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A remote monitoring early warning solution for ammonia releases for the OCI urea and melamine complex at Chemelot industrial park

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Ammonia is one of the best-known chemicals regarding safety measures for handling and storage in order to prevent hazardous releases. Yet no reliable measures have been developed for early warning and situation assessment in case of such incidents. The inherent risk was taken into account upon construction of todays facilities. Many of which are at least 40 to 60 years old. But growing productivity demands and ever-growing neighbouring cities constantly increased this risk. Warning for ammonia releases becomes an ever more urgent problem considering increasing worldwide demands for ammonia. And the prospect of ammonia playing a major role in the transportation and storage of hydrogen fuel as green fuel will eventually catapult the demand for ammonia storage and ammonia production to new heights.

Automated early detection of gas leaks and tracking of moving gas clouds in case of an incident – this combination of risk prevention and incident mitigation was the design task for the early warning *solution that was installed at CHEMELOT industrial park in Geleen, The Netherlands. In the first phase the scanfeld early warning solution safeguards the OCI melamine and urea complex. The site in close vicinity to a densely populated campus requires the warning of a release incident at any point within minutes. Once ammonia is in the air, the propagation of the moving cloud must be tracked and mapped live until it reaches the fence. The remote monitoring solution covers large areas and can locate a gas anywhere within sight. The early warning solution is based on spectroscopic analysis (FTIR spectroscopy) that allows safe identification and mapping of hundreds of different chemicals – both flammable and toxic – from large distances of up to 4 km.*

While the detection and visualization of an ammonia cloud was the primary target of the first phase installation, the design goal of the solution is to eventually cover the entire CHEMELOT north site.

INTRODUCTION

The Chemelot industrial park in the Netherlands is situated close to Maastricht on the Dutch and Düsseldorf on the German side. It is one of the largest chemical parks in Europe with numerous companies such as OCI, Arlanxeo, DSM, or SABIC. The major product lines onsite are naphta/gasoil through hydrocarbons to plastics and natural gas through ammonia to organic and specialty chemicals. Chemelot is connected via its own port, the main road network to nearby motorways and a rail terminal. One of the specialties of the CHEMELOT industrial park is the Brightlands Campus, a hub for startups, R&D facilities and education with more than 3.900 researchers, entrepreneurs and students (University, 2020). The campus is situated within close range to the production facilities, of which the OCI melamine- urea complex is within less than 400 m from the campus. OCI Nitrogen B.V. has three plants on site: OMM (OCI Nitrogen B.V. Manufacturing Melamine), OMA (OCI Nitrogen B.V. Manufacturing Ammonia), and OMF (OCI Nitrogen B.V. Manufacturing Fertilizers).

The scope of the first phase of the project focuses on the OMM production unit, in particular the reduction of risks due to unexpected airborne releases. A technical feasibility study for a future up-scaling to monitor the entire Chemelot north side has also been performed. There are 4 stacks within the OMM plant that must be monitored for a real-time detection of an accidental ammonia release. Once a release of ammonia is detected, the operator must be warned immediately. Situation assessment requires the specific information of the location of the release, the compound, that has been found in the air and the total amount of gas that has been released as well as the dimensions and the concentration of the gas. In case of a spontaneous large-scale emission, the gas cloud will not get diluted within close range of the incident and a gas cloud is formed that moves over the compound. This cloud bears a hazard potential especially for low to medium wind speeds.

Our question is: To what extent will the risks from an unexpected airborne release be reduced at OCI's Melamine and Urea plants at Chemelot using a scanfeld™ remote monitoring solution?

Among OCI's requisites the main ones are: A swift detection at levels from 10 ppm, visualization of the gas cloud in the control room in real time, no false alarms, continuous operation for at least 99.9% of the time, at least 4 hours operational in case of power outage, on site data storage, internet independence, and 24/7 support in case of outages.

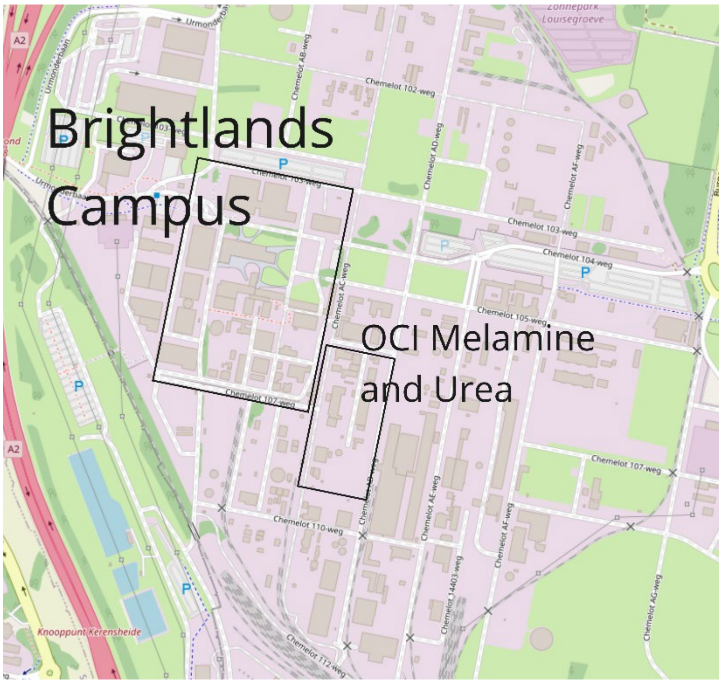

Figure 1: Map of Chemelot north showing the location of the Brightlands campus and the OCI production complex (OpenStreetMap 2020).

METHODS

Monitoring large industrial sites with FTIR based remote sensing

This report introduces a permanent monitoring solution for the prevention of hazardous incidents due to an unnoticed accidental release of a hazardous gas. The principle of this solution is to monitor all critical infrastructure in real time with a small number of measurement units. This is made possible by an optical remote sensing technique that is based on infrared spectroscopy (FTIR).

FTIR spectroscopy is a well-established optical measurement technology for analyzing remote objects. In principle, the distance between the object and the measurement device is irrelevant, which allows chemical analysis of a gas without the need to bring the sensor inside the gas cloud. Astronomy uses this technology for chemical analysis of remote planets or galaxies. Since the 1960s remote sensing within the atmosphere became a scientific subject. Various remote sensing systems have been developed and since 2006 remote monitoring technology has become standard equipment for European early response task forces (i.e. (Matz & Harig) or (Sabbah, et al., 2012)).

The measurement principle is based on the spectroscopic analysis of infrared radiation. Due to their temperature all objects emit infrared radiation, which allows chemical analysis from the distance around the clock. Within the spectrum of the infrared, one frequency range, called the fingerprint region (from 500 to 1500 cm^{-1}), is very interesting for remotely analyzing the chemical composition of a gas. In this spectral region, a great variety of chemicals interacts with radiation in a compound specific manner. The effect of this interaction is a spectral absorption feature in the spectrum of the infrared radiation, that is unique for the chemical compound – a fingerprint.

The FTIR remote sensor can detect a gas cloud instantaneously from several kilometers distance without any form of background calibration. The sensor analysis the chemical composition of the gas and measures the gas concentration.

Covering a whole industrial site from the distance has significant benefits. Most important, it will allow the detection of gas without prior knowledge of their likely occurrence or position. It can also assess the entire gas cloud, locate its position and track its propagation.

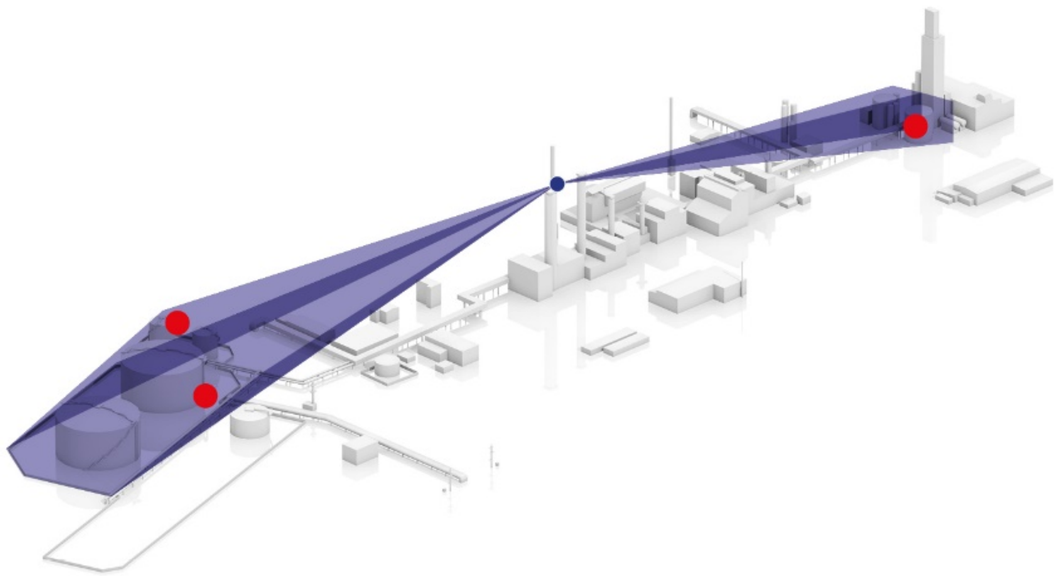

Figure 2: The remote monitoring principle: detection and localization of gas clouds from a long distance. The optical measurement technique uses FTIR spectroscopy to identify the chemical composition.

THE SCANFELD™ REMOTE MONITORING SOLUTION

The scanfeld™ monitoring solution uses scanning imaging remote sensing units. Covering the entire fingerprint region of the infrared, they detect and identify over 400 different chemical compounds, for instance ammonia or methane. The detection limit is a specific value for each chemical. For example: A 10 m wide ammonia cloud under normal ambient circumstances and at 1 km distance, this detection limit is in the order of 4 ppm. The identification algorithms and quantification techniques that can automatically identify and quantify a chemical compound in the infrared spectrum, are certified according to VDI4211. Due to the spectral region in the infrared over long distances the measurement technique is not affected by weather conditions such as rainfall or fog. Without the need for ambient light, the measurement technique also works day and night 24/7.

Figure 3: The scanfeld™ sensor unit is a scanning imaging FTIR spectrometer. The picture shows the sensor (white) with the large aperture infrared telescope head. The sensor is moved continuously by a pan-tilt unit (black) to scan the area of interest.

The scanfeld™ sensor units are designed to automatically scan predefined scan areas from distances of up to 4 km. Mounted in elevated positions they overview large areas. The large aperture infrared telescope of the sensor unit focuses the field of view to 3 mrads. The maximum spatial resolution that a sensor unit can cover is thus appr. 0.3 m at 100 m distance (or 3 m at 1 km distance, respectively).

Constantly analyzing the chemical composition within the field of view of the sensor, the sensor unit is moved along a predefined scanning pattern. The units can be positioned in a 360° horizontal and +- 90° vertical angle to point in every direction. They automatically scan predefined areas at an arbitrary scanning speed within wide speed range. Slower scanning increases the spatial resolution while higher scan speeds cover larger areas in shorter time. With a constant spectral acquisition rate of 6 measurements per second, a predefined scan area can be scanned within seconds. Once the sensor unit detects a known target gas, it is used to measure the location and dimension of the gas accumulation. The scan area and scan speed are adapted automatically to best fulfill the purpose of mapping the entire gas cloud.

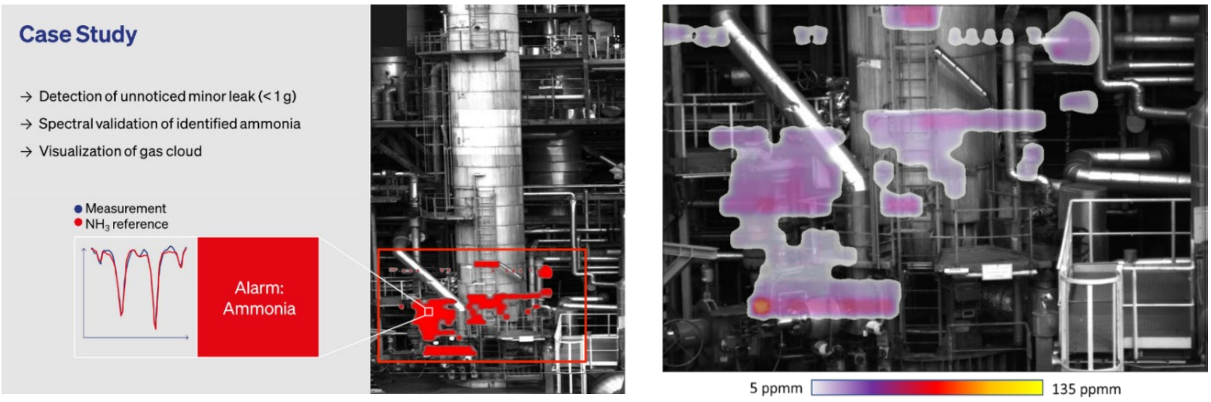

Figure 4: Measurement example: Detection of minor ammonia leak from 100 meters distance. On the left: The area where the gas is located is automatically displayed as a red overlay to a live video image of the scene. Ammonia is identified by spectral analysis and automatic comparison to a proprietary library of hundreds of gaseous compounds. On the right: The concentration distribution is displayed in false colors. The color-code maps the column-density of the cloud. From the point of view perspective of one sensor unit the column-density is the product of concentration and cloud depth

The scanning sensor units map and visualize the dimension and the concentration distribution of the gas cloud. In terms of risk management, this point-of-view visualization of a gas cloud in combination with the automatically generated alert, provides two barriers for the escalation of the situation. First, the operator is warned of an unexpected gas release with the specific information of how much of which gas is in the air. Secondly the point-of-view visualization of the gas distribution provides concise information about the leak location and the near-field propagation of the gas accumulation. Immediate action can be taken based on the specific information.

REAL-TIME TRACKING OF GAS CLOUDS WITH SCANFELD™

To localize a gas cloud, two or more scanfeld™ sensor units are needed for cross bearing and tomographic reconstruction of the gas cloud distribution. The scanfeld™ monitoring solution automatically coordinates the positioning and defines new scanning areas for all available sensor units for automatic localization of the gas cloud.

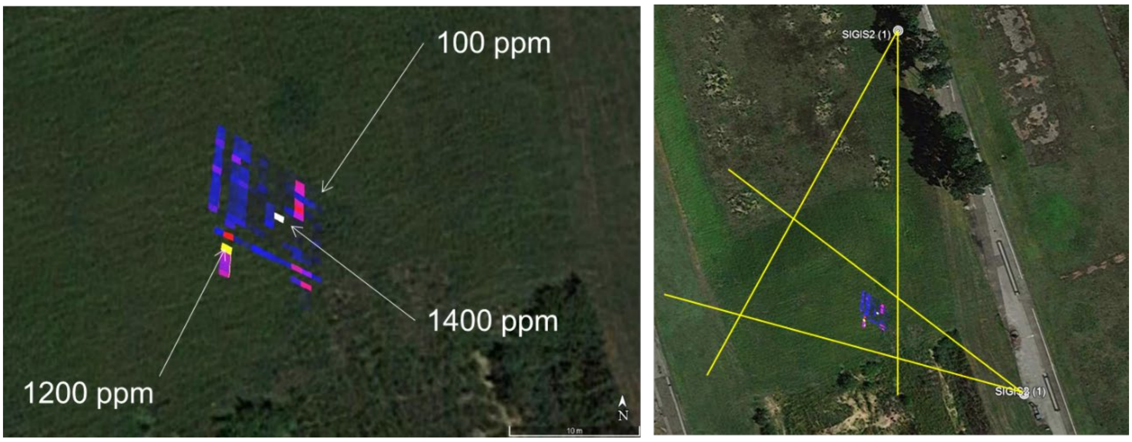

Figure 5: Measurement of an ammonia cloud from two measurement positions. The concentration distribution is displayed on a map.

Figure 5 shows how two sensor units map the concentration distribution of a small ammonia cloud in a release experiment. The concentration is depicted directly on a map that allows of immediate assessment of the situation in the field. First response can be coordinated effectively.

The alert generation and alarm log helps to assess how the event evolves. For a better understanding of the situation and 24/7 observation, both the visualization of the gas and the alerts are mapped on a timeline with time-shift and fast-forward features to move back and forth in time to quickly understand how the situation evolves over time (Fig. 6).

Figure 6: Screenshot of the user interface that shows how the point-of-view visualization of a gas cloud is organized together with the incident alert in a time line.

TOPOLOGY OF A TYPICAL SCANFELD™ INSTALLATION

The general setup of the monitoring solution is shown in Figure 7. The sensor units are connected via ethernet to an on-premises server. The server controls the sensor units and evaluates the measurements automatically. The user interface displays the events in a timeline display with alert logging. A dedicated software module analyses the alerts in time and space and classifies the incidents with alert levels. The classification is based on the evaluation of the total amount of gas in the air, the cloud size and the persistency of the event. The alert levels and a human readable report can be connected to the DCS.

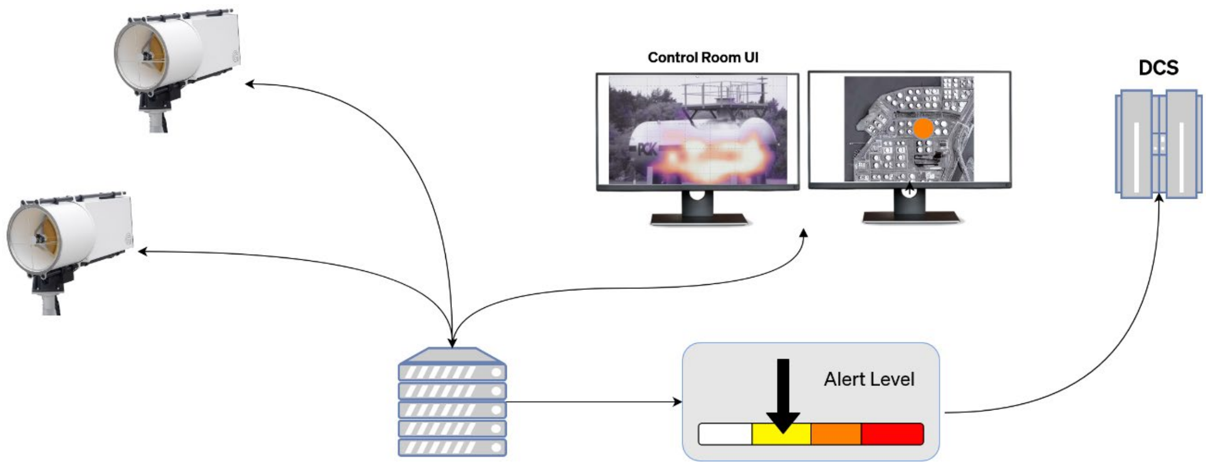

Figure 7: Setup of the entire scanfeldTM monitoring solution. The measurement units are controlled by the server. Alerts are generated that classify the incident. The user sees the POV distribution of the gas cloud and the localization on the map.

RESULT: INSTALLATION AT CHEMELOT INDUSTRIAL PARK

The number and the positioning of the sensor units is driven by the scope of the monitoring plan. Each individual sensor unit can cover a radius of 4 km. Large area monitoring of an entire facility can thus be accomplished by two or three sensor units. The installation at Chemelot focuses on fast early warning within 1 min and a quick monitoring of the immission into Brightlands campus. For the 3D localization of a moving gas cloud, two sensor units are installed monitoring autonomously the production area at OMM. The two units are coordinated in real-time to track the event.

The scanfeld™ solution sequentially monitors the four stacks of the OCI melamine plant OMM, including the urea plant for real-time detection of an accidental gas release. The two sensor units also oversee the entire Brightlands campus area to monitor any immission to the campus. The total monitoring area is approximately 350.000 m².

The first unit is installed at the highest point within the production complex that oversees the entire facility. Figure 8 shows the installation points for the two sensor units and the viewing areas that map the four potential emission points of OMM. The Brightlands campus is partly shown in the satellite image and marked yellow.

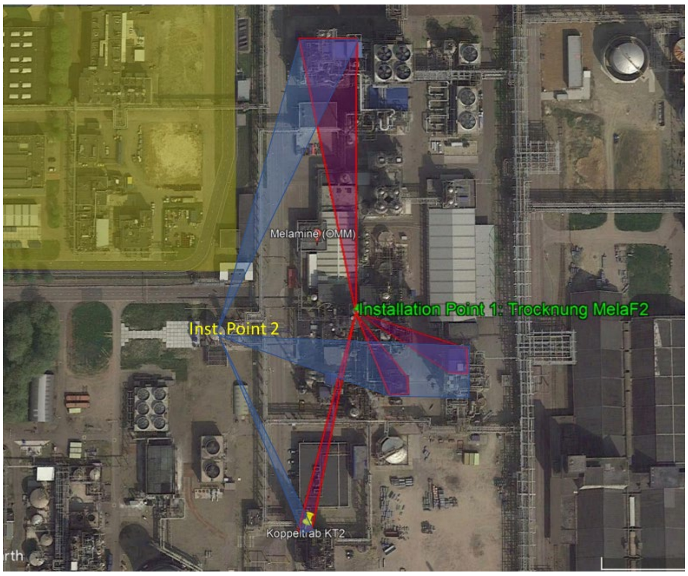

Figure 8: Installation point for sensor unit #1 at an elevated point within the production complex (the viewing areas are marked magenta) and sensor unit #2 at close distance outside the production site (blue viewing areas). The relatively close distance of the sensor unit to the target allows the fastest release detection and a high spatial resolution.

Each unit must be positioned according to the early detection principle and the requirements for real-time situation assessment. For the first criterium for the selection of an installation point maximum overview over areas of interest is essential. The distance to the area of interest is a balance between oversight and spatial resolution. To meet the second criterium the sensor units must have a clear view on the moving gas cloud along the propagation path over the chemical park. Figure 9 shows the area over the Brightlands campus that is visible to the two sensor units.

Figure 9: The image shows the installation point and the viewing area that effectively oversees the entire campus. The white arrows indicate the potential propagation direction of a release from one of the four stacks. The location of the sensor unit enables the continuous monitoring of a gas cloud from the point of release on over the entire monitoring area.

A precise localization of the gas cloud requires a wide enough angle between the two perspectives on the gas cloud. Figure 10 displays three possible scenarios for a gas cloud in the moment of entering the perimeter of the Brightlands campus and the resulting angles under which the two sensor units measure the gas cloud. In all three scenarios, the angle between the two perspectives is wide enough for localization precision within the spatial resolution of the instruments.

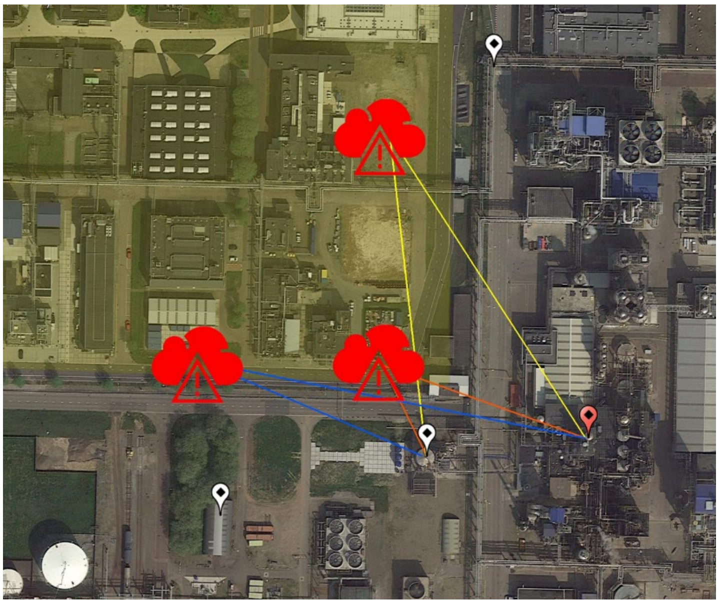

Figure 10: The image shows three scenarios for a gas cloud entering the perimeter of the Brightlands campus. In both cases the gas cloud can be monitored from both installation points under a wide enough angle to allow for precise localization.

DISCUSSION

Creating barriers

A hazardous event that has its root cause in an accidental gas release is the result of subsequent failures of preventive and mitigation measures. Risk analysis must take all stages of the incident into account and define safety measures to minimize risk. Figure 11 displays a fault tree model of the various stages of an incident. To prevent further escalation, each stage of the incident needs its own barrier. scanfeld™ establishes a barrier for each one of the stages by providing warning levels and detailed information when needed. Conversely, scanfeld™ helps to rapidly scale down alert levels once the immediate threat is gone and safe conditions are confirmed.

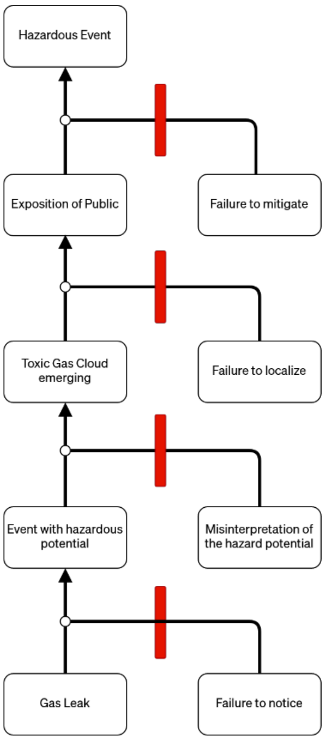

Figure 11: Fault tree model of a hazardous event with a gas release as root cause. Large area gas monitoring can provide barriers in all stages of the incident. They are drawn in red into the model.

Early Warning

One thinks of the release of a hazardous gas as a rare event. In normal operation mode the process is under control and therefore safe. Turnaround and startup-phase are considered more dangerous and are under closer observation. Statistics show in contrary that more than half of all large emissions do not occur in the startup-phase. It is during normal operation and in combination, that most of large-scale releases occur and with operator error most of catastrophic events happen (Lees, 2012). The first principle of a reliable monitoring solution is therefore permanent monitoring of the production and storage areas in normal operation mode and early warning in case of an unexpected gas release.

In the early stage of the event, quick notice and correct situation assessment are crucial. Early warning of the gas release can prevent further escalation of the situation if the operators in the control room recognize the situation for what it is correctly. Measures taken at an early stage of an incident are most effective. But from an operator's point of view they are also the riskiest decision to make if measures taken eventually lead to down-time and loss of productivity. The need for quick action and the pressure to take moderate measures are conflicting especially in an early stage of the event. Operators are naturally hesitant to shut down, until the situation is clear.
In order to prevent potentially hazardous situations, a significant gas release, as defined by (McGillivray & Hare, 2008) needs to be detected quickly and correctly assessed.

To fulfill the need for a solution that warns reliably in case of the unpredicted event, early warning monitoring must cover all relevant areas within the production site, the loading areas and all other critical infrastructure including pipelines.

In principle critical infrastructure can be monitored with local sensors. However, monitoring all flanges, valves and compressors units, as well as storage tanks with gas sensors would require considerable investment and, more important, following costs due to maintenance and regular calibration of the sensors. Remotely monitoring critical infrastructure is a more effective way of covering large areas with a small number of remote sensing units.

Based on the evaluation of the total amount of gas and an analysis of an event over time, an incident is automatically classified in three alert levels, the first of which merely indicating the presence of a gas and the highest concentration indicating the persistent presence of a major amount of gas. For each measurement in a scan, that results in a pixel in the mapping of the gas cloud, the identification algorithms identify the presence of each target gas within the target compound library. The algorithm is based on a radiation transfer simulation that takes into account the spectral signatures of interfering atmospheric and known potentially present technical gases. The incident level is calculated based on the amount of gas that is detected in each scan and a quality criterium for the identification including the signal-to-noise ratio and the confidence value for the target gas identification. The indication levels are also subject to a persistence criterium in time, that filters single identifications which are subject to cross-sensitivity or fugitive emissions. Both calculations are specific for both the target gas and the known behavior within the viewing areas. This feature enables the monitoring solution to learn the normal behavior of the plant over time and self-adapt.
The high-level information on the incident is visualized in the timeline as well as the alarm logs, giving the operator a clearly readable aid where to look. All prior events can always be brought back onto the screen, so in case an event is not recognized immediately, the information is not lost to the operator. The high-level incident information can be directly routed to the DCS via an OPC UA interface. This integration into the safety architecture of the control room is scheduled for the installation at Chemelot.

Mitigation measures

(Karimi, 2019) compares two kinds of hazard potential of an ammonia release: Ignition of the gas cloud and exposition to the toxic gas. Ignition of all kinds of flammable gases, including ammonia, becomes possible, when the local concentration of the flammable gas exceeds LFL. Mitigation measures must therefore detect gas accumulation in both toxic and flammable concentration ranges. The flammability limit of ammonia is between 14.8 % (LFL) and 33.5%. The gas is also immediately harmful to life or health in much lower concentrations. IDLH for ammonia is 500 ppm. Toxic hazards are mostly prior to flammable hazards, as toxic concentrations especially in case of ammonia are much lower.
Sensors must therefore work over a wide concentration range between the lower ppm range of up to double digit percentage levels for reliable mitigation tools. More importantly, it must be ensured that concentration information reflects the highest possible concentration. Therefore, any concentration information must always refer to the center of the gas cloud in order to assist situation assessment. FTIR spectroscopy as used in the remote monitoring solution that is presented in this paper has the benefit of identifying hundreds of various chemicals in a wide concentration range from single digits ppm to double digits percentage values.

Near-field mapping

Gas releases in the open are fundamentally different from gas emissions in confined spaces. The gas coming form the release point is diluted more quickly in open field than in confined spaces, which reduces the risk. On the other hand, it also makes it harder to detect and map the distribution of a gas cloud. As propagation is subject to wind dynamics, there is the risk of local gas accumulation and the areas of high likelihood for accumulation are hard to predict. Especially among dense infrastructure like production facilities, wind dynamics are extremely complex (ProcessNet-Fachgemeinschaft „Anlagen- und Prozesssicherheit“, 2017), (Lees, 2012). As a result, even the assumption that a gas heavier than air accumulates near to the ground is not necessarily true in the near field around the release point. Also, a gas lighter than air does not necessarily rise until complete dilution. The incident at the YARA facility in Rostock-Peetz, Germany 2005 (Bakli, Versteele, & Swensen, 2006) shows how a cloud of ammonia, which is lighter than air, was carried far before coming down again when the gas emissions could be smelled in a town 12 km from the incident.

Figure 12: Measurement of a release of a small amount of methane (20 g/min). The example shows how the gas cloud follows the changing wind direction. Measurement taken from (Feitz, et al., 2018).

Near-field monitoring (Figure 12) of the accumulation of a flammable or a toxic gas must therefore cover the entire area around the point of release to ensure monitoring of the entire gas cloud. With respect to the dynamic gas distribution, it must also cover the near field in real-time.

Compared to field operation with gas sensors either hand-held or part of monitoring vehicles, remote sensing offers the possibility to map the gas concentration in the near field, without prior knowledge of the location and the propagation of the gas cloud. Monitoring near field distribution can be performed in seconds. It is thus quick enough to map the dynamic propagation behavior of gas accumulations (Sabbah, et al., 2012).

Wide area mapping of toxic gases

(Karimi, 2019) compares the potential hazard of an ammonia release due to fire and the toxicity of the gas. The study finds that danger by the fire jet is imminent in a radius of appr. 300 m around the release point after ignition. Hazard potential due to the toxicity of the gas is less local around the release point. The study focuses on a release scenario with approx. 81 kg of ammonia and concludes that the concentration of the gas cloud at 1 km from the incident can still reach lethal levels of 1000 ppm.

Measures to mitigate the effects of an accidental gas release are most effective if they take the gas concentration within a wide radius of the incident into account. Without information on the location of a gas accumulation, wide areas of the compound need to be monitored continuously. Assessment of the gas concentration becomes more difficult the larger the area is that it needs to cover, until reliable situation assessment becomes impossible with common gas sensors.

With the dilution of the gas cloud, it spreads over the facility. But in a dynamic situation especially shortly after the release, the concentration at a certain point may change dramatically over time. The concentration of the gas can be low at a certain location but rise dramatically when the wind sweeps the gas cloud in this direction. The reading of a gas sensor can therefore create a false interpretation of safety when the location of the gas cloud is yet unknown. It can miss the cloud entirely or pick up only the wide-spread diluted parts of the gas cloud which can lead to false interpretation of the situation. Especially if one considers that gas concentration measurements in the field can only be taken a certain height, usually at ground level, whereas the propagation of the gas cloud can occur in greater heights. It must be noted that the general understanding of the propagation of a gas often leads to a false interpretation of the propagation of a gas cloud in the field. It is generally assumed that a gas lighter than air will travel upwards, while a gas heavier than air stays at ground level. But this assumption does not take the stream of the air into account, that can carry a heavy gas up, while a gas lighter than air can be blown down, even at locations far off the release point.

The propagation of the gas cloud is determined by the local wind situation which on the ground is far more complex to evaluated than just assuming that the general wind direction is also valid on ground level. The calculation of the distribution of a gas cloud is discussed at great length in the literature, i.e. (Lees, 2012). Mitigation measures rely on real time information of the location and distribution of a moving gas cloud. As most hazardous gases are invisible, the assessment must rely on measurement technology. A wide variety of distribution simulation software is available to fill the information gap. The general approach of distribution simulation takes the initial amount of gas release into account. More sophisticated software can also simulate the distribution of a known amount of gas among the infrastructure by simulation the air stream that carries the gas with it among the infrastructure of the plant. Local situation assessment takes gas concentration measurements into account.

Both measures are limited in their ability to provide correct situation assessment. The precision of the simulation of the air stream depends on the number of wind sensors that feeds the simulation tool. It narrows down the area of higher likelihood for a high concentration of gas. For a correct simulation of a local concentration distribution distant to the release point, the total amount of gas that has been released into the air is essential. In case of an incident the knowledge of this figure is vague, especially within the first minutes of the incident. The bigger the distance to the release point, the bigger the uncertainty becomes. Especially in cases when the gas concentration is likely to be high enough to be hazardous when the gas cloud reaches the perimeter of the compound and the risk assessment must include the hazard potential for the public. Gas concentration measurements are the only option.

Remote sensing early warning systems in comparison to common sensing technology provide both information on the location and concentration distribution of the gas cloud. In contrast to the deploying of gas sensors and filling the information gap by distribution simulation, remote sensing can be applied over wide areas within the field of view of the optical sensors. Remote sensing can continuously monitor and track the propagation of a gas cloud (Harig & Rusch, 2010). Due to their ability to continuously monitor large areas, a gas accumulation can be located and tracked from the moment of the release on. Over vast areas of up to several square kilometers the gas cloud propagation can be tracked, and the concentration distribution measured in real-time. Remote monitoring of the moving gas cloud works also in heigh elevation profiles, that conventional gas sensors cannot reach.

Information on the propagation behavior of the gas cloud and the location of the gas while the event is unfolding are essential for a precise and fast understanding of the hazardousness of the situation and the coordination of mitigating measures. Fire brigades must know where to set up a water curtain to rain down a hazardous gas. Workers must know which gathering points or buildings are safe and within reach (Hofstra, 2002).

CONCLUSION & OUTLOOK

The scanfeld™ monitoring solution is a highly automated monitoring tool that scans predefined scan areas automatically in a programmed order. In normal operation mode the scan pattern is optimized for quick turn-around in order to map the status of the plant in minutes. The scan-pattern is specific for the scope of the installation with a free definition of scan-speed and spatial resolution. Thus, monitoring areas with the potential release of highly toxic or flammable gases can be optimized for speed, whereas large area monitoring can be optimized for high spatial resolution. Once a gas release is detected, the scan pattern shifts to automatic gas cloud distribution mapping. In the user interface, the operator is notified on all events with an indication. As technical emissions naturally occur in production facilities and fugitive emissions from other areas periodically come into view, an automatic situation assessment aids to better distinguish hazardous situations from harmless emissions.

At OCI Chemelot, by the careful choice of two installation sites in the near vicinity of both the OMM and the Brightlands campus, a very short response time to unexpected releases at the OMM is realized. With a minimal time-to-alert the scanfeld™ installation will provide the exact knowledge about What, Where, and Level of unexpected gas emission incidents. Hereby it creates four levels of barriers for the prevention of hazardous events and protects the Brightlands campus. Furthermore, it allows the speedy post-incident release of affected areas as soon as the dispersion of the gas cloud is confirmed by the scanfeld™ sensors. Compared to conventional gas sensor networks, scanfeld™ is cost effective and provides much more detailed information both from the near and wide field point of view.

In the future the coverage of the scanfeld™ solution can be extended to the entire Chemelot North site (Fig. 13). Since the scanfeld™ system is highly scalable, just two additional sensor installations will allow for the coverage of the complete area and provide additional safety to the site and its direct neighborhood.

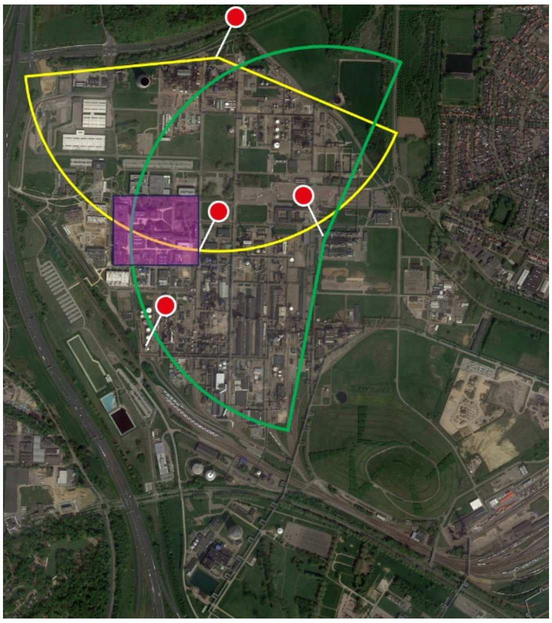

Figure 13: A sketch for an installation of two additional sensor units to monitor the entire Chemelot north chemical site. The monitoring area covers 1.6 km². The monitoring solution covers 8 toxic or flammable gases.

The scanfeld™ monitoring solution as presented in this paper is installed in March 2021 with a full on-site acceptance test scheduled for May 2021. Future presentations will discuss the performance of the monitoring solution and present first results.

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