Well Test Flare Plume Monitoring  
– Literature Review

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Executive Summary

Natural gas exploration and production is proceeding in rugged and remote areas of Alberta and B.C. Wells need to be tested to evaluate reservoir parameters and this often requires flaring of sour natural gas. A combination of dispersion modelling to predict SO2 levels and ground monitoring to measure SO2 at locations of concern is used to ensure that ground level concentrations of SO2 do not exceed provincial ambient air guidelines during flaring.

Accurate dispersion modelling is difficult in mountainous terrain. Also, the use of truck or fixed SO2 monitors to reliably track the plume and monitor ambient SO2 levels can be restricted by the lack of roads and the cost of installation in remote mountainous terrain. Hence more cost-effective plume tracking methods and associated SO2 measurement devices are required.

The objective of this project was to identify, evaluate and demonstrate a technology with the potential to be a practical and cost effective method to track plumes from well test flares and to monitor ground level SO2 to ensure compliance with environmental guidelines. The ideal system would be able to operate in remote, rugged areas with limited road access with a high level of availability and reliability. This report covers the first phase of the project, which consisted of a literature review to identify candidate technologies and the development of a proposal for testing of the candidate technologies.

The Differential Absorption Light detection and ranging (DIAL) technique was the only method identified in the literature review that can remotely measure SO2 concentrations at multiple points in the vicinity of well test flares. The DIAL technique can remotely measure SO2 concentration to ppb levels at a volume point of the atmosphere at a distance up to several kilometers. DIAL instruments have been used in Europe to analyse volatile organic hydrocarbons, SO2, NO2 and ozone emissions from urban areas, industrial facilities, oil field flares and volcano plumes. As a laser is used as the light source, the system works day and night and can operate under some conditions of rain and snow. When used with tracking optics and computer data analysis, 2D and 3D concentration profiles of the plume can be measured and displayed. The DIAL equipment is expensive. A truck-mounted system with tracking optics costs in the order of $1,000,000 to $1,500,000 Canadian.

Several other optical techniques measure the average SO2 concentration in a column of air between a light source and detector. The methods fall into two groups. One group measures SO2 absorption of either background sunlight (Correlation Spectroscopy) or background infrared (Image Multi-Spectral Sensing). The second group uses a remotely mounted mirror to reflect a laser or other light source back to the detector (Fourier Transform Infrared). These systems may be a less expensive option than DIAL for visualizing the plume, but cannot currently meet the requirement for analysis of SO2 at a defined point in space. Image Multi-Spectral Sensing has the most promise as a method for rapid imaging of the plume either by detecting SO2 or CH4 and would be able to operate day and night.

Light Detection and Ranging (LIDAR) may be a suitable technique for rapidly imaging the well test flare plume based on aerosols or particulates created by the flare. Although the technique
would not detect SO$_2$, the method would discriminate the plume’s position relative to the local geography in close to real time.

Based on the literature review and discussions with instrument suppliers, the following major options for the first phase of field testing a remote SO$_2$ monitor are presented:

<table>
<thead>
<tr>
<th>Phase 1 Testing Option</th>
<th>Major Tasks</th>
<th>Estimated Phase 1 Cost</th>
</tr>
</thead>
</table>
| 1. Performance testing of mobile DIAL system for SO$_2$ | - use existing European general purpose DIAL system for 1 month test  
- operate at sour gas flare site near Edmonton or Calgary  
- compare with plume dispersion model predictions and point sampling with conventional SO$_2$ monitor  
- demonstrate ability to meet industry needs | $400,000 |
| 2. Design study for an optimised mobile DIAL system | - define industry needs for distance, operating conditions, SO$_2$ sensitivity, terrain, etc.  
- contract an existing optics company to design and cost an ‘optimised’ DIAL system  
- decide on whether to build an SO$_2$ DIAL | $120,000 |
| 3. Testing of mobile LIDAR for plume imaging | - use existing Ontario-based LIDAR for 1 month test  
- image flare plume based on aerosol and particulates  
- attempt to correlate plume image with SO$_2$ levels | $100,000 |
| 4. Performance testing of IMSS plume imaging system | - use existing IMSS system from California for 1 month test for imaging well test flares  
- operate at sour gas flare site near Edmonton or Calgary  
- compare plume images with plume dispersion model predictions and point sampling with conventional SO$_2$ monitor  
- demonstrate ability to meet industry needs | $75,000 |

Some DIAL systems can also measure unburnt hydrocarbons in a flare plume. Performance testing of a European DIAL system could be expanded to include both SO$_2$ measurements and flare combustion efficiency measurements for a more comprehensive test program at a relatively small additional cost.
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1. Background

Natural gas wells need to be tested to evaluate reservoir parameters. Often this testing requires the gas to be flared. Most well test flares in Alberta and British Columbia burn sour gas containing H₂S that, when flared, produces SO₂. The Alberta Air Quality Guidelines allow a maximum 1 hour average ground level concentration of SO₂ of 450 ug/m³ (equivalent to 170 ppb). This guideline for ground level SO₂ should not be exceeded during a well test.

Dispersion modelling of the well test flare consistent with Alberta Environment’s “Air Quality Model Guideline” is used to predict ground level SO₂ concentrations and to identify areas of possible SO₂ exceedances. Traditionally, truck or ground mounted SO₂ monitors have been used to measure ground level SO₂ concentrations in areas of concern to confirm dispersion modelling predictions and to enable the option to stop flaring under conditions exceeding the guideline.

Natural gas exploration and production is proceeding in rugged and remote areas of Alberta and B.C. Accurate dispersion modelling is difficult in mountainous terrain. Also, the use of truck or fixed SO₂ monitors to reliably track the plume and monitor ambient SO₂ levels is restricted by the lack of roads and the cost of installation in remote mountainous terrain. Hence more cost-effective plume tracking methods and associated SO₂ measurement devices are required. A typical well test site requires between 5 and 10 remote SO₂ monitors often located on mountain ridges. An example cost for 8 monitors is $4,000/day plus $5,000 for location scouting and set-up.

2. Objective

The objective of this project was to identify, evaluate and demonstrate a technology with the potential to be a practical and cost effective method to track plumes from well test flares and to measure ground level SO₂ concentrations to ensure compliance with Alberta Environment Guidelines. The ideal system would be able to operate in remote, rugged areas with limited road access with a high level of availability and reliability.

This phase of the project consisted of a literature review to identify candidate technologies and to develop a proposal for testing of the candidate technologies.

3. Literature Review of Candidate Technologies

A literature search and technology review using the Alberta Research Council Inc. library services was performed to identify and compare potential monitoring methods. This review examined capabilities of each technology for both plume identification and tracking and for analysis of SO₂ with sufficient sensitivity for this application. Technologies were compared based on their capability, cost and state of development.

Table 1 lists the candidate technologies identified along with advantages and disadvantages of each technique. This table is followed by a description of each technique and, where available, claimed SO₂ detection limits and example experimental data from plume measurements.
Table 1: Candidate Technologies for Well Test Flare Plume Monitoring

<table>
<thead>
<tr>
<th>Method</th>
<th>Type</th>
<th>Remote SO$_2$ at a point</th>
<th>Quantitative SO$_2$ measurement</th>
<th>Mirror or target required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Differential Absorption Light Detection and Ranging (DIAL)</td>
<td>volume point, laser reflected from particles in air</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Image Multi-Spectral Sensing (IMMS)</td>
<td>integrated line, uses background infrared</td>
<td>no</td>
<td>not demonstrated</td>
<td>no</td>
</tr>
<tr>
<td>Correlation Spectrometry (COSPEC)</td>
<td>integrated line, using sunlight</td>
<td>no</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Fourier Transform Infrared (FTIR)</td>
<td>integrated line between lamp and detector</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Differential Optical Absorption Spectroscopy (DOAS)</td>
<td>integrated line between lamp and detector</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Tunable Diode Laser</td>
<td>integrated line between laser source and detector</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Light Detection and Ranging (LIDAR)</td>
<td>volume point, laser reflected from particles in the air</td>
<td>no</td>
<td>no</td>
<td>no</td>
</tr>
</tbody>
</table>

All of the instruments identified in Table 1 are based on optical techniques utilizing the unique absorption/emission spectrum of different compounds. Some techniques, such as FTIR, measure the spectrum profile over a range of wavelengths while other techniques, such as DIAL, measure the signal at two or three specific wavelengths. Ragnarson, 1994, provides a good technical overview of optical techniques for remote sensing of atmospheric gases, describing their principals and limitations.

3.1 Differential Absorption Light Detection and Ranging (DIAL)

The DIAL technique was the only method identified during the literature review with the potential to meet industries objectives to both remotely monitor SO$_2$ levels near well test flares and to track or image the plume. The DIAL technique can remotely measure the SO$_2$ concentration to ppb levels at a volume point of the atmosphere. As a laser source is used to excite the gas, the system works day and night and can operate under some conditions of rain and snow.

DIAL is a laser based optical method of measuring the concentration of a gas species at a remote point in the atmosphere. The laser source and detector are mounted adjacent to each other with no requirement for remote reflectors or remote light sources. A pulsed laser operating at two wavelengths, one absorbed by the gas species of interest and one not absorbed, sends a beam of
focussed light toward the target gas volume. An optical telescope equipped with detectors measures the light reflected from particles and aerosols in the atmosphere (Mie scattering) at each of the two wavelengths. The pulsing of the laser light source enables a distance determination from the speed of light and the time taken to receive the reflection (similar to Radar). The relative strength of absorbed and non-absorbed wavelengths enables determination of the gas species concentration. Most previous studies use wavebands around 300 nm for the absorbing non-absorbing wavelengths when analysing for SO$_2$. Figure 1 shows the absorption spectrum for SO$_2$, ozone and NO$_2$ in the range of interest for DIAL methods.

![Absorption Spectrum for SO$_2$, Ozone and NO$_2$ in the Wavelength used for DIAL](image)

**Figure 1: Absorption Spectrum for SO$_2$, Ozone and NO$_2$ in the Wavelength used for DIAL**

Similar to some of the other techniques described in this report, the DIAL method measures the integrated concentration of the gas along the line of sight. Unlike the other techniques, the length of the line of sight is known from the time for return of the reflected laser pulse. Using a time series of laser pulses and reflections, the change in gas concentration along the line of sight can be calculated. By measuring the gas concentration profile along the line of sight and by scanning the laser-detector system, a 2D or 3D map of gas species in the atmosphere can be created. When combined with meteorological measurements of wind, pressure and temperature, these concentration maps can also be used to calculate mass emissions of gas species from a point source, such as a flare.
Several research groups have used this technique over the past 20 years for studies of gas species in the atmosphere. These studies have included:

- measurement of unburned hydrocarbons in oil-field flare plumes and calculation of combustion efficiency (Boden et al., 1996)
- mapping of SO$_x$ and NO$_x$ in plumes from coal fired power plants and calculation of total emissions (Egeback et al., 1983)
- mapping of SO$_2$ plume and calculation of total SO$_2$ emissions from volcanoes (Weibring, et al., 1998)
- identifying fugitive emissions of SO$_2$, methane, other hydrocarbons (benzene, toluene) and mercury from tanks and industrial facilities (Ednar et al., 1995; Weitkamp et al., 1996; Goers et al., 1993)
- mapping of nitrogen oxide and ozone concentrations over cities (Kolsch et al., 1992)
- mapping of ozone concentration in the upper atmosphere (Fufii et al., 2001)

Spectrasyne Ltd. (www.spectrasyne.ltd.uk), United Kingdom, and ELIGHT Laser Systems Gmbh, (www.elight.de) Germany, are two private companies with mobile DIAL systems operating in Europe. These systems have been used extensively in Europe for monitoring fugitive emissions from industrial facilities and for monitoring SO$_x$, NO$_x$, ozone and particulates in urban and industrial areas.

ELIGHT both operates and sells mobile DIAL systems. Figure 2 shows a typical mobile DIAL setup (LIDAR 510M) made by ELIGHT. The brochure for the LIDAR 510M is attached as Appendix A. The unit uses all solid state lasers rather than cumbersome die lasers. The approximate cost of such a system is 880,000 Euros ($1,200,000 Canadian). The system can be used to monitor SO$_2$, NO$_2$, ozone, toluene, benzene and aerosols. Technical specifications for the ELIGHT LIDAR 510M model include:

- SO$_2$ detection limit 8 ug/m$^3$ (10 ppb)
- SO$_2$ detection range 2200 m
- best spacial resolution 7.5 m
- time for typical 90° scanning concentration profile 15 minutes

Each specification above is for ideal conditions of the other parameters. The actual detection limit achieved will be a function of distance, resolution and time taken for the analysis. Most of the data reported in the literature consisted of mapping or profiling pollutants requiring a trade off between accuracy and the time taken to complete a profile. In the well test flare monitoring application, the analysis would most likely be at a few fixed points in space with sufficient time for accurate analysis.

Figure 3 shows the measured SO$_2$ concentration in the plume from a refinery complex in Belgium. The plume is easily identified by the high SO$_2$ concentrations between a distance of 100 and 300 m.
Figure 2: ELIGHT Mobile DIAL (LIDAR 510M)

Figure 3: SO$_2$ Measurements downwind of a refinery (ref. ELIGHT Laser Systems GmbH)
Spectrasyne Ltd., UK is the other major company with a mobile DIAL unit that they operate on a project basis or will build for sale. Figure 4 is a photo of the Spectrasyne Ltd. truck mounted DIAL instrument and associated weather stations. Spectrasyne’s unit is a duplex DIAL system that allows them to monitor 2 species or groups of species simultaneously. Most of Spectrasyne’s work has been for the oil industry measuring mass emission rates of VOCs and aromatics from refineries, storage areas, terminals and other facilities. Figure 5 shows a typical set up of the mobile DIAL system for remote measurements.

Figure 6 is a cross section of the methane plume from the vent of a ship being loaded at dock. The Spectrasyne DIAL instrument was located about 130 m downwind of the ship’s vent. The x axis shows the distance in meters from the DIAL instrument while the y-axis is the height from ground level. Contours of methane concentration are shown from 0 to 12 mg/m$^3$ (0 to 17 ppm). Spectrasyne Ltd. has used their system to measure
- VOCs (Volatile Organic Compounds) individually or as mixtures
- benzene
- toluene
- NO and NO$_2$
- methane
- SO$_2$

Figure 4: Spectrasyne Ltd. Mobile DIAL System with Weather Stations
Figure 5: Typical Mobile DIAL Set Up (Spectrasyne Ltd.)

Figure 6: DIAL Results for Cross Section of Methane Plume 130 m Downwind of Ship Loading Vent (methane concentration from 0 to 17 ppmv, ref. Spectrasyne Ltd.)
DIAL systems require a laser pulse in the order of 10 to 20 mJ to achieve the distance and accuracy requirement of the well test flare monitoring. Conventional lasers of this power output are physically large and require significant electrical power in the order of 10 to 20 KVA. Some of this power is required to operate the lasers and some is required for air conditioning and cooling. Recent studies have examined options for simplifying the system and reducing size and power requirements. Toriumi et al., 1997, developed a DIAL system based on solid state lasers (Ti:sapphire laser and a Nd:YAG laser) for monitoring NO\textsubscript{x} in urban areas up to an altitude of about 1000 m. The solid state lasers were used to improve stability and life of the lasers. Fischer and Teak, 1997, design a compact field-deployable DIAL system for measuring ozone in the atmosphere. This system was based on RAMAN shifting of a Nd:YAG laser using deuterium and hydrogen to produce wavelengths suitable for detecting ozone. The goal of measuring ozone to 1 ppb at up to 6 km was not achieved but measurement to 10 ppb at 3 km was possible. This system design might be suitable for SO\textsubscript{2} measurement as the wavelengths used for SO\textsubscript{2} are similar to ozone. Both Spectrasyne and ELIGHT claim to use modern laser and computer systems to reduce size and simplify operation of the units.

Fujii et al., 2001 describes a dual DIAL system for measurement of atmospheric SO\textsubscript{2} emissions from ground level to 3000 m elevation. At the wavelengths typically used for SO\textsubscript{2} DIAL systems (two signals near a wavelength of 300 nm) there is a small interference due to ozone (O\textsubscript{3}) which becomes significant at low levels of SO\textsubscript{2} (less than 100 ppb). Using a three wavelength DIAL system, this ozone interference can be removed along with the interference from aerosol backscatter. The authors claim the three wavelength system can measure SO\textsubscript{2} in the order of 1 ppb.

From published literature and manufacturer performance specifications, DIAL systems should be able to measure SO\textsubscript{2} in the order of 10’s of ppb at ranges of 1 to 3 km and spacial resolution in the order of 10’s of meters. The portable DIAL systems developed and used in Europe are generally designed to be multipurpose and capable of measuring several gases. For the commercial application of monitoring well test flares, the DIAL instrument may be simpler and cheaper than the mobile general purpose units reported in the literature. The target areas for potential high SO\textsubscript{2} levels would be known a priori from the plume dispersion models of the well test flare. The requirement would be to determine whether SO\textsubscript{2} levels are above or below 170 ppb as apposed to a unit calibrated over a wide range of SO\textsubscript{2}. Possible instrument simplifications include:

- simplified tracking optics
- simplified detectors specific to SO\textsubscript{2}
- reduced computational requirements in dealing with only one gas
- reduced computational requirements with point analysis only, no profile mapping
- profiling of lower edge of plume only (i.e. surface map of SO\textsubscript{2} concentration of 170 ppb).

There are at least two Canadian companies that may be capable of building a DIAL instrument specific to the well test flare monitoring application. Optech Incorporated (www.optech.on.ca), based in Toronto, Ontario, designs and sells LIDAR systems for range finding, terrain mapping, wind speed measurement and has also constructed DIAL systems for measuring ozone, aerosols.
and temperature profiles in the atmosphere. Spectral Applied Research (www.spectral.ca), based in Concord, Ontario has designed and constructed a mobile LIDAR system for monitoring suspended particulates in urban areas and has extensive experience in laser and optical systems. Either of these companies could perform a design and costing study for a simplified SO$_2$ monitor for the well test flare application based on the DIAL technique.

### 3.2 Image Multi-Spectral Sensing (IMSS)

A second promising technique is Image Multi-Spectral Sensing (IMSS). Pacific Advanced Technology (www.patinc.com) has developed a field portable IMSS for numerous defence related applications. These include detection and warning analysis of targets such as missile plumes and chemical warfare agents. These new Infrared remote monitoring and image processing technologies are reliable, robust, and can provide a relatively low cost, hand held imaging camera that can be applied to the leak detection and measurement problem for industry and the government. One application studied extensively by the company is methane leak detection. Recent breakthroughs in Digital Signal Processors (DSP) and Field Programmable Gate Arrays (FPGA) permit these sophisticated image-processing techniques developed for the military to be applied to display fugitive gas leaks to the operator in real time. This system may be suitable for imaging and tracking well test flare plumes. Figure 7 shows an image of a methane vent taken in daylight to show methane concentrations. The unit is sensitive enough to operate at night using infrared radiation from terrain as its light source.

To date Pacific Advanced Technology has not used the IMSS system for SO$_2$ detection, although the SO$_2$ spectrum does have useful features in the correct wavelength range. Without further testing and development, the detection limit, range and sensitivity to SO$_2$ cannot be determined. Similar to the COSPEC method, the IMSS instrument measures an integrated concentration of SO$_2$ along the column of air between the IMSS instrument and the source of infrared radiation. Further experimentation is needed with an instrument adjusted to wavelengths suitable for SO$_2$ detection to assess the quality of plume monitoring and the range and detection limits for SO$_2$. The IMMS method does have the potential to be a compact, relatively inexpensive way to visually monitor plumes from well test flares.
3.3 Correlation Spectrometry (COSPEC)

A correlation spectrometer (COSPEC) is a remote sensing device that can repeatedly measure ambient concentrations of either sulfur dioxide or nitrogen dioxide in the air column extending along its line of site. Measurements are made using scattered solar radiation as the light source. The instrument measures the absorption of the gases in the UV-Vis spectral range (290 to 320 nm) a wavelength range with strong absorption by the target gases and minimal interference from other atmospheric compounds. Source intensity changes are compensated by additionally measuring the intensity of radiation at nearby wavelengths known to have little or no absorption to the target gas. This modulated signal is then processed to produce output signals directly proportional to target gas concentrations (in this case, the SO\textsubscript{2} concentrations) in the air column being measured.

COSPEC has been used routinely in studies to track plumes from volcanoes and to estimate the total SO\textsubscript{2} emissions from them (Heliker et al., 1986; Sutton et al., 1992). In the 70’s and 80’s, COSPEC was also used in the study of plumes from coal-fired power plants and other industrial sources to track the plumes and to attempt to measure the total SO\textsubscript{2} emissions (Sperling, 1975; Brown et al., 1975). DIAL instruments have largely supplanted the use of COSPEC in the study of industrial plumes as the DIAL instruments enable point concentration measurements.

To track plumes and to determine mass emissions of SO\textsubscript{2}, the COSPEC instrument was typically mounted on a vehicle, pointed skyward and traversed across the path of the plume. In this manner a cross section profile of integrated gas column SO\textsubscript{2} levels was measured and used to identify the edge of the plume. By combining these measurements with wind speed, the total mass emission of SO\textsubscript{2} could be calculated. Alternately, the COSPEC instrument was mounted at a point and scanned through the plume. The COSPEC instrument was developed in the 70’s.
Pujada et al., 1995, describe a redesign of the instrument using more modern digital and optical techniques to improve its accuracy and ease of use.

The COSPEC instrument is inexpensive relative to other optical techniques and may be the least expensive method for identifying or tracking a plume containing SO\textsubscript{2} or NO\textsubscript{2}. However the instrument requires sunlight to operate and does not measure SO\textsubscript{2} concentration at a point unless it is combined with computed tomography techniques (see Section 3.7). The reported detection limit is in the order of 5-10 ppm x meter (Pujadas et al., 1995) which is not sufficient for the application of measuring in the order of 100’s ppb. The COSPEC instrument would not be suitable for the well test flare application because of these limitations.

### 3.4 Open Path Fourier Transform Infrared

Fourier transform infrared (FT-IR) spectroscopy measures the interaction of IR radiation with gas molecules. FTIR spectrometers for gas analysis have an infrared emitter and associated optics to pass a beam of infrared radiation through a known distance of gas followed by a detector that measures the signal strength over a range of wavelengths. Gases amenable to FTIR analysis absorb energy in the IR range due to vibrations of functional groups and polar bonds and each gas has a characteristic spectrum of absorption. The concentration of the gas can be determined from the relative intensity of the spectrum. Figure 8 shows the IR spectra for SO\textsubscript{2}.

FTIR’s can be used for point analysis of gas concentration (similar to a gas chromatograph) by sampling of the gas into a gas cell with a known path length. Advantages of FTIR analyzers over a gas chromatograph include:
- concurrent analysis of many different gas compounds
- rapid analysis (in the order of seconds)
- stable sensor
- low detection limits

However FTIR’s can only analyze compounds that absorb IR radiation. Gases such as O\textsubscript{2}, N\textsubscript{2} and He can not be analyzed. The spectra for water and CO\textsubscript{2} in the IR range can also interfere with many compounds of interest.

Open Path FTIR’s typically have the IR source and detector in the same instrument with the IR emission reflecting from a remote mirror back to the detector. Alternatively, the detector may be located remotely from the IR source. If the distance from sensor to the detector is known, the instrument can be calibrated to measure the integrated gas column concentration of a component such as SO\textsubscript{2}.

An open path FTIR would not be suitable for the well test flare application for two main reasons. The first is the requirement for a remote sensor or mirror placed at the end of each column of gas to be analyzed. This would cause similar problems as the current issue of placing remote SO\textsubscript{2} monitoring stations. The second is the restriction that the instrument integrates along the total path and does not give a point SO\textsubscript{2} analysis. Computed Tomography may be able to overcome this restriction as discussed in Section 3.7.
Figure 8: Absorption Spectrum for Sulphur Dioxide in the Infrared Range
3.5 Differential Optical Absorption Spectroscopy (DOAS)

Differential optical absorption spectroscopy analyzes information from the UV and visible spectral regions. It has been used for atmospheric remote sensing since the early 80’s. The system typically uses a high pressure xenon arc lamp as a light source focussed with a telescope to create a light column. This light column is reflected off a remote reflector to return to the detector. The received light is dispersed in a grating spectrometer and the measured spectrum is analyzed. The signal can be averaged for several minutes to improve signal to noise ratio. The instrument set up is similar to the open path FTIR, with a combined light source and sensor instrument using a remote reflector. DOAS can also simultaneously measure several compounds. Instruments are available commercially (http://www.thermoei.com) that are suitable for SO2 analysis to ppb levels. As with FTIR, the DOAS instrument measures an integrated concentration over the length of the light path. Due to attenuation in the atmosphere, there is a maximum allowable distance between the DOAS light source and detector. For the commercial instrument offered by Thermo Environmental Instruments Inc., this maximum separation is about 500 m for SO2.

A DOAS instrument would not be suitable for the well test flare application for three reasons. The first is the requirement for a remote reflector placed at the end of each column of gas to be analyzed. This would cause similar problems as the current issue of placing remote SO2 monitoring stations. The second is that the instrument gives an average concentration along the light path and does not give a point SO2 analysis. It may be possible to overcome this restriction using Computed Tomography, as discussed in Section 3.7. The third is the limited distance (about 500 m) allowed between the light source and reflector for SO2 analysis.

3.6 Tuneable Diode Laser Spectroscopy

Tuneable diode laser spectroscopy (TDL) is an open path technique that measures the absorption of a specific wavelength by gases in the atmosphere. Similar to FTIR and DOAS, the instrument typically contains the light source (a tuneable diode laser) and detector in one unit. A laser beam is reflected off a remote reflector back to the detector. Rather than measure a spectrum of the reflected light, the TDL method measures absorption at the wavelength produced by the laser light source. Part of the laser light is passed through an onboard cell containing the gas of interest. By comparing the relative absorption in the atmosphere to that in the reference cell, the average concentration of SO2 in the column of air analyzed can be calculated. Boreal Laser Inc. (http://www.boreal-laser.com/index.htm) is an Alberta company that produces TDL instruments.

A TDL would not be suitable for the well test flare application for two main reasons. The first is the requirement for a remote sensor or mirror placed at the end of each column of gas to be analyzed. This would cause similar problems as the current issue of placing remote SO2 monitoring stations. The second is the restriction that the instrument integrates along the total path and does not give a point SO2 analysis. It may be possible to overcome this restriction using Computed Tomography, discussed in Section 3.7.
3.7 Computed Tomography

Computed Tomography (CT) can be used to analyze data from open path analyzers, such as the open path FTIR, to give a 2D map of a gas species concentration. Similar to the application in CAT scans in the medical field, the mathematical techniques of computed tomography can be used to ‘back calculate’ point concentrations of the gas from a series of intersecting columns of integrated concentration results (Todd et al., 2001). In this manner, an array of intersecting optical paths can be used to obtain a 2D map of gas concentrations in the plane of the optical paths. The accuracy and resolution of the calculated results will be partly a function of the number of optical paths and partly a function of the accuracy of the integrated path measurements.

The computed tomography method promises the ability to use a detector such as the open path FTIR or other column concentration method to obtain 2D concentration maps at a much lower cost than DIAL. However, it would still require the remote placement of reflectors in strategic locations such that the computed tomography would be of sufficient resolution and accuracy.

It may be possible to perform the computed tomography without the need for intersecting optical paths. Price, 1999, reports a numerical study that demonstrated the possibility of using a central instrument with the path-integral data as a series of spokes out from the central instrument. The open path instruments would still require remotely located mirrors.

3.8 Space Based Monitoring

Remote sensing from satellite-based systems has been primarily used for military purposes but has seen a recent increase in civilian applications, including monitoring of the environment. By nature, the typical sensors used are optical methods that primarily analyze the frequency spectrum of reflected sunlight and/or infrared radiation from solid objects.

Space based instruments have been used to measure tropospheric SO$_2$ (Eisinger and Buirrows, 1998). The Global Ozone Monitoring Experiment (GOME) onboard the European Remote Sensing Satellite (ERS-2) performed spectral measurements of backscattered earth radiation and solar irradiance in the UV/visible wavelength range. From these measurements, column amounts of SO$_2$ were determined in the troposphere with sufficient sensitivity to detect SO$_2$ plumes from erupting volcanoes and to detect an increase in SO$_2$ concentration due to lignite fired power plants in southeast Europe. The measurement of integrated SO$_2$ concentration in the atmosphere was over a swath of 40 km x 320 km, with best sensitivity on cloud free days at low solar zenith angles.

The DIAL technique has been proposed for a satellite based system called ‘ORACLE’ for studying ozone concentrations in the atmosphere (www.optech.on.ca/prodspace.htm, http://www.space.gc.ca/science/space_science/paper_reports/long/atmos/level3/oracle/back.asp). The design objectives were to measure ozone concentrations between 0 and 50 km from the satellite. This is still a design study without an operating satellite. Details on if and when the ORACLE project might be completed and details on the instrument capabilities were not
available. ORACLE would be a spaceborne differential ozone LIDAR that could measure ozone profiles through the Earth's atmosphere with 100x100 km horizontal resolution, 3 km vertical resolution and to an accuracy of about 5 ppb. ORACLE is targeted for both day and night observation. The requirement to be able to measure tropospheric ozone with the above precision requires a large primary optic (>2m aperture) on the DIAL receiver. The ORACLE system is scheduled for initial space shuttle testing in 2003 and deployment in a satellite by 2009. This is an example of the current state of the art in space based monitoring of the type of system that would be needed for the detection of SO$_2$ in plumes. Even this system does not have the resolution to look at plumes, as its planned spacial resolution is in the order of kilometres.

Space based terrain mapping is a well established technology, with Canada’s RADARSAT 1 supplying day and night and all weather radar data to a resolution of 8 meters. This system can be used for terrain mapping with sufficient accuracy to monitor ground subsidence due to oil and gas production. (www.rsi.ca/resources/map_insar_rsi.htm). RADARSAT 2 scheduled for launch in 2003 will have a resolution of 3 meters. It may be possible to use RADARSAT data for terrain mapping to be used as input to dispersion modelling for well test flaring.

Frequency of coverage may be an issue with space based monitoring. Unless the satellite is in a geo-synchronous orbit, the coverage of a location on earth will be intermittent. In the case of RADARSAT, the sensor covers a 925 km swath of earth during each orbit, with 14 orbits a day. This means that any point location on earth can only be imaged every 1 to 5 days, depending on latitude.

It may be possible in the future to monitor SO$_2$ plumes from individual flares using a satellite based system. This potential is shown by current monitoring of CO concentrations from space with the Canadian built MOPITT system on the TERRA satellite (http://visibleearth.nasa.gov/cgi-bin/viewrecord?8086). This instrument uses correlation spectroscopy of reflected sunlight. However current space-based instruments for gas analysis in the atmosphere have resolution in the order of several kilometers, only work during the day and do not give an elevation specific gas analysis. A DIAL type system for point volume analysis may not be available until at least 2009.

### 3.9 Light Detection and Ranging (LIDAR)

Light Detection and Ranging (LIDAR) is a laser based optical method of measuring the distance from the instrument to solid objects and/or aerosols or particles in the atmosphere. LIDAR is similar to radar in its application and analysis of data but uses shorter wavelengths than radar. By using these shorter wavelengths, LIDAR systems are more sensitive to atmospheric properties. The laser source and detector are mounted adjacent to each other with no requirement for remote reflectors or remote light sources. A pulsed laser source and moving optics can be used to rapidly build up a 3D or 4D (including time) image of the sky in the order of minutes. If the instrument is calibrated to local geographic coordinates, atmospheric features can be measured referenced to local geography.
LIDAR systems cannot measure gas species concentrations unless they are used in the DIAL configuration (Section 3.1). However, they may be used to track plumes based on aerosols and particulates present in most combustion plumes. An Ontario company, Spectral Applied Research has recently constructed a mobile system for remotely tracking plume dispersion as a means of monitoring dust and aerosol dispersion and for tracking fugitive emissions back to their source. Appendix B is a brochure describing the Spectral LIDAR system. Figure 9 is a 3D picture of initial results from Spectral’s mobile LIDAR system. Plumes are shown from three distinct sources. The instrument required about 1 minute to collect the data presented in Figure 9. The current instrument has a range of 10 km and resolution of 1 meter.

**Figure 9: 3-D Plot of Plumes from LIDAR Measurements (Spectral Applied Research, 2001)**

For the current application to well test flares, the LIDAR technique cannot measure SO$_2$ concentration. However, LIDAR may be a suitable technique for imaging the flare plume based on aerosols or particulates created by the flare and for discriminating the plumes position relative to the local geography. What is not clear and would have to be established by testing is the relationship between concentration of aerosols or particulates in the plume and SO$_2$ concentrations, particularly at the 170 ppb level of interest.
4. Proposal for Phase I Testing of Candidate Technology

Optical methods, such as DIAL, have been used for measuring SO\textsubscript{2} concentrations in plumes from flares and stacks. These instruments have been used primarily as research tools but more recently mobile DIAL instruments are being used for industrial studies. To the author’s knowledge, DIAL instruments have not yet been used as a means of ensuring compliance with ambient air guidelines for SO\textsubscript{2}. This proposal addresses the next phase of testing required to demonstrate the use of remote monitoring of well test flares using the candidate optical techniques.

4.1 Objective of Phase I Testing

The objective of Phase I testing would be to confirm that the candidate technology is capable of remotely tracking the plume and/or measuring SO\textsubscript{2} concentrations near the allowable limit (450 \text{ug/m}^3 in Alberta). The maximum amount of information would be obtained by comparing the measurements from the candidate technology to both plume dispersion predictions and conventional SO\textsubscript{2} monitoring equipment.

The overall objective is to identify, evaluate and demonstrate a system that would be able to operate in remote, rugged areas with limited road access with a high level of availability and reliability.

4.2 Phase I Testing Plan

The DIAL instrument is the only instrument identified that can remotely measure SO\textsubscript{2} concentrations at a point with the required sensitivity. Two companies in Europe currently operate mobile DIAL systems that could be used for monitoring SO\textsubscript{2} concentrations in a well test flare plume. The cost to purchase a mobile DIAL system is in the order of $1 to 1.5 million Canadian. The cost to ship one of the European systems to Alberta and operate it for a 1 month test is in the order of $300,000 to $400,000.

Due to the high cost of either purchasing or renting a DIAL system, the proposal for Phase I testing of a well test flare monitor includes several options with varying costs and expected outcomes. Table 2 lists these options, the major tasks and their estimated cost. The major options, listed roughly in order of decreasing cost, are:

1. test a DIAL system using one of the European DIAL operators
2. proceed with a design study for a DIAL system specific to the well test flare monitoring requirements (based on literature information, accept that the DIAL instrument can measure SO\textsubscript{2} to the level required)
3. test a LIDAR system using an existing Canadian mobile system to determine whether LIDAR can image the plume as a surrogate to actual measurement of SO\textsubscript{2} concentrations
4. test the IMMS system as a means of imaging the flare plume.

Prior to developing a detailed work proposal and cost breakdown, the Steering Committee must decide on which of the above options to pursue. The Spectrasyne DIAL system can also
measure unburnt hydrocarbons in a flare plume. Performance testing of a European DIAL system could be expanded to include both SO\textsubscript{2} measurements and flare combustion efficiency measurements for a more comprehensive test program at a relatively small additional cost.

Table 2: Options for Phase I Testing of Candidate Technologies for Well Test Flare Monitoring

<table>
<thead>
<tr>
<th>Phase I Testing Option</th>
<th>Major Tasks</th>
<th>Estimated Phase 1 Cost</th>
</tr>
</thead>
</table>
| 1. Testing of mobile DIAL system for SO\textsubscript{2} | - use existing European general purpose DIAL system for 1 month test  
- operate at sour gas flare site near Edmonton or Calgary  
- compare with dispersion model predictions and point sampling with conventional SO\textsubscript{2} monitor  
- demonstrate ability to meet industry needs | $400,000 |
| 2. Design study for an optimised mobile DIAL system | - define industry needs for distance, operating conditions, SO\textsubscript{2} sensitivity, terrain, etc.  
- contract an existing optics company to design and cost an ‘optimised’ DIAL system  
- decide on whether to build an SO\textsubscript{2} DIAL | $120,000 |
| 3. Testing of mobile LIDAR for plume imaging | - use existing Ontario-based LIDAR for 1 month test  
- image flare plume based on aerosol and particulates  
- attempt to correlate plume image with SO\textsubscript{2} levels | $100,000 |
| 4. Testing of IMSS plume imaging system | - use existing IMSS system from California for 1 month test for imaging well test flares  
- operate at sour gas flare site near Edmonton or Calgary  
- compare images with dispersion model predictions and point sampling with conventional SO\textsubscript{2} monitor  
- demonstrate ability to meet industry needs | $75,000 |

The following describes major tasks for Phase I testing of a flare plume monitor. The detailed work plan would depend on the instrumentation to be tested.

4.2.1 Select Flare Test Site

In consultation with industry, a site with an operating sour gas flare will be selected for testing of the candidate flare plume monitor. Properties of an ideal site would include:
- location near either Calgary or Edmonton
- simple surrounding terrain for accuracy of plume dispersion modelling
- flare gas H\textsubscript{2}S concentration similar to that expected in the final target market for the monitor
- good road access and space for location of monitoring equipment outside of hazardous areas requiring explosion proof electrical
- existing plume dispersion simulations
4.2.2 Develop Detailed Test Plan, Objectives and Cost

Based on the selected candidate technology and test site, a detailed test plan and cost will be developed. This task will include negotiating any required sub-contracts for equipment rental, etc. The detailed plan will be reviewed with project participants.

4.2.3 Safe Operating Procedure

Alberta Research Council Inc. policy requires a Safe Operating Procedure for all experimental projects. The SOP will be developed in consultation with the test host to ensure that the SOP conforms to the safety procedures at the test site. All staff participating in the test will receive H₂S Alive training.

4.2.4 Commission Equipment at Site

The selected candidate flare plume monitor will be set up and commissioned at the test site. A weather station will also be set up to measure temperature, wind direction and wind speed during the data collection.

4.2.5 Data Collection

This task will collect flare data with the candidate plume monitor, weather station and other sampling equipment. As much as possible, the monitor will be tested day and night and under a range of weather conditions.

4.2.6 Plume Dispersion Modelling

If required, plume dispersion modelling will be performed for the test flare under the weather conditions existing during data collection. These predictions will be compared to the measurements taken with the flare plume monitor.

4.2.7 Final Report and Recommendations

A final report will be prepared to summarize the work performed and the data collected during the field test. Conclusions on the capability of the technology to fulfill the participant requirements and recommendations for further testing will form part of the report.
5. Recommendations

Differential absorption LIDAR (DIAL) techniques are capable of measuring SO$_2$ remotely and with sufficient sensitivity to determine whether the SO$_2$ levels are above or below Alberta ambient air guidelines. In addition to SO$_2$, the DIAL method can also measure NO$_x$, ozone and incomplete combustion products.

Based on the results of the literature review and contacts with equipment suppliers, the following is recommended:

1. Lease a European portable DIAL system with operators to perform about 1 month of testing on a sour gas flare located in the vicinity of Calgary or Edmonton. This testing would demonstrate the feasibility of using DIAL for remote SO$_2$ monitoring in flare plumes.

2. Coincident with the above testing, use the DIAL system to measure unburnt hydrocarbon concentrations in a flare. Combined with wind measurements, these concentrations could be used to calculate flare combustion efficiency. These results would extend the work performed at the University of Alberta to full scale flare testing and provide data difficult or impossible to obtain by physical sampling techniques.

3. Investigate industry interest in using the DIAL system for studying fugitive hydrocarbon emissions from petrochemical facilities and/or emissions from power plants, etc.

The cost of transporting a DIAL system from Europe would be a significant part of SO$_2$ monitoring testing. By spreading these costs over several projects, the cost per project would be reduced. The Spectrasyne DIAL system can also measure unburnt hydrocarbons in a flare plume. Performance testing of a European DIAL system could be expanded to include both SO$_2$ measurements and flare combustion efficiency measurements for a more comprehensive test program at a relatively small additional cost.
6. Glossary

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>COSPEC</td>
<td>Correlation Spectrometry</td>
</tr>
<tr>
<td>DIAL</td>
<td>Differential Absorption Light Detection and Ranging</td>
</tr>
<tr>
<td>DOAS</td>
<td>Differential Optical Absorption Spectroscopy</td>
</tr>
<tr>
<td>FTIR</td>
<td>Fourier Transform Infrared</td>
</tr>
<tr>
<td>IMMS</td>
<td>Image Multi-Spectral Sensing</td>
</tr>
<tr>
<td>LIDAR</td>
<td>Light Detection and Ranging</td>
</tr>
<tr>
<td>TDL</td>
<td>Tuneable Diode Laser spectroscopy</td>
</tr>
</tbody>
</table>
7. References


Fujii, T. et al., ‘Dual differential absorption Lidar for the measurement of atmospheric SO\textsubscript{2} of the order of parts in 10\textsuperscript{9}’, Applied Optics, V. 40, No. 6, 20\textsuperscript{th} February 2001.

Goers et al., ‘A differential absorption Lidar for the depth-resolving measurement of sulfur dioxide, nitrogen dioxide and ozone’, Int. Conf. on Air Pollution Monterrey, Mexico, February, 1993.


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Air pollution monitoring with the LIDAR 510M

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1 Air pollution

During the last decades big efforts have been carried out world-wide to reduce or at least to put a stop to the increasing impact of air pollution on the population. For example, air control units have been implemented at power plants and other industrial plants to reduce the emission of dust, or catalysts at the cars to reduce the traffic emissions.

Some successes in the reduction of specific pollutants could be achieved in this way. Nevertheless, world-wide infringements of the limits given by the World Health Organisation (WHO) for the protection of human health clearly illustrate that the measures carried out are not enough and that there is still much to do.

The importance of the different air pollutants is a function of the temporal and especially from the spatial scale:

For the global scale, the climate relevant air pollutants as carbon dioxide (CO$_2$), methane (CH$_4$) and chlorofluorocarbons (CFC) are important. At present, emission limitations and certificates are being discussed for CO$_2$. In the regional scale (a few hundreds to about one thousand kilometers), especially the increment on many years of the tropospheric ozone (O$_3$) is of importance. Numerous and even contradictory reduction concepts are being discussed. In the local range, for example in the area of a big metropolis, nearly all anthropogenic air pollutants like sulphur dioxide (SO$_2$), nitrogen oxides (NO$_x$), carbon monoxide (CO), hydrocarbons (VOC), ozone (O$_3$) and aerosols (dust, soot) present increased concentrations and clarify the necessity of further measures. In big cities the situation is especially aggravated due to the emission of large amounts of pollutants by numerous sources (vehicles, industries, power plants, house heating) in a relatively small area and due to the high population density, leading to a large number of persons are affected by the air pollution.

The concentration at a certain place and at a certain time always is a function of numerous, partially very different influences that can be divided in three fields: the transition of the pollutants from sources to the free atmosphere (emissions), the transport and the physical-chemical conversion of the pollutants in the atmosphere (transmission) and the impact (immission) of the pollutants on a receptor (humans, animals, plants, buildings, etc.)

To adopt appropriate, that is effective and cost effective measures for the reduction of the air pollution levels, an accurate analysis of the causes and causal connections is required that takes into consideration all the important influence factors of above mentioned fields. Which of these factors are especially important depends e.g. on the pollutant, the geographic conditions or the season.

For this reason, suitable systems for the measurement of air pollutants must be able to determine qualitatively the different elements of the emission, transmission and immission and quantify their impact on the resulting concentration.
2 LIDAR 510M – A measurement device for a many-sided monitoring of air pollution

The mobile system LIDAR 510M for air pollution monitoring, developed and manufactured by Elight Laser Systems GmbH, bases on a similar principle than radar. Instead of using radio waves light pulses are emitted into the atmosphere, where they are scattered and absorbed by the pollutants (molecules and particles). The backscattered light is registered by a sensitive detector and analysed by the integrated software, delivering time and spatially resolved data on the pollutant’s concentration. In this way, the LIDAR 510M allows the determination of the pollutants down to a few µg/m³ and with a spatial resolution down to a few meters. With only one system it is possible to obtain information on the three fields emission, transmission and immission. The technical specifications of the LIDAR 510M and the measurable pollutants are given in the annex.

In comparison with the conventional measurement devices, the LIDAR 510M presents decisive advantages which can be described by the following concepts:

- Remote sensing
- Spatial resolution
- 2D and 3D measurements

2.1 Remote sensing

Its measurement principle allows the LIDAR 510M to carry out remote measurements up to a few kilometres (see annex). This implies for the user, that no direct access to the source is necessary and that no probe must be taken from the air or the exhaust respectively. Especially for difficult accessible sources (high stacks, diffuse emissions, forest fires, etc.) an important facilitation of the measurement procedure is achieved. As the pollutants can be measured directly and without contact in the air, no modification of the probe can occur that may lead to false results. The good mobility of this measurement device (thanks to a complete integration in a commercial minibus or van) allows an easy change to other measurement sites. The following measurement example (fig. 1) shows an emission measurement at a refinery in Antwerp, Belgium. Clearly to make out are the very high sulphur dioxide concentrations (over 1000 µg/m³) in the centre of the emission plume.
2.2 Spatial resolution

Due to its measurement principle, the LIDAR 510M allows spatially resolved measurements of air pollutants in the atmosphere. While conventional measurement techniques only allow measurements at a certain place (point measurements) or integrated over a certain path (DOAS), the LIDAR 510M offers the possibility of a spatial resolution down to a few meters. This is especially important when high gradients of the pollutant’s concentration exist. This is the case for the pollutant’s distribution in street canyons, above important street crossings or for the numerous emissions of an industrial or power plant complex. For the identification of the main producers of the air pollution in an area with a high population and emission source density, a good spatial resolution of the pollution distribution is nearly indispensable. Fig. 2 shows an ambient air measurement of NO₂ over Geneva, Switzerland. The left measurement shows a situation with high concentrations, the right side, three days later, an episode with low pollution levels. With the help of these measurements, the exhaust of an underground parking lot (direction Southeast) could be identified as an important emission source.
2.3 2D and 3D measurements

For the human health the ground-level air pollution concentrations are decisive and must be measured in the frame of the atmospheric monitoring. In many countries, the environmental laws prescribe the observation of defined thresholds at ground-level as well as the number and the measurement sites of the monitoring devices. In the meantime, nearly for all significant pollutants conventional measurement systems are commercially available and have proved their worth. Yet, due to their measurement principle, these systems only offer punctual information on the air pollution level. For this reason, for an area survey (e.g. in a city) a large number of these measurement systems is required. Due to financial reasons it is often necessary to renounce to a sufficient spatial resolution, which can lead to an insufficient understanding of the local air pollution phenomena.

Horizontal measurements with the LIDAR 510M allow for spatially resolved information over an area of a few square kilometres. Due to the high mobility of the system it is possible to change the measurement sites in the frame of a campaign and thus cover even bigger areas.

The knowledge that the processes responsible for the ground-level pollution concentrations not
only occur near the ground but mainly at higher altitudes in the lower troposphere (up to a few kilometres), is of elementary importance for the understanding of the causes of high pollution levels at ground level. These processes are advective and convective transport and mixing processes as well as photochemical and physical transformations of the pollutants during their transport. These processes are mainly steered by meteorological parameters like wind speed and direction, solar radiation, turbulence and precipitation (rain, snow, etc.). The LIDAR 510M allows measurements of the air pollutants at the transport and mixing heights and therefore leads to a better and necessary understanding of the concentration causes at ground level. For example, at higher altitudes often so called reservoir layers are formed that under certain meteorological conditions are mixed down to the ground leading to very high concentrations. This phenomenon could be observed and studied in different measurement campaigns with the LIDAR 510M. A layer at about 1000 m with very high ozone concentrations could be detected for example in the metropolitan area of Athens, Greece (figure 3).

Fig. 3: Vertical ozone measurement over Athens (Greece)
3 Overview on the application fields of the LIDAR 510M

Its measurement principle gives the LIDAR 510M a large variety of applications. The following tables give an overview on the applications fields in which the LIDAR 510M has proved its worth since many years. Further examples of measurements carried out with the LIDAR 510M are presented in a separate brochure.

<table>
<thead>
<tr>
<th>Emissions</th>
</tr>
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<tbody>
<tr>
<td>Remote sensing of emissions from stationary plants (power plants, industrial plants, households)</td>
</tr>
<tr>
<td>Detection of the total emissions from area sources (industrial complexes, airports)</td>
</tr>
<tr>
<td>Detection of emissions from line sources (streets)</td>
</tr>
<tr>
<td>Observation of the temporal and spatial behaviour of plumes</td>
</tr>
<tr>
<td>Detection of diffuse emissions (e.g. from a storage tank)</td>
</tr>
<tr>
<td>Delivery of valuable in-put data for dispersion models</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Transmission and immission</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observation of transport and reaction processes in the lower troposphere</td>
</tr>
<tr>
<td>Detection of storage and inversion layers</td>
</tr>
<tr>
<td>Delivery of data for the evaluation and further development of atmospheric models (transport models, forecasting models)</td>
</tr>
<tr>
<td>Support at the planing (or re-definition) of air measurement networks</td>
</tr>
<tr>
<td>Effect determination of anti-pollution measures (e.g. alternative traffic routes)</td>
</tr>
<tr>
<td>Delivery of extensive data for a better understanding of summer and winter smog episodes</td>
</tr>
<tr>
<td>Detection of so called “hot spots”, places with highly increased pollution concentrations</td>
</tr>
<tr>
<td>Delivery of important information on the causes of high local pollution levels (strategy of counter measures)</td>
</tr>
</tbody>
</table>
**Annex:** Technical specifications of the LIDAR 510M

**Measurement principle:**
DIAL (Differential Absorption LIDAR)

**Parameters:**
SO₂, NO₂, Ozone, Toluene, Benzene (in µg/m³ or ppb)
Aerosols (as extinction)

**Detection limits:**
- SO₂: 8 µg/m³
- NO₂: 20 µg/m³
- Ozone: 2 µg/m³
- Toluene: 10 µg/m³
- Benzene: 10 µg/m³
- Aerosols: 0.05 km⁻¹

According to the norm VDI 4210 for DASL systems (synonym for DIAL) the detection limits are given for a measurement interval of 15 minutes, a spatial resolution of 1000 m, ozone concentrations below 30 µg/m³ and a distance of 1000 m.

**Ranges:**
- SO₂: 2200 m
- NO₂: 2500 m
- Ozone: 2100 m
- Toluene: 1700 m
- Benzene: 1600 m
- Aerosols: 3000 m

According to the norm VDI 4210 for DASL systems, the range is defined as the distance at which the detection limits exceeds ten times the optimal detection limit (see above).

**Operational point:** 350 m

**Best spatial resolution:** 7.5 m

**Measurement time:**
The required time for a 90° scan depends on the number of steps or measurement angles as well as on the number of averaged laser shots. These parameters depends on the measurement task, e.g. a fast scanning for the detection of heavily polluted air masses or a detailed mapping of a pollutant's distribution. Typically a 90° scan takes about 15 minutes.
Mobile Scanning Lidar

Spectral Applied Research Inc. is proud to announce its development of a mobile scanning lidar. This technology development was initiated by CRESTech (Centre for Research in Earth and Space Technology). Spectral has an exclusive license for the commercialization of the lidar system. Designed to map atmospheric aerosol concentrations in 3D, it will measure dust diffusion from demolition sites, track plumes from smokestacks, and create new opportunities for monitoring air quality. This self-contained system is mounted in a cube van for rapid deployment to its next measurement site.

Spectral's scanning lidar uses the backscattered light from aerosols and the underlying atmospheric density to form a snapshot of the atmospheric state. From this snapshot, many atmospheric properties can be inferred, including aerosol distribution, opacity, boundary layer height, diffusion coefficients, and air parcel trajectories. The measurements can be used for monitoring aerosol loading, fugitive emission detection, cloud top and cloud bottom detection, calculating back trajectories from in situ instrumentation, source identification, and plume monitoring. It can operate day and night, winter and summer. With a range of 10km and 1 metre resolution it allows us to see the atmosphere in ways not previously possible. Whether it is pinpoint monitoring or full sky coverage, the lidar can do it.
A lidar (laser radar) uses short pulses of laser light to probe the atmosphere in a fashion similar to a radar using radio waves. But because lidars use shorter wavelengths than radar, they are inherently more sensitive to atmospheric composition and thus provide information about the atmospheric state unavailable from radar.

After the scanner is calibrated to the local geographic coordinates, it can measure atmospheric features in absolute reference to local geography. Capable of scanning at high speeds, this lidar gives full sky coverage in less than a minute, and over longer time scales the lidar will build a 4D image (i.e. 3D plus time) showing the evolution of the suspended aerosol with time. Tracking the transport of suspended matter for several kilometers becomes a reality.

Use it to track the dispersion of stack plumes long after they become invisible to the eye, provide fence line monitoring where dissipation of dust and aerosols must be controlled, detect fugitive emission sources, visualize back trajectories when interpreting in situ measurements, measure cloud and boundary layer height, or even get direct measurements of opacity. Talk to Spectral to learn more about how this exciting new technology can help you with your air monitoring needs.

For more information on using this unique system, contact Richard Berman, Spectral Applied Research.