Optical Measuring Technologies for Detecting Fugitive Emissions

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Abstract

Leak detection and repair activities in the USA and around the world are mainly concerned with regulatory compliance. The spirit of these activities is to hunt for leaks and stop them. A milestone study by the API revealed that in a typical refinery 90% of the fugitive emissions come from less than 5% of the monitored components. Optical measuring technology fits the task of finding that 5% in an expeditious manner. Three major methods are covered – forward looking infrared-FLIR, fenceline Fourier transform IR and dispersive absorption lidar-DIAL. These technologies are in use around the world and finding their place in standard plant integrity and reliability activities.

Background

The spirit of regulations and leak detection and repair (LDAR) programs around the world is to locate and stop leaks in hydrocarbon and chemical processing plants. The green house effect of volatile organic compounds (VOCs) such as methane[1] can be many times that carbon dioxide. Traditional measurement technologies have focused on point monitoring with hand-held vapor analyzers (Figure 1).

Figure 1 – Toxic vapor analyzer in use. Courtesy of Team Industrial Services, Inc.

These methods require a technician to visit each potentially leaking component, measure the leakage and deposit information in a database for analysis and reporting. There can be 25,000 to 100,000 such components in a typical refinery or chemical process plant. Optical methods were investigated in the 1990's to improve the speed at which large leaks could be detected and be repaired. These technologies have been adopted by companies around the world and by the USA's Environmental Protection Agency (EPA) to expeditiously detect and stop leaks. In 2008 rule for using optical measurement methods to detect fugitive emissions called the, "Alternative Work Practice to Detect Leaks from Equipment," (AWP) was made law.[2]

The Air Pollution Control Act of 1955 was instituted to provide research and technical assistance related to air pollution control[3] and formalized concern for the public's health. In 1962 Rachel Carson's book, "Silent Spring" launched environmental activism with its exposé of the affects of pesticides on birds and the environment. And so, environmental health issues came onto the public stage. The Clean Air Act (CAA) of 1963 regulated all industrial stationary plant sites. In 1970 the EPA was instituted and the CAA expanded to include emissions from motor vehicles. In 1990 the CAA was amended instituting leak detection and repair (LDAR) programs and the permit process for the lawful release of pollutants and inventorying. In 2009 the EPA stated, "GHGs (greenhouse gases) are the primary driver of climate change, which can lead to hotter, longer heat waves that threaten the health of the sick, poor or elderly; increases in ground-level ozone pollution linked to asthma and other respiratory illnesses; as well as other threats to the health and welfare of Americans."[4] This marked the first time the EPA declared that GHGs caused climate change and so posed a health danger to USA citizens. This declaration by the EPA has been challenged but the fact remains, controlling and eliminating air pollution is a priority. Table 1 lists these regulatory milestones.

Table 1 USA Environmental Regulation Milestones
1955 – Air Pollution Control Act 1962 – Publication of Rachel Carson's, "Silent Spring" 1963 – Clean Air Act (CAA) – Regulates stationary plant sites. 1970 – President Nixon institutes the EPA. 1970 – CAA Amended – Regulation of motor vehicle sources. 1972 – Clean Water Act 1990 – CAA Amended – Formalized the permit process and required LDAR-leak detection and repair-programs. 2008 – Institution of the, "Alternative Work Practice to Detect Leaks from Equipment," rules. 2009 – EPA declares GHGs a danger to public health

Aims of Optical Emission Measurement

The move to optical emissions detection is part of a common progression when the politics, technology and society converge. It started with the problem of air pollution affecting the general health of society. This caused governments to issue regulation to protect the public's health. Technology holders made plant sites and regulators aware of solutions to meet regulations. Regulators began to mandate the technology to plant sites which spawned new regulations. The new regulations establish a new normal and so the cycle iterates as seen in Figure 2.

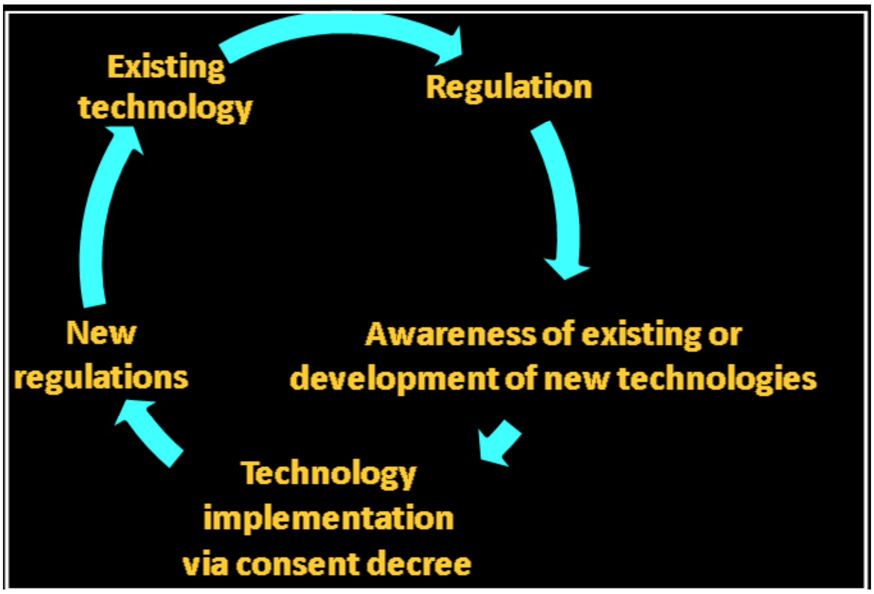


Figure 2 – Regulatory-technology cycle.

In 1997 a multi-year study by the American Petroleum Institute (API) was published. "Analysis of Refinery Screening Data," API Publication 310 showed that over 90% of all fugitive emissions come from less than 5% of the components. In a typical refinery with 50,000 components under fugitive emission compliance, less than 2500 valves, pumps, compressors, flanges, etc. were responsible for over 90% of the emissions. In addition, this the small population of leaking components had high magnitude leaks greater than 10,000 ppm.[5] Consider the fact that the threshold for a categorizing a component as leaking is usually 500 ppm and one asks the questions: Why are we monitoring all these components that are not leaking or are small leaks? How can we identify the components with large leaks and eliminate 90% of our emissions?

Prior to 2008, the primary sanctioned method for determining leaks was the over 30 year old, "Method 21-Determination of Volatile Organic Compound Leaks," (Method 21)[6] illustrated in Figure 3.

Figure 3 – Method 21 uses an organic vapor analyzer (OVA) or toxic vapor analyzer (TVA). The component is approached and, "sniffed," to record the leak concentration. Left, a technician uses TVA to check emissions on a valve's gasket joint. (Courtesy of Team Industrial Services, Inc.). Right, emissions from a valve's stem seal are measured. (Courtesy of Sage Environmental Consulting.)

Method 21 requires a dedicated team of technicians travelling routes that visit all regulated components as often as four times a year regardless of their performance. In contrast the AWP aims to find large leaks quickly by surveying many components at once through the lens of an infrared camera.

Methods

This paper will cover three optical emission measuring technologies:

- **F**orward-**l**ooking **i**nfra**r**ed – FLIR
- Fenceline **F**ourier **t**ransform **i**nfra**r**ed – FTIR and **u**ltra**v**iolet – UV
- **Di**spersive **A**bsorption **Li**ght **d**etection **a**nd **r**anging (LIDAR) – DIAL

FLIR

IR is emitted by all objects and increases with increasing temperature of the body. In the case of sensing gases specialized IR sources in handheld devices sense and see the gas regardless of its temperature (Figure 4). AWP uses FLIR technology. Hand held cameras are used to, "see," leaking hydrocarbons.

Figure 4 – Gas detecting IR camera. Courtesy of Sage Environmental Consulting.

The handheld optical measuring device (camera) is tuned to the IR spectra (Figure 5) characteristic of methane, ethane, propane, etc.

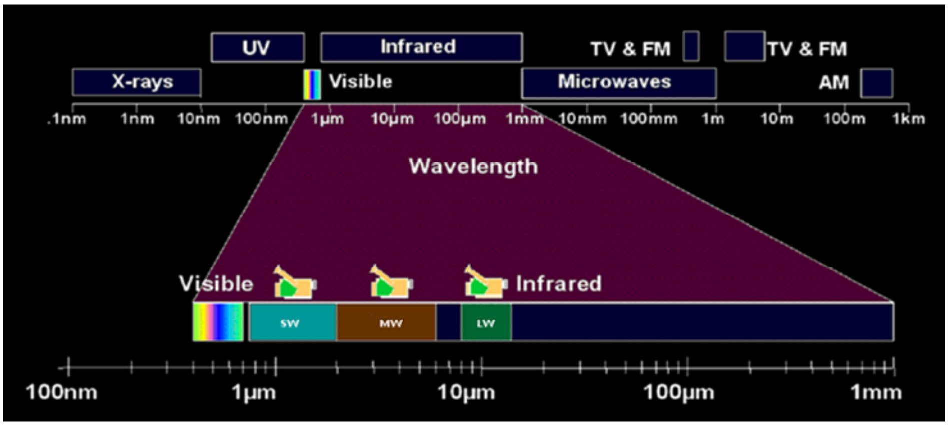
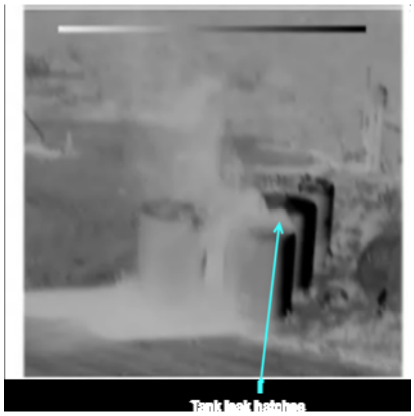


Figure 5 – The chart shows the visible and invisible light spectrum. Within the IR spectrum, manufacturers like FLIR Systems, Inc. divide and apply the "bands" to short-wave (SW), mid-wave (MW), and long-wave (LW) camera systems. Courtesy of FLIR Systems, Inc.

The emissions of the target gases absorb the IR light and appear on the visual display as black smoke (Figure 6).



Figures 6 – Top left and right, FLIR camera depicts valve and tank leak as black smoke on the display. Bottom, technician uses a FLIR Systems, Inc. GasfindIR® (GasfindIR ® registered trade mark of FLIR Systems Inc.) to survey equipment. Photos at top left and bottom courtesy of FLIR Systems, Inc. Photo at top right is from an EPA a nd FLIR Systems presentation[7]

FLIR pros and cons

FLIR technology shows visible images of hydrocarbon gas emissions in real-time. The magnitude of those leaks corresponds to Method 21 concentration levels of 5000 ppm and greater. Some of the latest cameras claim sensitivity to 2500 ppm. Components that are difficult to monitor or pose safety risk to measure are ideal candidates for FLIR since equipment can be scanned from a distance. Inspections don't require work interruption

since camera operators simply move through the plant's normal walkways and accesses to view the components. The process is quick relative to Method 21 since a large number of components can be viewed and assessed within the sweeping field of the camera's lens. The identification of leaking equipment is quick and can expedite repair actions.
If FLIR is used to meet the AWP regulations it requires surveys of up to every 30 days depending on the sensitivity of the camera used. And, the biggest deterrent to AWP's use in US plants for LDAR compliance is that it still requires a yearly survey using Method 21 because a definite quantity is needed for EPA's annual Toxic Inventory Report; the camera does not quantify the leak level. Operators must be trained and skilled in the operation, techniques and visual interpretation of the visual display to fully take advantage of the speed and leak identification. If FLIR is used for regulatory compliance all video records must to be saved. This can require terabytes of computer storage space. The cost of hydrocarbon gas detecting FLIR cameras can range from US$50,000 to US$75,000.

How FLIR technology is used
Plants in the USA are using the IR cameras to supplement Method 21 regulatory requirements, not for regulatory compliance. Operators and reliability personnel are using FLIR cameras to inspect units prior to start-up to find leaks and qualify system integrity. This has resulted in smooth startups. Plants that practice this have caught the spirit of leak detection and hunt for leaks[8] using the camera in parallel with or beyond regulatory requirements.

Fenceline FT IR and UV spectrometry
FTIR for the purposes of this paper refers to open path FTIR. FTIR units found in a laboratory are closed space spectrometers. A FTIR system can detect, report the constituents and concentrations found in an ambient air space in real time. FTIR can be active or passive. Active systems' infrared or UV wavelengths are tuned to identify particular media types (species) and concentrations. An example would be a UV system tuned to seek out benzene in and around a refinery's benzene units and fenceline. Passive systems look for any and all species within range of IR or UV light. These systems along with their associated analysis software can identify a large number of hazardous air pollutants and their concentrations.
Open path systems are open to the atmosphere. Light of a known range of wavelengths (spectra) is emitted from a source. The light is aimed at the desired airspace and returns to the source's receiver where the differences in the spectra sent are compared to what returns. This difference is analyzed to divulge the species in the air and their concentrations. The light returns to the source by being reflected back by a stationary reflector. The distance range of a typical system can be up to 1000 meters (Figure 7).

Figure 7 - Open-path FTIR source and reflector (From the EPA Clean-Up Information Technology Innovation Program website - http://clu-in.org/programs/21m2/openpath/op-ftir/)

Example of a FTIR fenceline system

ConocoPhillips Rodeo Refinery in Rodeo, CA, USA is outfitted with open path FTIR, UV and Laser (Light Amplification by Stimulated Emission of Radiation) monitors. As part of their agreement and service to the local community.[9] The Rodeo Refinery posts updates several times each hour of the part per billion levels of various air pollutants of interest. The data tables in Figure 8 from the Rodeo webpage show the typical publication of data. A link is provided to view the website live.

ConocoPhillips Rodeo Refinery Fenceline Data

Note: These are raw data values that have not undergone quality assurance or quality control review and are subject to change.

These data were recorded at **2012-01-19 12:00:28** Pacific Standard Time

FTIR Data

Chemical (values in PPB)	South	North
Signal Strength	NA	NA
Data date	2011-08-22	2012-12-12
Data time	15:26:34	10:50:47
1,3 Butadiene	368.5	0
Carbonyl Sulfide	0	0
Total Hydrocarbons	0	262
Carbon Monoxide	387.9	247.5
Ethanol	0	0
Ethylene	674.6	0
Nitrous Oxide	0	246.28
Ammonia (NH3)	236.4	0
Mercaptan	14201.9	0
Methane	0	4207.7
MTBE	212.9	0
Sulfur Hexafluoride (SF6)	0	0

Detectable levels of chemicals are indicated in green. Otherwise the level is below the measurable threshold of the instrument and the value shown is not significant.

Click on the chemical names for more info.

UV Data

Chemical (values in PPB)	South	North
Signal Strength	1946.1	2059.4
Data date	2012-01-19	2012-01-19
Data time	12:01:50	11:57:29
Benzene	2.494	2.494
Carbon Disulfide	0	0
Ozone	0.486	8.369
Sulfur Dioxide	2.494	2.494
Toluene	2.494	2.494
Xylene	2.494	2.494

Weather Conditions

Date	2012-01-19
Time	12:00:28
Temperature in degrees f	NA
Wind Speed (MPH)	6
Wind dir (from) South 181 degrees.	

http://fenceline.net/fence.php

Figure 8 – Snap shot of ConocoPhillips live fenceline emissions reporting.

Consent decrees promote technology

In 2010 Murphy Oil in Meraux, LA, USA came under consent decree to correct a number of compliance issues. One of the actions to satisfy their decree was to perform a supplemental environmental project (SEP) that required the installation of a fenceline FTIR monitoring system.[10]This is a first. The SEP required the construction and operation of an ambient air monitoring station. Further, the emissions data is to be published on an internet website established and maintained by Murphy Oil. Interesting to note is that Alternative Work Practice of 2008 which allows the use of optical monitors was tried as a SEP prior to becoming a regulation. Time will tell if fenceline systems become regulation in the USA.

Costs of an FTIR fenceline system**

One monitoring station including light source, reflector, receiver and analysis software can run from US$80,000 to US$100,000. A typical refinery or chemical plants might require three to five stations to effectively cover the site perimeter. Total investment can be US$150,000 to cover one unit within a plant and upwards of US$500,000 for a typical multi-unit refinery. Service providers that bring monitoring equipment systems on site for a one month event can cost around US$45,000.[11]

DIAL – Dispersive Absorption Light detection and ranging

DIAL like fenceline monitors can utilize IR, UV and Laser optics. Light of a known spectrum is emitted into the airspace of interest. The particles in the air reflect the spectra that were not absorbed by the species in the air back to the source/receiver for analysis. The typical scan plane is 500m long x 50m high (Figure 9).[12]

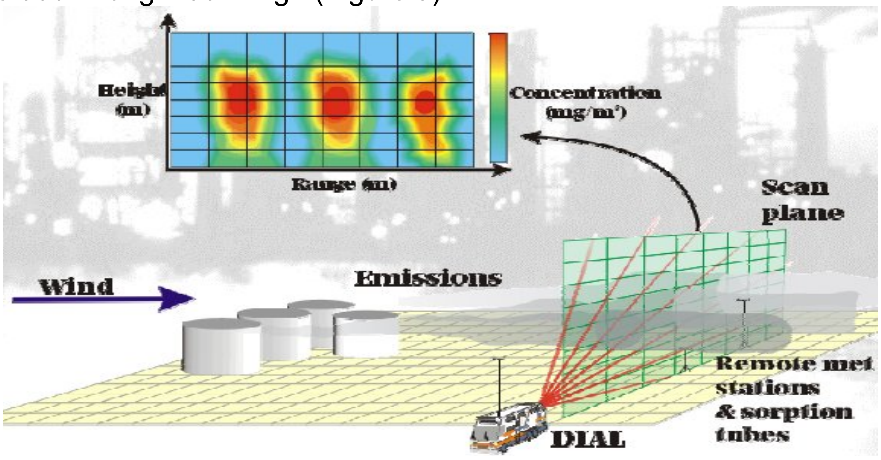


Figure 9 – Ground based DIAL. Source: Spectrasyne Ltd.

The spectral analysis along with global positioning systems (GPS), meteorological data such as, wind speed and direction are analyzed to reveal what species and concentrations are in the air. The results are snap shots of the current air quality conditions. When the snapshots for a survey event are pieced together they give a picture of the site's current state. Plant surveys are done with mobile ground or air units and gas pipelines with air units.

At present Scandinavian countries such as Sweden require surveys every few years as part of regulatory compliance. Canada has hosted a number of survey projects and has a favorable view of this technology as part of their overall air quality programs. In 2007 BP Texas City performed a DIAL survey.[13] Conversations with those involved with such surveys indicates that they require a large amount of concentrated effort, can be tedious and that wind and weather are real spoilers to expediting the process. A provider of mobile ground DIAL is Spectrasyne, UK. Spectrasyne's technology was developed under BP Research beginning in 1979. In 1992 a management buyout agreement created the current company. Airborne DIAL providers include E.On Ruhrgas's CHARM® - CH4 Airborne Remote Monitoring gas pipeline survey system, LaSen Inc.'s ALPIS™ - Airbourne LIDAR Pipeline Inspection (Figure 10), New Era Technology Inc. and Pergam-Suisse AG.

Figure 10 - Airbourne DIAL. Source: LaSen website[14]

Results and general benefits of optical monitoring systems
Using optical methods can speed leakage surveys and identification of high leaking components. If plants are not using optical methods to comply with local laws they are using it to ease unit start-ups and to find leaks. Identifying leaks has proven to be invaluable to those involved in such activities. Finding a leak during pressure testing or early in the start cycle can save hundreds of man-hours and product sales especially with units requiring multi-day start cycles. During the course of some DIAL ground surveys, technicians measuring air pollutants in the mobile unit communicate with teams in the plant. When anomalies are observed by the DIAL team information is sent to the plant teams to pinpoint the leak source and repair it.

Summary/Conclusions

Optical methods are being specified by regulation such as the USA AWP using FLIR and Sweden's DIAL survey requirements. Plant operators find it to be of great help for start-ups. Communities in the proximity of oil/chemical processors develop trust by the transparency allowed when web pages with real time air quality data are published. Time and use should prove the validity and staying power of these technologies.

Footnotes

[1] http://www.epa.gov/outreach/scientific.html#greenhouse – "Methane is about 21 times more powerful at warming the atmosphere than carbon dioxide (CO_2)"

[2]" Alternative Work Practice to Detect Leaks from Equipment,"
http://www.tceq.texas.gov/assets/public/implementation/air/rules/ldar/2006_17402.pdf

[3]"Origins of Modern Air Pollution Regulations," EPA website,
http://www.epa.gov/eogapti1/course422/apc1.html

[4]EPA news release, December 7, 2009 - "EPA: Greenhouse Gases Threaten Public Health and the Environment/Science overwhelmingly shows greenhouse gas concentrations at unprecedented levels due to human activity."
http://yosemite.epa.gov/opa/admpress.nsf/7ebdf4d0b217978b852573590040443a/08d11a451131bca585257685005bf252!OpenDocument

[5]"API Smart LDAR Project Overview/Status," Slide number 3, Siegell and Wilkinson, ExxonMobil Research & Engineering - PERF July 12, 2006
(http://www.perf.org/images_ee/uploads/Events/2006SanFrancisco/SmartLDAR.pdf)

[6]"Method 21 - Determination of Volatile Organic Compound Leaks," http://www.epa.gov/ttn/emc/promgate/m-21.pdf

[7]"Oil and Natural Gas Industry Compliance Assistance Presentation," page 23 - 2010 by Roger Fernandez-EPA, Craig R. O'Neill-FLIR Systems, Larry S. Richards-Hy-Bon Engineering, Tony Robledo-EPA Region 6 and Himashu Vyas-EPA

[8]"Enhancing Your Current LDAR Program with Optical Imaging-Finding the Missing Piece," Dolmage-LyondellBasell and Celestine-Inspection Logic Corp, 9th LDAR Symposium, May 2009, Austin, TX.

[9]ConocoPhillips webpage giving the history of the fenceline monitoring system - http://fenceline.net/sea/index.html

[10]Murphey Oil Supplemental Environmental Projects and consent decree - http://www.epa.gov/compliance/resources/cases/civil/caa/murphyoil.html#projects

[11]"Use of Open-Path FTIR Spectroscopy to Address Air Monitoring Needs During Site Remediations," Minnich and Scotto, page 4, *Remediation* Magazine, Summer 1999. http://www.msiair.net/web%20-%20Paper%209.pdf

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[13]"Critical Review of DIAL Emissions Test Data for BP Petroleum Refiner in Texas City, TX," November 2010, RTI International for the Office of Air Quality Planning and Standards-EPA, http://www.epa.gov/ttn/atw/bp_dial_review_report_11-15-10_psg2.pdf

[14]LaSen graphics - http://www.laseninc.com/advantages.html and http://www.laseninc.com/alpis.html

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Key words

optical, emissions, infrared, GHG