Open Path Gas Detection Information Note: Mie Scattering — A Possible Culprit for Anomalous OPGD Performance

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Infrared gas detection is a relatively new technology, it was first introduced on offshore installations in the 1990s. These detectors were initially designed outwith the challenges typical of an offshore environment, which led to complications integrating the early generation models. The subsequent generations were developed based on offshore experience, designing out the initial problems of vibration, stability, alignment and optical interference. Now, infrared is considered the superior gas detection technology, relative to traditional catalytic/pellistor type, unless not suitable for the application/target gas. This is not to say, however, that the technology is without limitations, as this paper will address.

One of the main challenges offshore is extreme weather conditions. This is unavoidable in many areas of the oil and gas/process industry, and can result in personnel injury or even structural damage. These are undesirable consequences hence associated safety factors and processes are heavily regulated with strict procedures in place. One of the lesser discussed topics, is how this ever changing environment impacts on the functionality of detection systems; are they suitable for the application/fit for purpose? Unfortunately, these less than favourable weather conditions are not limited to offshore platforms, any external instruments must be suitable for the elements expected in their proposed location – it is common for onshore sites to experience these issues also. With the widespread use of infrared technology both offshore and onshore, end users have an expectation that the technology will be immune from false readings. When false alarms therefore occur, the inference is that it must be the fault of a specific manufacturer or model, but in reality, all current open path gas detectors will be affected by similar stimuli, and we must therefore be vigilant in where and how to place such devices.

Micropack are aware of particular instances, both offshore and onshore, in which the presence of fog coincides with unexpected gas readings, resulting in spurious alarms. To speculate as to why this may be an issue, we must outline the operating principles of infrared gas detection. This in turn introduces the phenomenon of Mie scattering.

Mie scattering in the specified instance for discussion is caused by water droplets (i.e.: fog) passing through the beam of the OPGD, it occurs when the diameter of the water droplets are close to the wavelengths at which the detector operates. When the water droplets approach this critical size this causes the infrared to be scattered differently, which can upset the balance between the measurement and reference signals, meaning both positive and negative gas readings can momentarily appear. The likelihood of having the exact critical size of water droplet to interfere with the measurement and reference signals is small, hence the phenomenon is considered exceptionally rare, but not impossible. This is particularly true in a changeable environment like the North Sea.

The paper will go on to discuss potential future work; refinement of these technologies, plus the importance of beam attenuation in mapping these devices. However, the purpose of the paper is to inform the industry of the possible culprit for this anomalous open path gas detection performance. The ultimate aim is to increase awareness of this rare phenomenon for consideration in the maintenance and operation of these systems, rather than simply dismissing particular manufactures before understanding the root cause. If everyone is aware of this issue across the industry we can work together to ensure the detector technology is developed and positioned/mapped to perform in its required function.

Keywords: Infrared Gas Detection, Infrared Absorption Spectra, IRPGD, OPGD, Unexpected Gas Readings, Spurious Alarms, Oil and Gas Industry, Process Industry, Gas Detector Placement, Fire and Gas Mapping, Hazard Identification, Mie Scattering

Operating Principles of Infrared Detection

Infrared gas detection technology is used when the release of combustible hydrocarbon gases and vapours are undesirable, due to their highly volatile nature. As such they are typically installed on sites that process/produce various alkanes, this is not limited to the oil and gas/process industry. Various applications where the operator and surrounding personnel need to be aware of a release to take corrective action or initiate evacuation procedures; as long as the technology has been identified suitable for the target gas, during hazard identification/performance target definition process specific to the site, has been considered.

There are two types of infrared gas detector; point and open path. The operating principle for both is the same and is based on the well-established principles of infrared absorption spectroscopy, which involves the interaction of infrared radiation with matter, and utilises the fact that many molecules have a unique fingerprint within the infrared spectrum (Smith, 1979).

The concept is based on direct measurement of the absorption of infrared radiation passing through a volume of gas. This is achieved by projecting a beam of infrared light from a detector, onto a mirror, that then reflects the light back into the detector. The typical Infrared Point Gas Detector (IRPGD) is comprised of; an infrared light/energy source, reference and measurement optical filters plus control electronics – refer to Figure A (Davidson, 2007).

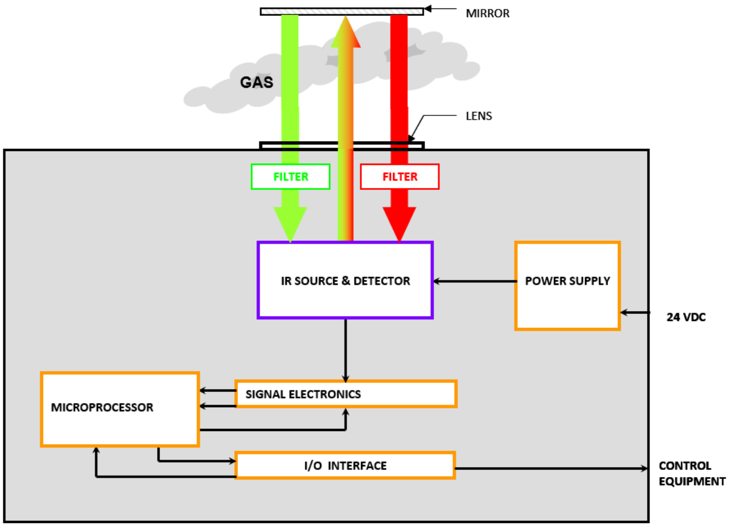

Figure A – Point Gas Typical Infrared Detector (IRPGD)

The typical Open Path Gas Detector (OPGD) is comprised of; an infrared light/energy source transmitter, an optical receiver capable of monitoring reference and measurement channels and control equipment interface – refer to Figure B (Davidson, 2007).

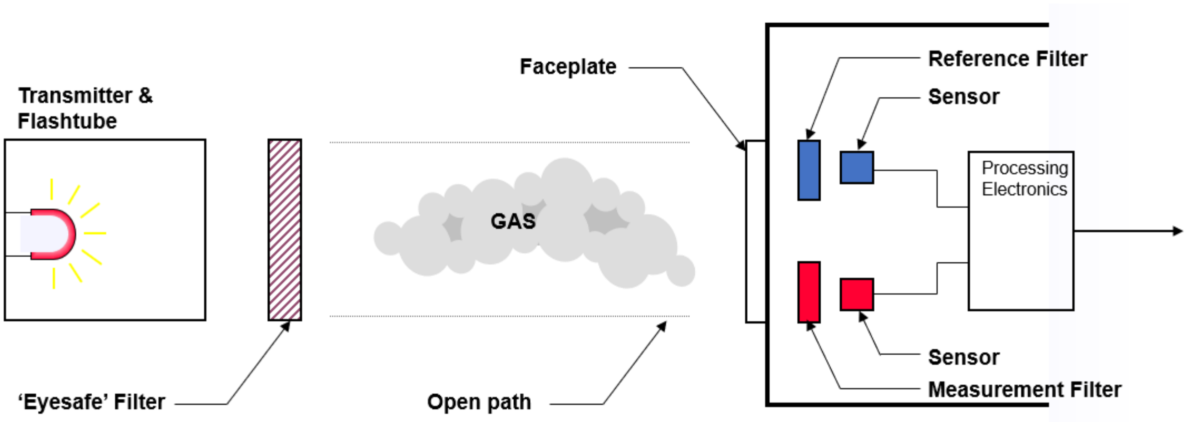

Figure B – Typical Open Path Gas Detector (OPGD)

Hazardous gases/vapours are detected at a specific wavelength selected according to its specific spectral absorption or fingerprint. Hydrocarbon gases typically have these fingerprints in the mid IR range (1 μm – 3.5 μm) as indicated in Figure C. The detection process involves two separate filters each operating at different regions of the spectrum: one transmitting radiation that is absorbed by a particular gas, and one that is not sensitive to it.

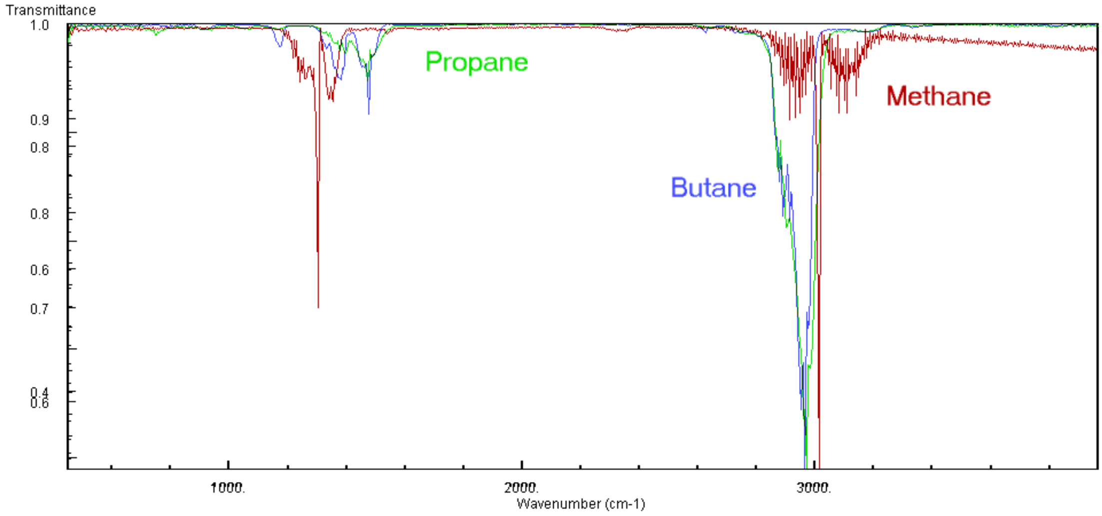

Figure C – The IR absorption spectra in relation to the wavelengths at which alkane group of gasses absorb IR (Davidson, 2006)

As different types of gas have very distinct absorption lines, these can easily be identified by accurate/effective selection of the infrared wavelength (λ_M) at which absorption is measured. Radiation at a second wavelength (λ_R) close to measurement filter wavelength (λ_M), but not absorbed by the target gas, is used to measure the overall transmittance through the optical path. By comparing the transmittance at the two wavelengths (λ_M & λ_R) the amount of predefined target gas in air can be determined. Having chosen a wavelength (λ_M) that is a specific characteristic of the target gas to be measured, other types of gas will not cause a false alarm.

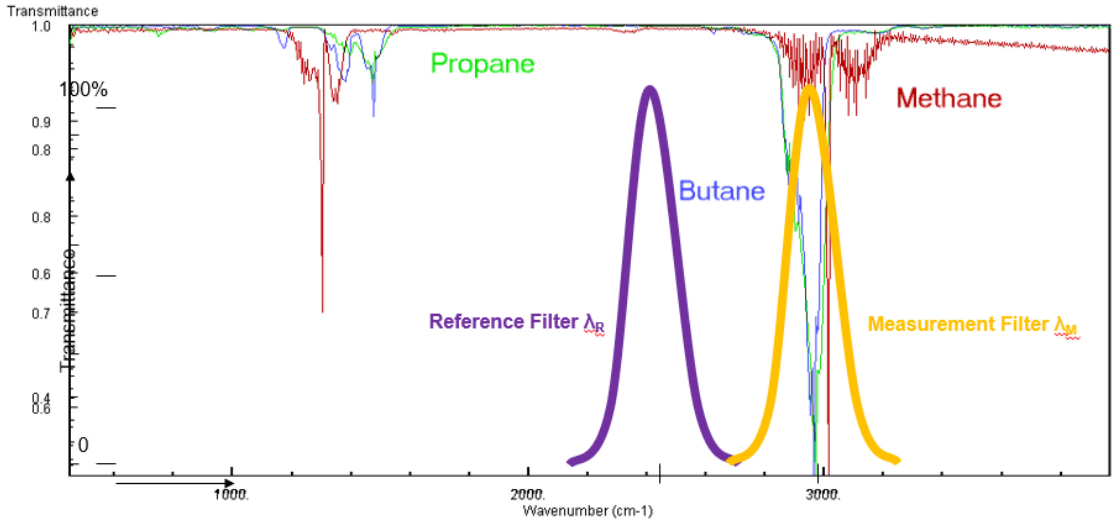

Figure D – The IR absorption spectra in Figure C with overlaid Measurement & Reference wavelengths

With IRPGDs, radiation from the two infrared sources passes through two narrow-band optical filters, which define the measuring wavelength (λ_M) and a reference wavelength (λ_R). IRPGDs typically operate at a measurement wavelength of around 3.4µm (λ_R). The signal amplitudes are used by the microprocessor to calculate the amount of gas and are presented as a current signal. The reference signal wavelength remains unaffected by the presence of target gas, whereas the measurement signal wavelength changes depending on the amount of the target gas present. It is this ratio between reference and measurement signals that is a function of gas concentration. For an OPGD it is the same principle only there are two reference wavelengths λ_{R1} & λ_{R2}, hence radiation from two infrared source passes two or three narrow-band optical filters, which select measuring wavelength (λ_M) and a reference wavelength(s) (λ_{R1}, λ_{R2}). Therefore by comparing the transmittance at three wavelengths the amount of predefined gas in the air can be determined. OPGDs typically operate at a measurement wavelength between 2.1 – 3.4µm.

Infrared gas detectors do not respond to gases with no infrared absorption characteristics (E.g.: hydrogen), they are based on the unique infrared absorption pattern associated with hydrocarbon gases and vapours. For example, having chosen or predefined λ_M suitable for alkanes, the characteristics of the gas can be measured but other types of gas, like aromatics, will not cause an alarm.

It is important to note that the limit at which water absorbs infrared is around 3.4µm. Hence detectors operating at or near that measurement wavelength are sensitive to interference, due to a narrow overlap around 3.39µm where both the specific spectral absorption of hydrocarbon gases/specific alkanes and the absorption of water occurs. As indicated visually by Figure E with respect to Methane (CH4) there are two regions; one free from water interference and other is very sensitive.

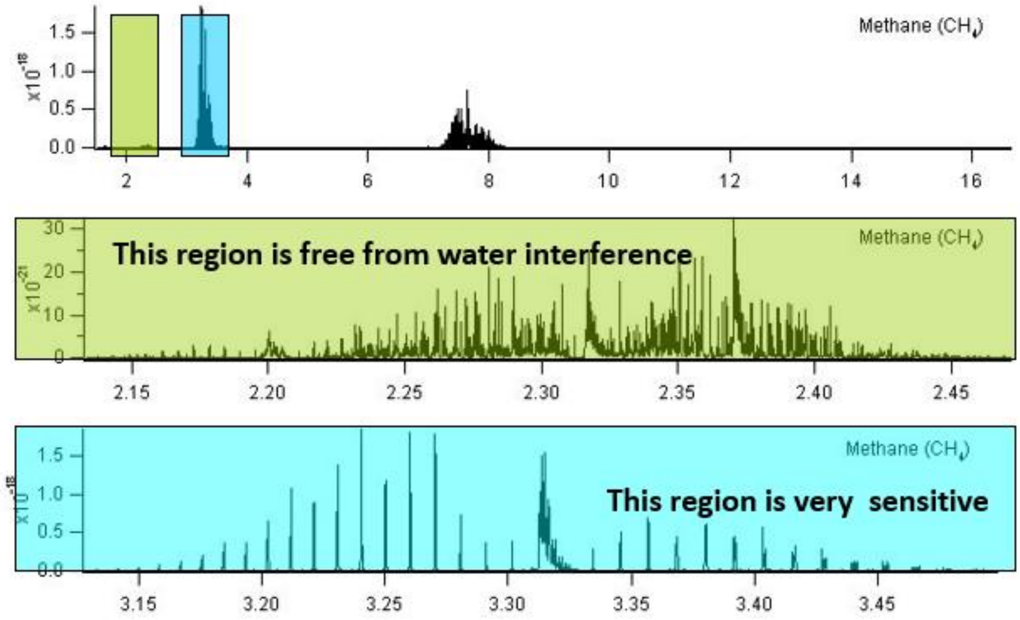

Figure E – Methane spectra

Early open path systems were designed with no experience in the field and difficulties developed. Table A outlines the brief evolution of OPGDs. Early difficulties arose from; alignment of optical elements (initial setup, long term stability), sensitivity to external IR sources (sun, flare) and the use of single ended elements with reflector plate.

Table A – OPGD Evolution

Generation	Arrangement	IR Light/Energy Source	Wavelength (µm)	Comments
1	Reflector / Transceiver	Incandescent Bulb	2.1 / 2.3	Prone to Interference from Sunlight / Vibration
2	Transmitter & Receiver	Xenon Flash	3.0 3.4	Prone to Water in Optical Path. Great Improvement in Unwanted Alarms (Flash Lamp)
3	Transmitter & Receiver	Xenon Flash	2.1 / 2.3	Improved Alignment & Stability Immune to External Interference

The purpose of any gas detector is to measure gas concentration and relate this to an industry standard Lower Explosive Limit (LEL) concentration. The LEL is the minimum volume of gas needed to create a credible dangerous explosion hazard. Typically a point gas detector will be configured to raise the alarm whenever the measured gas concentration reaches a significant percentage of LEL.

For open path gas detection it is slightly different, in that, LELm is the industry standard used to state the sensitivity of the open path gas detector which is independent from and unrelated to, the actual path length of the installed detector. This sometimes causes confusion for those unfamiliar with the devices so the following Figure F and text aims to outline.

The majority of open path detectors available on the market today have a standardised measuring range of 0 - 5LELm (1LELm = 1m of 100% LEL gas/ or 5m of 20% LEL gas. Both = 1LELm. 5LELm = 5m of 100% LEL gas). The foundation for this is the fact that the detection system is based on detecting a 5m cloud at 100% LEL concentration. This is independent of the flammable gas grade performance target in the area.

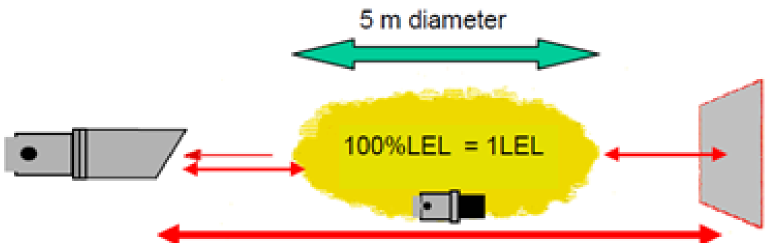

Figure F – OPGD Operation

For example if an OPGD measuring range spans 10m, a 5m gas cloud of 100%LEL (5LELm) concentration present along the detectors measuring path will still be detected. It would produce the same output as an OPGD spanning 5m with a 5m gas cloud of 100%LEL within its measuring range. The longer a measuring path is, the more difficult it becomes to determine whether a damaging gas cloud is actually present. (To give another example – for a detector spanning 30m – the same output reading would result from a 1m cloud of 100% LEL concentration or a 10m cloud of 10% LEL concentration).

Unexpected Gas Readings & Spurious Alarms

Micropack are in a unique position of impartiality regarding gas detection and reported instances of anomalous OPGD performance, as we do not manufacture gas detection. However, having been involved in the industry for 30+ years in both the gas detection mapping, and the installation, commissioning, operation and maintenance of the systems, this gives us access to a range of differing operators and detector manufacturers across the industry worldwide.

As such we are aware of particular instances, both offshore and onshore, in which the end user, unable to pinpoint the root cause, corelate unexpected gas readings, resulting in spurious alarms to bad weather and the presence of fog. The event of anomalous OPGD performance is not a new or recent development and in our experience is not limited to a specific make or model of gas detector.

With the widespread use of infrared technology both offshore and onshore, end users often have an expectation that the technology will be immune from false readings. When false alarms therefore occur, the inference is that it must be the fault of a specific manufacturer or model, but in reality, all current open path gas detectors will be affected by similar stimuli, and we must therefore be vigilant in where and how to place such devices. It must be noted, however, the vast improvements which have been made in recent gas detection technologies and that such performance issues are now comparatively rare in contrast with generations 1 and 2 of OPGD.

Mie Scattering

These unexpected gas readings are thought to be caused by an effect known as “Mie scattering”. Mie scattering is elastic scattering, or re-direction, of light of particles that have a diameter similar to or larger than the wavelength of the incident light. There is a strong angular dependency of the scattered intensity especially for smaller particles (Hahn, 2009). The reader may be more familiar with this in respect to weather – cloud droplets scatter all wavelengths of visible light creating the appearance of white clouds.

Mie Scattering in the specific instance discussed here is caused by water droplets (i.e.: fog) passing through the beam of the OPGD and it occurs when the water droplets are close to the wavelengths at which the detector operates. When the water droplets approach this critical size it causes the infrared to be scattered differently (Bohren, 2010) which can upset the balance between the measurement and reference signals. The Mie effect is a function of wavelength droplet size and droplet concentration.

In the field this is very difficult to prove as we cannot replicate exact conditions as it is virtually impossible to ascertain the exact scattering droplet size(s) and concentration(s) at the time of any unwanted alarm.

The reader can begin to comprehend this by considering the variance between clouds, fog, mist, haar and rain. In order to have rain we must have a cloud, a cloud is made up of water vapour (particles of varying diameter) and tiny particles called condensation nuclei. Mist is comprised of smaller droplets of water suspended in air. The difference between mist and fog is the density of the cloud. The denser a cloud, or less visible through with higher obscuration is typical of fog. Conversely a less dense cloud, with lower obscuration or more visible through is typical of mist. Fog differs from cloud only in that the base of fog is at the earth's surface while clouds are above the surface. Haar is basically sea fog that occurs when warm air passes over cold sea, unfortunately it is very common in Aberdeen. All having varying droplet sizes, concentrations and densities.

Normally fog droplets are large compared to the wavelengths used by the typical infrared gas detection and have a large variation of size because they will have coalesced randomly in a 'mature' cloud. However, in the situation where a volume of air is hovering around the dew point (temperature at which water vapour in the air condenses into a solid) the fog cloud will keep evaporating and reforming. As these droplets evaporate they leave tiny salt particles behind. These seed new droplets that tend to be of similar size and grow at similar rates. When these growing droplets approach the sizes that can cause disruption to the detector's measurement and reference wavebands, both positive and negative gas readings can momentarily appear. The positive readings might be sufficient to momentarily break through the dead band. Due to the dynamic nature of the fog any such readings will be very brief (a matter of seconds).

The likelihood of having the exact critical size of water droplet to interfere with the measurement and reference signals is small, hence the phenomenon of Mie scattering is considered exceptionally rare, but not impossible. Mie scattering is a real physical effect and there is little that can be done to prevent it occurring. This is not a new phenomenon. With the increased of ease of information sharing we can now correlate previous reports of seemingly anomalous open path gas detector performance.

This is not to say we should rush to come to this conclusion, thorough investigation into seemingly spurious alarms and anomalous OPGD performance must be conducted. There are various external factors which could have an effect, such as electrical disturbance from an external source, earthing, incorrect setting of dead band or confusion with alarm management in FGS/ICSS, to name but a few.

Worthy of note is the high visibility the issue of false alarms from OPGD caused by fog has with end users, compared to, for example, the interference fog can have on Infrared flame detection. As the water mist/ clouds can interfere with the IR of a gas detector, it also absorbs the IR from a flame, blinding IR flame detectors to the presence of a flame. This is a well-known limitation of IR flame detection; however, it does not provide end users with an alarm and can therefore be easily ignored, despite a very real potential fail to danger. This should be addressed in future research, and is perhaps of greater concern than the occasional false alarm from Mie scattering. If the presence of fog can 1) occasionally cause false alarms on gas detection and 2) always eliminate the entire flame detection system on a platform, while being unrevealed, the author has strong opinions on which is of greater concern.

Preventative Actions, Potential Solutions and Importance of Adequate Positioning of OPGDs

More often than not, adequate positioning of infrared gas detection to perform in its required function will reduce the likelihood of occurrence of anomalous OPGD performance. Therefore, it is essential to consider the surroundings and practical constraints when designing detector layouts that utilise OPGDs.

Typically where a clear path exists most major operators prefer the use of open path gas detection, where geometry allows, rather than point gas detectors. The arrangement of open path gas detectors, based on infrared absorption, should be designed for; detection of gas clouds with explosion potential or monitoring of perimeter between hazardous and non-hazardous areas. A Gas Detection Placement Review including system performance criteria definition specific for the application and coverage mapping study is a logical method of documenting such analysis.

Principles of Fire and Gas Mapping with Respect to OPGDs

It is physically and logically incorrect to map open path gas detectors by simply ascertaining if an open path gas detector 'passes' through the risk volume. Open Path Gas Detectors operate on the principle of beam attenuation as mentioned previously; therefore it is necessary to calculate the beam attenuation (reduction of the amplitude of a signal through various concentrations of gas cloud) for mapping purposes. As the plan view of two open path gas detectors shows below (Figure G), a different attenuation calculation will be gained due to one passing through the denser cloud and the other only passing through the dilute cloud. Therefore to accurately calculate whether an open path gas detector will effectively detect a certain sized gas cloud, the distribution and density of the target gas cloud has to be accounted for.

Obscuration = Length (of Chord, i.e. C1) x Concentration = LELm

HazMap3D, for example, utilizes the beam attenuation principle to measure whether alarm set points for open path gas detectors are reached or not. The software ascertains how much of the open path beam (i.e. the length) passes through the dense and/ or dilute gas clouds. This is then multiplied by the concentrations of the dense and dilute gas clouds (for conservatism this is assigned 60% (HiGas) and 20% (LoGas) LFL respectively on average, however the assumption is acceptable for other setpoints with similar ratios such as 10% LoGas / 25% HiGas). The product of this is the beam attenuation value in LFLm (distance of beam x concentration it passes through). Hence mapping assessments which show where the alarm LELm set points have been met or not, accounting for the assumed change in concentration across the theoretical gas cloud diameter. An easy way of appreciating this is understanding that the open path beam will have to travel a certain length through the dense cloud and a greater distance through the dilute portion of a cloud to achieve a high enough beam attenuation to meet alarm values/ provide adequate coverage.

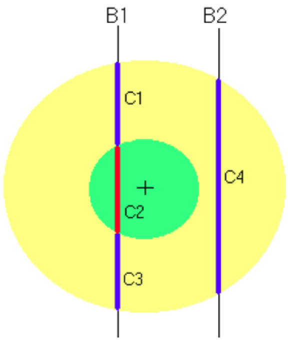

Figure G – Sample analysis of single pixel using beam attenuation model. Note the red chord through the dense cloud, and the blue chord through the dilute cloud.

Conclusion

Mie scattering is a real physical effect and there is little that can be done to prevent it occurring. Unfortunately, there is no solution to this problem presented by the typical open path detection technology currently on the market. In the meantime, as we understand the above phenomenon as a limitation of the current generation of infrared detection technology, we can recognise as long as these devices utilise filters they will always be prone to some extent from interference from water, chemicals and oil films.

Micropack have been informed that gas detector companies are currently working to develop the next generation of OPGD to combat this. There are emerging laser based gas detection technologies which are gas-specific and operate at a wavelength less prone to water vapour interference. These devices could potentially give greater reliability and performance in challenging environments, such as fog, rain and snow. Limitations do exist, however, as they are not widely used in petrochemical applications, hence they are relatively untested/unproven in real life hazardous environments and are more expensive per unit than current infrared based OPGD technologies on the market.

We can take a preventative action approach by ensuring detection placement studies are undertaken and mapped using the appropriate tools. With the Mie scattering phenomenon in mind, we should ensure adequate detector placement, with the aim of reducing potential occurrences. HazMap3D (Milne, 2006) is equipped with all the tools to design an effective detection system, no matter which of the approaches above is selected. Assessments are performed utilising on-site gas detector set points (outlined in site cause and effects documentation) and applying the appropriate cloud dilution factors in compliance with the applicable philosophy, where applicable.

This information note is to be read with reference to infrared open path gas detection technology only; other detector models and technologies may not be affected. Each present their own strengths and limitations, hence require separate consideration.

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