The Application of Differential Absorption Lidar (DIAL) for Methane Monitoring

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NPL

- Founded in 1902
- Unique position as the UK's National Measurement Institute
- 600 staff (450 scientists)
- Government owned - Department of Business, Innovation & Skills (BIS)
NPL’s work in environment / atmospheric science
European cooperation in energy gas metrology

- **EMRP Characterisation of Energy Gases**
  - Developing the new metrology to allow alternative fuels to enter the European pipeline system

- **EMRP Metrology for Biogas**
  - Development of a comprehensive metrological toolkit to ensure compliance to European biogas specifications
Environmental Measurements to support industry

- Stack Emissions Testing
- Equipment assessment and calibration
- Landfill monitoring
  - Volatile emissions (methane & VOC)
  - Bioaerosol – *Aspergillus fumigatus*
- Environmental impact assessments
- Remote sensing by Differential Absorption Lidar
Open-path Spectroscopic Measurement Methods

Direct Absorption Spectroscopy

![Diagram of Direct Absorption Spectroscopy](image)

**Beer's Law**

\[ I(\lambda) = I_0(\lambda) \exp(-\alpha(\lambda)NL) \]

where
- \( I \) = measured intensity
- \( I_0 \) = incident intensity
- \( N \) = concentration
- \( L \) = pathlength
- \( \alpha \) = absorption coefficient, at wavelength \( \lambda \)
- \( I/I_0 \) = transmittance
Optical Open path configurations

Integral concentration measured in this region
How does DIAL work?

- Laser
- Dual-wavelength laser pulses
- Source of emissions
- Plume
- Wind

$$\lambda_{OFF} \quad \lambda_{ON}$$
How does DIAL work?

- OFF
- ON

Detector

\[ \lambda_{\text{OFF}} \lambda_{\text{ON}} \]

Source of emissions

Wind

Back-scattered light
The Differential Absorption Lidar Principle
Atmospheric Absorption

Atmospheric Water Vapour Transmission (500 metres)

Atmospheric Methane Transmission (500 metres)

Absorption Spectrum of Unleaded Petrol
NPL Differential Absorption LIDAR (DIAL)

- Optical Radar
- Range resolved concentration
- Able to measure wide range of species
  - VOCs including methane, ethene, methanol, and general hydrocarbons
  - SO$_2$, NO$_2$, NO, Hg, HCl
  - Benzene, Toluene, Xylenes
- Spatial resolution <8 metres
- Range up to 3 km
- Measurement sensitivity typically 50 ppb
DIAL Truck
Flux Measurements with DIAL

- Vertical scans enable plume mapping and flux calculation
- Combine integrated concentration with simple wind field to give flux
- Can measure a distance away from source – less complex wind
Examples of DIAL campaigns

- Cement plant
- Methane
  - Landfill
  - LNG terminals
  - Agricultural emissions
DIAL Measurements at a Cement Plant
Sulphur Dioxide Plumes Measured 2.1 km Downwind of Source
Sulphur Dioxide Plumes Measured 2.3 km Downwind of Source
Plume tracking
Plume tracking
Plume Tracking

Plume grounding
Measurement of Methane

- Methane is an important greenhouse gas 25 times greater effect than CO$_2$
  - IPCC fourth assessment
  - http://www.ipcc.ch/

- Major source in UK GHG emissions inventory
  - Total CH4 50 Mt CO$_2$ equivalent
  - ~10% of CO$_2$

- Landfill is an important source
  - ~20 Mt CO$_2$ equivalent
Measurement of Methane
NPL Current Business

- Routine monitoring of landfill
  - France – favourable tax regime

- Support for legislators
  - UK – lagging Europe in landfill
  - NPL establishing base data at variety of landfills
    - Closed
    - In operation
    - Prior to methane capture

- LNG plant
Measure Downwind Emissions from Area Sources
Horizontal Scan Across Tipping Zone

- Can identify leaks points and hot spots
LNG Terminals

- DIAL used to measure methane (and benzene)
- DIAL truck not “intrinsically safe” but did not need to enter area
- Monitoring of emissions for tanks, vent stacks and flares over a 5-day campaign
Independent assessment of DIAL capability

Strengths:
• Concentration data spatially resolved
• Beam path up to 3000m
• No retro-reflector
• Scan along measurement plane in 10 – 15 minutes
• Mobility
• Near real-time data
• Multi-wavelength, multispecies
Independent assessment of DIAL capability

Limitations:

- Species with common absorption bands can only be measured as a “class”
- Sufficient aerosol must be present to create sufficient back-scatter
- Rapid changes in wind speed or direction may affect mixing ratios
- Limited number of vendors (in USA)
- High system cost
- Beam path is limited by geographical constraints at measurement location
Summary

DIAL offers a valuable technique for the remote measurement and spatial resolution of methane at a wide range of concentrations.
Further information
<table>
<thead>
<tr>
<th>Species</th>
<th>Sensitivity</th>
<th>Max Range</th>
<th>Species</th>
<th>Sensitivity</th>
<th>Max Range</th>
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<td>50 ppb</td>
<td>1 km</td>
<td>NO</td>
<td>5 ppb</td>
<td>500 m</td>
</tr>
<tr>
<td>C₂H₂</td>
<td>40 ppb</td>
<td>800 m</td>
<td>N₂O</td>
<td>10 ppb</td>
<td>500 m</td>
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<tr>
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<tr>
<td>CH₃OH</td>
<td>200 ppb</td>
<td>500 m</td>
<td>Xylenes</td>
<td>20 ppb</td>
<td>500 m</td>
</tr>
</tbody>
</table>

NB: The sensitivities apply at a range of 200 m for a 50 metre plume.
Windowless Cell for ‘Free-space’ Calibration / Validation

- 10 m long x 1 m diameter
- External calibration of open-path instruments
- No reflections from windows
- On-line monitoring of internal conditions
- Dynamic operation
- Also provides range-resolution data for lidar-type instruments
Existing Facilities

NPL presently operates a 10 m open-path cell as a proven ‘free space’ validation technique for the DIAL (Differential Absorption LIDAR) environmental remote sensing system.

- Utilised to provide range resolution for LIDAR type instruments.
- Windowless.
- Generates dynamic gaseous atmospheres.
- Features on-line monitoring of generated conditions.

New Facilities

The Area Source Emissions Simulator is currently being developed at NPL to meet the need to effectively simulate a broad range of real world gaseous emissions scenarios to challenge and validate new monitoring techniques.

The simulator can create customised emissions landscapes, with defined rates and fluxes of gas release at levels comparable to situations found in industry.

Summary of Capabilities

- A broad range of pure or mixed ratio gaseous species can be emitted.
- Traceable emission rates from 0-55 kg/hr for propane and carbon dioxide, and 0-20 kg/hr for methane.
- Release characteristics can be formed by the individual or combined use of various nodes: a vertical jet, a 10 m line source, 3 x 0.65 m² area sources and a 78 m² area source.
Measuring VOCs from Flares

- Flare efficiency measurements at a number of sites
- Able to directly measure unburnt VOC’s
- Typical values for efficiency ~99%
- Have seen poorly performing flares with ~9% emission factor
System Description

- Trailer based laboratory with built-in facilities: generator, air conditioning, optical laboratory, work stations, pneumatic mast for deploying weather sensors.
- Two lasers systems: IR and UV each consisting of a Nd:YAG pump laser followed by a Dye laser.
- Scanner system to direct emitted light in azimuth and elevation.
- 0.5m diameter Dall Kirkham telescope followed by IR and UV detector channels.
- A two channel 40 MHz data acquisition system that acquires signals from optical detectors.
- Boresight camera plus three cameras to provide a wide field of view of area of interest.
- Customised software to manage data acquisition and perform data analysis.
- Meteorological system to record wind conditions and other weather parameters such as temperature and solar radiation.
- GPS and level sensor.