APPLICATIONS OF CONTINUOUS MONITORING WITH INTELLIGENT ANALYTICS FOR FUGITIVE EMISSIONS MONITORING IN THE AUSTRALIAN OIL AND GAS SECTOR

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Introduction

Emissions mitigation has become a major focus globally as a sense of urgency to tackle climate issues has led to international efforts by companies, countries, and local governments to reduce greenhouse gas (GHG) emissions. In a report released in 2018, the Intergovernmental Panel on Climate Change found that a net-zero emissions target by 2050 is necessary to limit global temperatures within the 1.5°C target set by the 2015 Paris Agreement (Rogelj *et al.* 2018). Commitments to net-zero targets are becoming widely adopted, with at least 61% of countries committed to reaching net-zero GHG emissions by 2050 (Black *et al*. 2021).

The monitoring and management of fugitive emissions are an essential part of industrial operations. These programs help companies and governments demonstrate progression, innovation, and responsibility for protecting their communities and the environment. Oil and natural gas operations emit GHGs, volatile organic compounds (VOCs), and other compounds harmful to the environment and public health. These compounds include methane, benzene, and hydrogen sulphide (H_2S). In recent years, efforts to address climate change have placed a greater focus on reducing methane emissions. Methane is a short-lived, but potent GHG that is approximately 84 times more powerful than carbon dioxide over a 20-year period (Myhre *et al.* 2013). Reducing methane is seen as a quick strategy to slow down global temperature increases.

The Australian oil and gas industry has grown steadily in the last several years with the increasing demand for energy (Department of Industry, Science, Energy and Resources 2021). Australia has substantial gas resources consisting of both conventional (mainly offshore) and unconventional gas resources, including coal seam gas (CSG), shale gas, basin-centred gas, and in-situ gasification products (Geoscience Australia 2021). The CSG industry has rapidly expanded since the mid-1990s to become an integral part of Australia's oil and gas industry. Additionally, the country is currently one of the world's largest exporters of liquefied natural gas (LNG). Helping with the transportation of natural gas is the large network of natural gas transmission pipelines, consisting of more than 39,000 km (APGA 2022), with more pipelines proposed or currently under construction. However, despite the growth of this industry, there is a lack of research and measurement-based information on fugitive emissions in Australia though studies are currently underway to address this information gap.

In Canada and the United States (U.S.), fugitive emissions are traditionally monitored using portable handheld monitoring instruments or optical gas imagining (OGI) cameras. Given the nature of fugitive emissions, handheld gas detectors and OGI cameras are found to be inadequate for detecting and monitoring fugitive emissions as leaks can often be missed by these approaches. This results in the underreporting of emissions, affecting data accuracy. Having accurate data on emissions allows operators to easily assess the severity of a leak and determine the most appropriate strategy to address the issue. Without reliable emissions data, companies will find it difficult to overcome barriers placed by government regulations and public pressure.

The deficiencies of traditional approaches have identified areas for improvement, resulting in the emergence of new technologies including aerial-based approaches, vehicle-based surveillance, and continuous monitoring systems. Each technology varies in its effectiveness at overcoming the obstacles of monitoring fugitive emissions. These newer technologies have been utilized in the oil and gas industry in the U.S. and Canada. Now, the Australian oil and gas industry has the opportunity to learn from these experiences and determine the best path forward for managing emissions.

Here, we will discuss the challenges of monitoring fugitive emissions and the effectiveness of different monitoring approaches. The capabilities of continuous emissions monitoring systems will be explored and compared to periodic emissions monitoring technologies through case studies at midstream and upstream oil and gas facilities. Applications of continuous monitoring of emissions from the oil and gas industry in Australia will be explored, including its application at gas fields, compressor stations, and gas pipelines. Finally, this paper will provide an outlook on the future of continuous monitoring systems in air emissions monitoring.

The Challenges of Monitoring Fugitive Emissions

Fugitive emissions are undesirable or unintentional leaks of gas or vapour that are harmful to the atmosphere. Fugitive emissions can occur from pressurized equipment or components at an industrial plant including valves, piping flanges, storage tanks, and compressors (Sotoodeh 2021). These emissions are considered fugitive as they are not part of the design of the equipment. Aging equipment, equipment failure, and component defects are some causes of fugitive emissions.

Often, emissions from a small number of large emitting sources known as super-emitters contribute to the greatest proportion of emissions. A study of natural gas leakage data collected in North America found that the largest 5% of leaks accounted for over 50% of total emissions (Brandt *et al.* 2016). A different analysis of data from six gas facilities in Canada, testing an average of 14,594 components per facility, found that the largest 10 leaks at each facility accounted for over 85% of total hydrocarbon (THC) emissions (Prince 2005). Evidently, there is a significant opportunity to reduce fugitive emissions through the early detection of super-emitters.

The challenge with managing fugitive emissions is that they can occur in unsuspecting (or unexpected) locations and their timing is uncertain, making them hard to predict. Offsite sources of emissions can also add confusion for operators when plumes from these sources blow onto the site. The ability to quickly identify a fugitive emission source location is important for emissions mitigation in order to decrease potential product loss, protect the environment, and improve site safety.

Emission rates can also vary over time. Capturing this variability provides operators with information on the condition and performance of equipment, helping them to identify areas for improvement regarding the process and site operations. Having accurate emissions data equips operations managers with more confidence in handling emissions. Measurement and a data-driven approach provide a way of empirically evaluating the effectiveness and success of proposed emission reduction plans. This requires monitoring technologies that can provide accurate data to bring certainty to emissions.

The Traditional Approach to Fugitive Emissions Monitoring

In many jurisdictions including the U.S. and Canada, operating oil and natural gas facilities are required by the regulator to implement leak detection and repair (LDAR) programs. The main purpose of the LDAR program is to detect fugitive emission sources and repair leaks. Traditionally, LDAR monitoring has followed Method 21 (EPA 2022), a methodology designed by the U.S. Environmental Protection Agency (EPA). According to Method 21, a portable handheld monitoring instrument such as a flammable ionization detector (FID) or photoionization detector (PID), is used to inspect every regulated component at a facility. Equipment components located at heights or in areas that are not safe for a technician to access can be deferred in an LDAR program. LDAR surveys are typically conducted a few times a year, with minimum inspection frequency requirements defined by the regulator of each jurisdiction. In Canada, LDAR surveys must be performed at least three times a year (Government of Canada 2020).

Surveying a site using the Method 21 approach can be labour-intensive, time-consuming, and expensive, especially for larger facilities. This is due to the close-range nature of the approach, which requires the handheld monitoring instrument to be brought directly to each regulated component to register a leak. A leak can be missed if the instrument is not held directly over the leak location. The accuracy of this method is dependent on the competency of the technician and the placement of the instrument. Additionally, the close-range requirement for using handheld instruments means that offsite sources cannot be detected by this method.

Another critical drawback of this approach is its susceptibility to undetected leaks. Method 21 is a periodic approach, meaning that monitoring is performed on an intermittent basis. As such, leaks that begin between LDAR surveys may go undetected until the next scheduled inspection. Consequently, a significant release of emissions into the environment may occur. As can be observed by comparing Figure 1a with Figure 1b, the longer the period between the start of the leak and detection, the more emissions are discharged into the atmosphere which negatively impacts the environment and can result in financial loss. The leak may also worsen with time, further compounding the situation. A greater ability to quickly detect leaks can help to mitigate more emissions from being released into the atmosphere. Through better detection and identification of leaks, facilities can reduce product loss, increase site safety for workers, and decrease the exposure of nearby communities to emissions being released into the air.

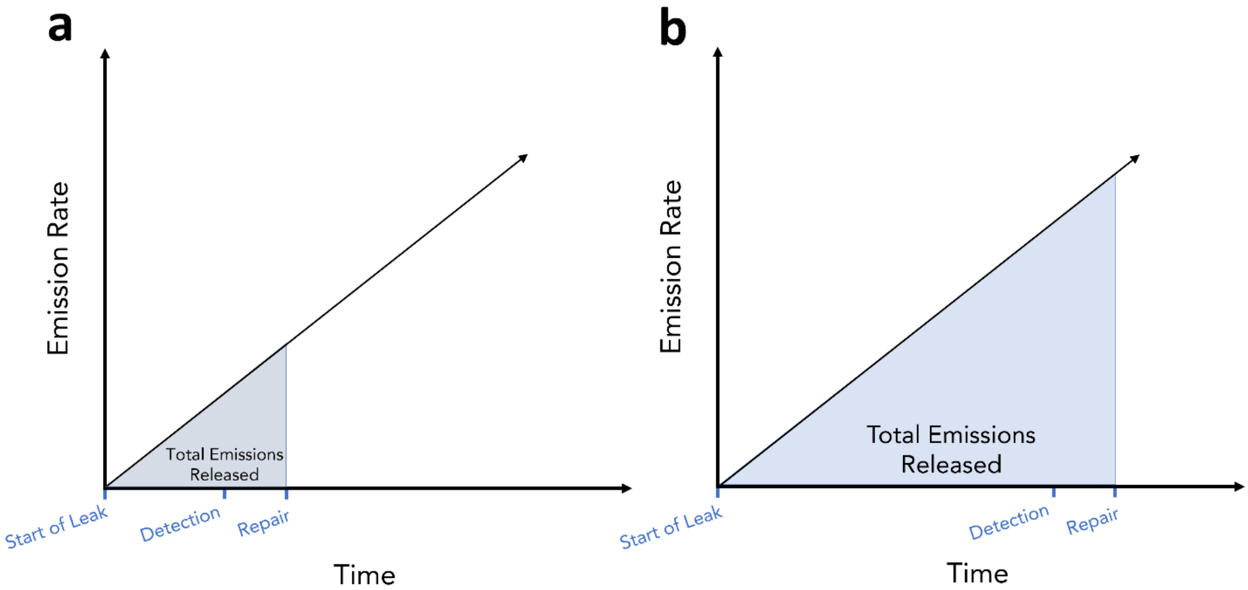

Figure 1. Illustration of the impact of time between the start and detection of a leak on the total emissions (area under the plotted line) released from the leak into the atmosphere. a) A shorter time between the start of a leak and detection will reduce emissions being released into the atmosphere. b) A longer time between the start of a leak and detection will result in more emissions being released into the atmosphere.

OGI cameras are a regulatory-approved alternative to Method 21. OGI cameras can provide a visualization of a leak at a distance of a few meters, allowing it to scan more equipment components at a time. Less time is required to perform an LDAR survey of a facility compared with Method 21. However, this approach is periodic and leaks occurring in between inspections can go still undetected. The accuracy of the approach is also dependent on the competency and experience of the technician. Experienced OGI camera technicians can find nearly twice as many leaks compared with less experienced technicians (Zimmerle *et al*. 2020).

Method 21 and OGI cameras work on the assumption that a leak will be found at a suspected location, based on the list of regulated equipment components that must be inspected in every LDAR survey. Both approaches require the monitoring instrument to be in close range of the leaking component. However, leaks do not necessarily occur only at the regulated components, such as a flange or fitting. Fugitive emissions can occur in unexpected places, such as at a corroded pipe. There is an inherent bias in these two approaches and leaks in unsuspecting locations risk going undetected for a long time due to this bias. This is another key disadvantage to traditional approaches for fugitive emissions monitoring.

Monitoring Emissions from a Distance

The weaknesses in traditional approaches have directed considerable development in air emissions monitoring technologies. Newer technologies which include satellites, aircraft, drones, and vehicle-based solutions have emerged as alternative approaches to emissions monitoring.

- *Satellites*: Using shortwave infrared (SWIR) radiation or thermal infrared (TIR), satellites can efficiently monitor large geographical areas, including entire basins. This enables monitoring of both onsite and offsite emissions. However, current satellite technology is unable to provide localized identification of an emission source to the component level and is unable to detect emissions through cloud cover (Jacob *et al.* 2016).
- *Aircraft*: Compared with satellites, higher resolution site-level monitoring can be performed using aircraft equipped with an emissions monitoring instrument. Repeated flyovers to collect multiple samples can be easily completed, providing more data on an emission source. However, the capabilities of the aircraft are affected by weather conditions. Additionally, aviation guidelines must be followed during its operation, which can affect the aircraft's ability to intercept a plume and measure emissions.
- *Drones*: The small size of a drone, or unmanned aerial vehicle (UAV), offers the ability to approach areas closely without jeopardizing the safety of a technician. Several sites or areas can be monitored in a day. Like with aircraft, drones are subject to local aviation guidelines and their ability to operate is dependent on weather conditions.
- *Vehicle-based systems*: A sensor is mounted to the vehicle, which will detect and measure emissions by intercepting emission plumes on its path. This system can monitor a site from a distance or be placed near the site. Its ability to detect emissions is affected by the distance of the vehicle from the emissions source (von Fischer *et al.* 2017).

Unlike Method 21 or OGI cameras, aerial and vehicle-based emissions monitoring systems do not require an instrument to be placed in close-range to a leak. Emissions at a site can be monitored from a distance and enable more accurate quantification of overall emissions from a site. This provides several advantages including being able to monitor locations that are inaccessible to a technician due to safety or accessibility concerns, removing the bias inherent in traditional methods, and effectively monitoring emissions over wide geographical areas. However, component-level attribution of the source can be difficult with satellites, aircraft, and even vehicle-based surveillance. More importantly, all fugitive emissions monitoring approaches discussed thus far only provide periodic monitoring of the site. These solutions provide monitoring on an intermittent basis, still making them vulnerable to emissions going undetected, which points to an area for improvement.

The Continuous Monitoring Approach and the Role of Data Analytics

Continuous monitoring technologies have gained greater attention in recent years for their ability to overcome the key challenges of monitoring fugitive emissions. Unlike periodic approaches, continuous monitoring systems provide 24/7 remote monitoring of an entire facility without the need for a technician to be onsite. Ambient concentration measurements and meteorological data, as well as other useful data such as temperature and relative humidity, are recorded continuously at a chosen frequency. Measurements can be taken as frequently as every second.

A few different configurations of the continuous monitoring system are possible. In one arrangement, several fixed sensors are placed around a facility to form a sensor network. Each sensor measures ambient concentrations independently of the other sensors. This arrangement is especially suitable for larger facilities such as refineries and can be used to monitor operations dispersed over large geographical areas. Alternatively, concentrations can be measured at different locations around a site using a single, centralized instrument. This is achieved by running tubing from the main instrument to remote sample inlets installed at strategic points around the facility. Through this arrangement, the process of performing instrument calibrations is simplified as calibration would be required for only one instrument versus several instruments. This configuration also enables low parts per million (ppm) or parts per billion (ppb) measurements to be collected by a higher-end instrument at a lower cost. For smaller sites such as a single wellhead, one sensor may be sufficient to adequately monitor emissions. A combination of the different configurations is also possible. Continuous monitoring is able to provide robust monitoring of emissions at both small and large facilities.

A continuous monitoring frequency is effective at capturing the variability of the emission rate over time, which is not adequately addressed by periodic monitoring approaches. This can be seen in Figure 2, where a continuous monitoring system and five periodic measurements taken by a hi-flow sampler are shown over an 18-month monitoring period. Periods of high emission rates were observed by the continuous monitoring system. These high emission rates were not captured by the snapshot measurements as the technician was not onsite when these events occurred. The snapshot measurements show that the underreporting of emissions can occur through this approach. The average emission rate obtained by the continuous monitoring system was five to seven times higher than the single-point readings obtained by the periodic inspections.

The location and emission rate of an emission source can be determined by applying intelligent analytics to the concentration, wind speed, and wind direction data. Observations from several positions allow for triangulation to be used to locate an emission source. This also gives the capability of distinguishing between offsite and onsite sources. With a continuous monitoring frequency, data analytics can provide information about a site’s emissions in real-time, informing operators on the efficiency of process operations and identifying areas for improvement. Any leaks that occur can be detected, identified, and addressed quickly to limit emissions being discharged into the environment.

A data-driven approach helps to eliminate human-based bias from emissions monitoring. Human bias is inherent in monitoring strategies that require the detector or monitoring instrument to be pointed directly at the emission source to register a leak. Artificial intelligence and machine learning are also providing opportunities to build greater capabilities in data analytics for emissions monitoring.

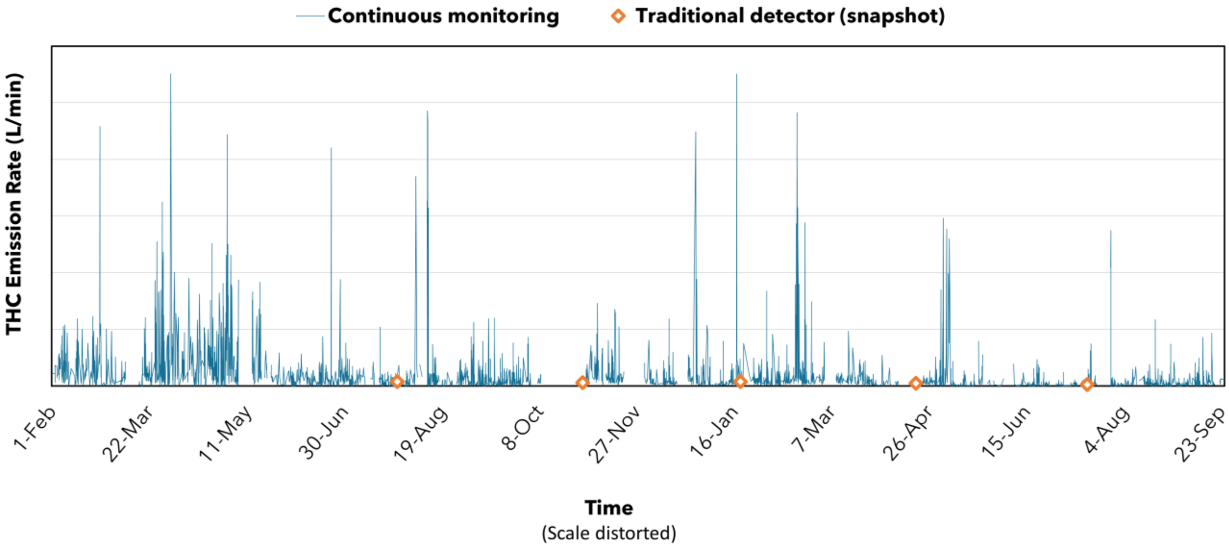

Figure 2. THC emission rate (L/min) over time from a tank as measured by the continuous monitoring system (blue) and periodic measurements using a hi-flow sampler (orange). The average emission rate obtained using continuous monitoring was five to seven times higher than the point readings obtained by the periodic monitoring approach.

Case Studies

Two case studies are presented here to demonstrate the capabilities of continuous monitoring systems over traditional approaches. Continuous monitoring has been applied in the oil and gas industry in North America with great success, resulting in cost savings, reduced greenhouse gas emissions, and improved safety at facilities.

Case Study 1: Detecting fugitive emissions at a midstream oil and gas facility

A continuous monitoring system was installed at a midstream oil and gas facility operated by Keyera Energy in Canada, as shown in Figure 3. This system was deployed to monitor ambient levels of total hydrocarbons (THC). The ambient air around the site was sampled from several remote sample inlets placed at different locations and connected to a central instrument via tubing. The monitoring system continuously measured THC concentration as well as wind speed and wind direction.

Through an analysis of the collected data, plume trajectories were obtained and triangulated to locate emission sources. Known emission sources were correctly identified at the tanks, which sometimes vented THC as a normal part of operations to relieve pressure. The analysis also identified an offsite emission source and the presence of an unexpected large emission source, which was identified to be at the compressor building. Quantification of the source at the compressor building showed that it was the largest of the identified onsite emission sources.

Method 21-type handheld monitoring instruments were used to survey the compressor building for a leak. Initially, the emission source could not be detected by the technicians, but the continuous monitoring system continued to indicate that a leak was present at the compressor building. Upon further investigation, it was found that a vent located 1.2 m off the top of the compressor building was the source of the leak. The vent that was supposed to be discharging only pure air was instead discharging gas composed of 4% air and 96% THC (composed of 94% methane). A considerable amount of methane was being leaked from this vent with a potential value of $520,000 (CAD) per year.

At first, the leak could not be identified as the technicians only investigated the side of the compressor building where it was presumed a gas leak would occur. This introduced bias and impacted their ability to find the leak. If only the Method 21 approach was used, the leak could have gone undetected for a long time. A continuous monitoring system removes this bias allowing all emissions at a site to be monitored at any time.

The continuous monitoring system also helped to demonstrate reductions in emissions after improvements to operations were made to reduce the frequency of venting from the tanks. Figure 4 shows a decrease in site emissions after interventions were made on June 9th, demonstrating to site management the effectiveness of the mitigation strategy taken to reduce emissions.

Figure 3. The layout of the midstream oil and gas facility with the set-up of the continuous monitoring system and the located onsite and offsite emission sources.

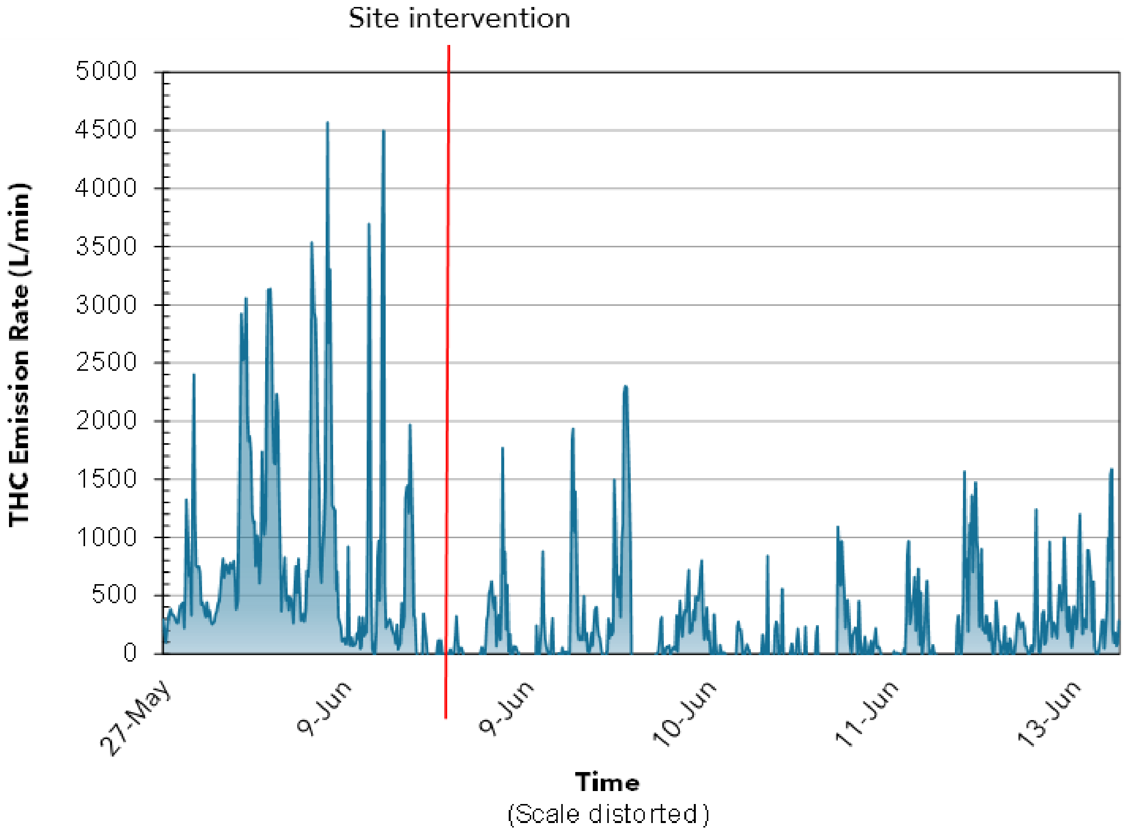

Figure 4. THC emission rate of a tank at the site showed a noticeable decrease in emissions after interventions were made starting around the 9th of June.

Case Study 2: Addressing H_2S and THC emissions at a steam-assisted gravity drainage (SAGD) facility

An upstream SAGD facility was experiencing odour issues caused by high levels of H_2S. Several known onsite sources of H_2S were identified as possible causes for the odour issues. However, it was suspected that the main source of the high levels of H_2S was the hot lime softener (HLS) system. A possible solution that was considered was to burn the vented steam from the HLS system. However, significant amounts of piping and processing would be required to remove water from the steam, making it costly to implement. A better understanding of the site's emissions was needed to make an informed decision, especially when significant resources could be spent.

A continuous monitoring system was installed to monitor the site's H_2S and THC emissions from different locations around the facility, as shown in Figure 5. The system confirmed that H_2S was being emitted from the HLS system. However, compared to the other identified sources, it was not the main cause of the odours. The tanks at the site were emitting much higher levels of H_2S and THC when they were venting. Additionally, a wastewater treatment facility located offsite was another emission source that was not identified previously.

The information provided by the continuous monitoring system provided facility management with valuable information that allowed them to choose the best mitigation strategy to address the odour issues experienced by the facility. Since the HLS system was not a huge emitter as previously thought, implementing the above-proposed strategy would not have been effective. Quantification of major emitting sources provided a better understanding of the emissions affecting the site and helped management to avoid spending millions of dollars on a solution that would not have resolved the problem.

Figure 5. Configuration of the continuous monitoring system and site layout of the SAGD facility, including the location of important emission sources identified through the analysis.

Applying Continuous Monitoring in the Australian Oil and Gas Sector

The remoteness of some oil and gas operations in Australia is a challenge for fugitive emissions monitoring. Relying upon a technician to perform traditional monitoring methods makes it difficult to monitor and measure emissions from assets regularly. Additionally, assets covering vast geographical areas, such as a gas field or pipeline network, can be time-consuming to manage.

Newer approaches such as aerial-based or vehicle-based surveillance offer better performance in capturing overall emissions at a site. However, inspections can only be performed periodically, making them vulnerable to unexpected leaks and skewing data accuracy. As such, a leak could go undetected for months until the next scheduled visit or worsen in between inspections. On the other hand, independent, continuous monitoring systems offer a robust solution to overcome the obstacles of monitoring fugitive emissions, requiring little maintenance and allowing data to be transmitted to a cloud to provide real-time updates. A technician is not required to be onsite often. Continuous monitoring provides increased data accuracy as it monitors the nature of emissions at a site continuously. Variability in the emission source is captured and enables operators to make faster and more accurate decisions. Operators responsible for wellheads or equipment dispersed over large areas, or long networks of pipelines can effectively allocate resources to the most important issues, allowing for more efficient deployment of existing resources. An accurate baseline is established with this data to show the current state of operations and identify the next steps for improvement.

The different arrangements of continuous monitoring make it possible to adapt the installation to the size and configuration of the site. For vast networks of pipelines or operations covering a large geographical area such as a gas field, a network of individual point sensors can be deployed around the area to monitor the integrity of assets. For a small site, such as a wellhead or compressor station, one or a few sensors can be deployed to monitor for leaks. Real-time data analytics can quickly identify abnormalities in emissions. When higher than normal emissions are detected by a sensor or sensor network, this may indicate the occurrence of a leak, triggering the system to send a notification to operators. A team could be quickly sent into the field to investigate the potential leak indicated by the sensor and locate the emission source. The necessary repairs to stop the leak could be started a few hours after the initial notification was received. All of this can be performed without the need for a technician to be constantly onsite.

The oil and gas industry in Australia has grown to become a net exporter of energy and is poised to continue growing, helping the world to meet its energy demands. However, as public concern for the environment continues to grow, it will become difficult to defend and gain support for these industrial operations, especially ones that are unsupported by reliable data. Uncertainty leaves companies vulnerable to scrutiny from the public and governments. By using advanced approaches to emissions monitoring, operators and management can confidently report to the public, shareholders, and key stakeholders about their operations.

Conclusions and The Future of Emissions Monitoring

In recent years, technology for monitoring fugitive emissions has developed rapidly, enabling the detection and quantification of emissions that were once thought impossible to determine. Out of these recent advances, continuous monitoring technologies with data analytics have emerged as powerful tools for managing emissions. Compared to periodic monitoring approaches, continuous monitoring can detect a leak quickly after it starts to reduce emissions being discharged into the atmosphere. Additionally, the variability of emissions can be captured to accurately quantify emissions.

Government-led emissions reduction mandates and numerous voluntary initiatives are being put forth to help companies set goals to reduce their emissions output, establishing a new normal for emissions management. However, commitment to these goals will require visible action, supported by evidence that companies are making progress in reaching their emission reduction goals. Without knowledge of emissions data, companies will find it harder to gain support for existing and new operations amidst growing concerns from the public about the environment. If companies are not aware of their emissions output, the environmental narrative can quickly leave their control, giving news agencies and environmental advocacy groups the power to control the story. To stay ahead of regulations and public pressure, the industry must not rely on traditional, outdated approaches to emissions monitoring.

Ongoing developments in sensor technology will continue to improve the performance and capability of continuous monitoring systems and other emissions monitoring approaches. Additionally, applications of artificial intelligence and machine learning will grow the quantification and source location capabilities of continuous monitoring technologies to increase the speed and accuracy of data analysis. The information generated from these improvements will better inform us of the progression and state of emissions.

Lessons learned from applications of various emissions monitoring technologies in Canada and the U.S. provide insights for the development of monitoring and emissions management practices in the Australian oil and gas industry. With advanced technologies available, the oil and gas industry in Australia has the potential to be a leader in emissions monitoring while sustaining industrial development to meet energy needs. The establishment of effective emissions monitoring practices will demonstrate the industry's responsibility for protecting the environment and surrounding communities.

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