[1], conducted on 3rd to 5th May 2017:

"A total of 30 points were identified as having methane leak rates of > 24kg/year and tagged for easy identification. The survey concluded that the total measured methane emissions from the site are estimated to be 41.4 tonnes/year (with an uncertainty estimate of ±4.1 tonnes/year), with over 70% of the total site emissions coming from two leaks within the AGI area. A total of 3,376 components having been screened of which 0.9% were found to be leaking.

One of these large leaks was in the SE corner of the [redacted] Gas AGI area, near sample point 11 of the real-time measurements system. Figure 4 shows that over the period 1st April to 31st May the probability that emissions come from this location was in the order of 24 to 28%. The modelled emissions from this area calculated by the source

[1] R P Lipscombe *et al*, FUGITIVE NATURAL GAS EMISSIONS SURVEY AT NATIONAL GRID COMPRESSOR STATION: [redacted], COUNTY DURHAM, 2016120303/[redacted], June 2017.

quantification model for this period was 12.0±0.9 tonnes per year. This compares well with an emission rate of 11.7±1.2 tonnes per year, calculated by the walk over survey.

From the source quantification module the average emissions for PIG trap areas north and west were 6.0 tonnes per year and 5.2 tonnes per year, respectively. During the May walk over survey leaks were found on 8 components in this area with a range of emissions from 0.084 tonnes per year to 4.5 tonnes per year, giving a total leakage across the two areas of 7.8 tonnes per year, again this shows good comparability.

Measurement and modelling uncertainty

The overall measurement uncertainty for the gas concentration measurements was calculated taking into account calibration cylinder uncertainty, analyser drift and calibration repeatability. Table 1 gives the uncertainty budget for the concentration measurements.

	Value %	**Divisor %**	**Standard uncertainty %**
Calibration cylinder	0.50	2	0.25
Drift	0.52	√3	0.30
Standard deviation of calibration factors	0.18	1	0.18
Combined standard measurement uncertainty			0.43
Combined expanded measurement uncertainty (*k=2*)			0.86

Table 1 Uncertainty budget for methane concentrations

For the modelling uncertainty the model splits the proposed source into 9 smaller sources and calculates the emission rate required for each source to deliver the measured concentrations. The reported emission rate is the mean of these 9 separate emission rates along with the standard deviation of the result to give an indication of uncertainty. Multiplying this standard deviation by 2 converts it to an expanded uncertainty (*k=2*). In general the longer the model period the lower the resulting model uncertainty. Table 2 give the mean, maximum and minimum model uncertainty for the longer duration, weekly and emission event model runs for individual sources at [redacted].

Duration	**Mean uncertainty, %**	**Min uncertainty, %**	**Max uncertainty, %**
2 months	20.9	5.6	63.1
1 week	37.3	7.5	88.6
Few hours – emission event	43.2	5.4	84.0

Table 2 Model uncertainties for emission rates from individual sources at [redacted]

Table 3 gives the model uncertainties for combined emission totals for the National Gas Grid sources and the [redacted] Gas sources:

	National Gas Grid			**[redacted] Gas**		
Duration	**Mean uncertainty, %**	**Min uncertainty, %**	**Max uncertainty, %**	**Mean uncertainty, %**	**Min uncertainty, %**	**Max uncertainty, %**
2 months	24.3	11.5	40.7	9.8	5.1	19.7

1 week	35.2	8.8	71.1	20.5	8.1	50.0
Few hours – emission event	32.4	5.4	73.2	44.3	13.9	74.8

Table 3 Model uncertainties for combined site emission rates at [redacted]

It can be seen that the modelled uncertainty generally decreases as the modelled period increases. This is not surprising as the model relies on a good time correlation between the simulated (modelled) concentrations and the measured concentrations. It can also be seen that the measurement uncertainty is insignificant when compared to the modelled uncertainty. Therefore measurement uncertainty has not been included in the uncertainty of the overall predicted emissions.

Short-term releases

As well as running the source location and quantification modules over long periods of time they can be run over short periods, to locate sources that contribute to short-term increases in measured concentrations and then quantify these short-term emissions. Figure 6 shows the emission probability map for 19th to 20th May which coincides with the loading and launching of a PIG from PIG Trap D. During this period measured concentrations reached 15 ppm as a 5 minute average and 60 ppm as an instantaneous reading.

Figure 6 Emission probability map for 19th to 20th coinciding with the loading and launching of a PIG from PIG Trap D

The emissions modelled for this period from the Northern PIG trap area were 0.57 g/s, which is equivalent to 18 tonnes per year if this was a continuous emission.

Portability of the measurement system

The monitoring system is mounted in a twin axle trailer to enable it to be moved to different AGI installations. To test the portability of the system it was decommissioned from [redacted] on 10th October and relocated to the compressor station in [redacted] on 16th October 2017. The sampling lies were sealed and left at [redacted] to enable future measurements if required. New sample lines were laid at [redacted] before the trailer was moved and

measurements started on 25th October. Figure 7 shows the sampling locations at [redacted] and the areas used in Airviro as probable emission locations:

Figure 7 [redacted] sampling and possible emission locations

Lessons learnt

During the installation, commissioning and running of the distributed sampling with real-time analysis system the following lessons have been learnt:

	Issue	Solution
1	2 delayed installation dates	Suppler delays + robust testing of complete measurement solution. Data capture delivered since installation has been >90%.
2	Electrical connection to trailer required improvement	Connectors relocated and passed by site electrician
3	Ground staking of met mast	Site infrastructure used to attach guys. Issue to be raised at [redacted] site survey to find suitable location for mast and guys. Ballasted connection points will be required be required
4	Poor site layout drawings	New drawings only containing above ground installation to be provided by NGG
5	Lack of accurate stack heights for modelling	NGG to provide accurate measurements for elevated emission points / stacks
6	Animal damage to sampling lines	Minimise use of PFA tubing where possible. Route sample lines away from existing animal trails. Damage to one of the mild steel sampling lines is shown in Figure 8.
7	Loss of results after monthly emergency generator tests	The analyser was not recovering from the power interruptions caused by the monthly emergency generator tests. A UPS was fitted to supply power during short term interruptions.
8	Water ingress into sampling tubes	Water was found to have penetrated the two sampling tubes to the cab vents during installation, due to the delay in fitting the final part of the sampling lines. In future, sample lines need to be sealed to ensure no water ingress when they are not fully installed / not in use.
9	Access problems to main site vents	Sampling from the main site vents at [redacted] was not possible due to access problems. Installing sample lines to the main vents at [redacted] was delayed due to similar access problems. An alternative solution needs to be found for future monitoring.

Table 4 Lessons Learnt during the project

Figure 8 **Animal damage to plastic coated mild steel sample line**