Gas Detection for Offshore Application

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Abstract: Release of hazardous and flammable gas is a significant contributor to risk in the offshore oil and gas industry and various types of automatic systems for rapid detection of gas are therefore installed to accentuate the elimination or reduction of the dangerous releases. There are different types of gases which may be released and gas may be released in different environments and under different conditions. Several principles for detecting gas are therefore applied and a variety of types of gas detectors are in use. However, a significant percentage of gas releases remain undetected by the dedicated detectors and hence unaccounted for and uncontrolled.

The objectives of this paper are: (1) to present a state-of-the art overview of gas detection in relation to offshore applications, (2) to present an overview of requirements for gas detection in the Norwegian offshore industry, and (3) to do a comparative study of performance standards for gas detection worldwide. The paper builds on a review of literature, standards and guidelines in relation to gas detection offshore.

Keywords: Flammable, Toxic, Gas, Detection

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1. INTRODUCTION

In the offshore industry, dangerous gases are naturally occurring or man-made in petroleum operations. Release of hazardous and flammable gas is a significant contributor to risk in the oil and gas industry. The ignition of flammable gas clouds or vapors can lead to major fire and explosion with highly devastating consequences as was the case in the Piper Alpha disaster [7]. Similarly, toxic gas release can lead to multiple fatalities over a wide area as was the case in the Bhopal gas tragedy [7], although this happened in an onshore location.

Gas detection is a crucial topic in the process industries, e.g. the Norwegian offshore industry where focus has been on safety barriers supported by the policy of reporting hydrocarbon leaks [20]. The process industry learns from related incidents/accidents in addition to being proactive to predict what can go wrong and how to control it. Various types of automatic systems for rapid detection of gas are therefore installed to control the risk. In fact, the safety of the offshore industry depends on the efficiency and effectiveness of the gas detection systems.

Gas detection has, however, experienced mixed results in the industry. Although it has achieved more success than failure, the failure statistics is significant. According to the report of a research conducted by [19], about 44% of all gas releases, or 38% of major gas releases were undetected by the gas detectors deployed. The offshore environment is being characterized by a complex mix of open and enclosed areas, low and high areas, diversity of hazardous gases and conditions for release, potential gas traps, and varieties of operational and environmental conditions that may influence the unreliability of gas detection. Besides, offshore installations have different challenging gas detection needs that require specific solutions; e.g. some facilities require that detectors identify gases at the lowest possible level (in ppm or LEL range), whereas other facilities are exposed to compounds or other gases that can undermine the detectability of the target gases (i.e. a problem of cross-sensitivity or non-specificity). Furthermore, complexities in ventilation patterns and in the size and composition of modules often make it extremely difficult to site gas detectors; this implies that availability of detectors is no guarantee for detection [19]. Other gas detection related problems include incorrect selection of gas detectors, deficiencies in design, installation, calibration and maintenance of gas detectors as well as users' lack of knowledge of the limitations of a given detection principle.

Several authors and companies have made or are making efforts to improve gas detection technologies. Work on enhancing the effectiveness of single technology has been carried out by several authors, e.g. [18] and [8] etc. The optimal placement of sensors under uncertainty has been studied by [12]. Furthermore, the development of versatile single technology or integrated technologies for multiple gas detection has been or is being explored by several others, e.g. [16], [5, 6] and [11].

The main objective of this paper is to present a state-of-the art overview on gas detection in relation to offshore applications. The rest of the paper is structured as follows. First, the types of releases that may occur and the conditions under which they may occur are described. This is followed by a description of relevant principles for detecting gas, and relevant Norwegian regulatory requirements and standard. A comparative study of gas detection standards worldwide is then presented, followed by conclusion and recommendations.

2. TYPES OF GASEOUS RELEASES, THEIR CHARACTERISTICS AND POTENTIAL SOURCES

The different types of gases which may be released in the offshore petroleum industry are described in the following:

- Hydrocarbon (HC) gas release: This is a flammable release that may occur at atmospheric conditions or under pressure from containment systems [13]. Such releases can occur in containment systems subject to the following failure mechanisms: corrosion, erosion, wear, manufacturing defects, operational loading, well pressure etc. Other possible causes include human factors in the form of normal operational releases, operators error and third party damage [13]. The release can occur at the topside where the process equipment are located or subsea in the form of blowouts from wells and leaks from subsea pipelines and isolation valves etc. Specific areas where releases are likely such as the rig floor, the vicinity of the test separator and the choke manifold require permanent rather than portable gas detection system [9]. It is also common to release methane (CH_4), a lower hydrocarbon, from combustion to generate electricity and to power compressors and pumps as well as from flaring of excess gas for safety and during well testing [15].
- Hydrogen Sulphide (H_2S) release: This is an extremely toxic release that usually occurs as a contaminant in produced gases. It occurs naturally together with natural gases from wells. During well testing, it is advisable to monitor the area to check the presence of Hydrogen Sulphide (H_2S) concentrations and that it is safe for working, since even in relatively low concentrations this release can readily lead to fatality [9]. The first significant presence of H_2S is readily noticeable from samples taken downstream of the choke manifold and at the gas outlet from the separator [9]. Furthermore, H_2S usually collect at the lowest points on rigs such as the cellar deck area (offshore) and on land rigs since it is heavier than air [9].
- Carbon Dioxide (CO_2) release: This is a release that becomes dangerous usually in relatively high levels in confined spaces. The release usually results from combustion of fossil fuels to generate electricity and to power compressors and pumps, as well as from flaring of excess gas for safety and during well testing [15].
- Carbon Monoxide (CO) release: This is a highly toxic release. It usually results from combustion of fossil fuel to generate electricity and to power compressors and pumps, as well as from flaring

of excess gas for safety [15].

3. PRINCIPLES FOR DETECTING GAS

Offshore gas detection system is necessary to warn about the presence of hazardous and flammable gases in unacceptable concentrations within a given ambiance in order to prevent major accidents. Several principles for detecting gas exist to cover the different types of gases which may be released under different environments and conditions.

The types of gas detection technologies applicable to the offshore petroleum industry, a brief description of their principles of operation as well as their safety-related applications are shown in Table 1.

Table 1: Operational principles and safety-related applications of gas detectors [1, 3, 10]

Operational principles of gas detectors	**Description of principles**	**Applicable gases**	**Safety-related applications**
Catalytic	Uses a catalytic bead to oxidize combustible gas; a Wheatstone bridge converts the resulting change in resistance into a corresponding sensor signal.	All combustible gases (non-selectively)	Flammable gas detection
Electrochemical	Uses an electrochemical reaction to generate a current proportional to the gas concentration.	Many toxic gases, environmental pollutants, combustion products and oxygen.	Toxic gas detection
Solid state	Measures the change in resistance of a metal oxide in response to the presence of a gas; the change in resistance translates into a concentration reading.	HCs, CO, O_3, H_2S, organic vapors, etc.	Flammable gas detection
Thermal conductivity	Measures the gas' ability to transmit heat by comparing it with a reference gas (usually air). The change in electrical resistance as a result of the heat transmission is proportional to the gas concentration.	Binary gas mixtures (often a known gas in air); combustible and toxic gases	Flammable and toxic gas detection
Photoacoustic Infrared (IR)	Uses a gas ability to absorb IR radiation and generating an audible pressure pulse whose magnitude indicates the gas concentration present.	Many IR absorbing gases; combustible gas, toxic gas	Flammable and toxic gas detection
Infrared (Absorptive)	Applies absorption spectroscopy such that a specific gas absorbs a specific wavelength in the infrared (IR) spectrum, and the gas concentration is proportional to the amount of IR light absorbed.	Many mid-IR absorbing gases, e.g. CO_2, CO, CH_4, NO etc.	Flammable and toxic gas detection
Ultrasonic (or acoustic)	Uses ultrasonic sensors to detect leak based on the sound generated by escaping gas at ultrasonic frequencies.	All types of gases whether combustible, toxic or inert.	Flammable and toxic gas detection
IR gas cloud imaging	Applies an absorption imaging technique whereby the image of an area illuminated by infrared radiation is captured by an infrared camera.	Gases that absorb IR radiation at the wavelength of the IR radiation, e.g. hydrocarbon gases.	Flammable gas detection

The coverage of gas detection is a crucial factor to consider in addition to the vulnerabilities of the detection technology that can be exploited by certain operational and environmental conditions. To this end, the various principles for gas detection are classified based on coverage and each of the detection principles was described further by its application area, strengths and weaknesses as shown in Table 2.

Table 2: Further gas detection characteristics [10, 11, 14]

Coverage	Detection principles	Application areas	Strengths	Weaknesses
Point detection	Catalytic	Point sources - potential leakage points (e.g. pumps, compressors, major packing, seal or gasket vulnerable points, etc).	Robust, easily installable and operable, simple to calibrate, long lifetime with a low life-cycle cost, detectability of a variety of gases, wide range of operating temperature, easily calibrated to gases undetectable by infrared absorption, e.g. hydrogen.	Passive detection (not fail-safe), gas must diffuse into catalytic bead so as to be detected, contaminants can poison or deactivate catalyst, the only means of identifying loss of sensitivity due to catalyst's poison is by testing with appropriate gas regularly, requires oxygen for detection, sensor performance may become degraded from prolonged exposure to high concentrations of ignitable gas.
	Electrochemical	Same as above	Speedy response, high accuracy, versatility (detects a wide range of toxic gases), low power consumption.	Less effective at low ambient temperatures ($\leq -40^oC$), cannot withstand dry environment (<15% RH) over several months, operates in a narrow pressure range (1 ± 0.1 atm)
	Solid state	Same as above	Robust, versatile (detects a wide range of gases), wide range of operating temperature, resistant to corrosive and low-humidity environment, long operating life (2-10 years)	Usually not selective, although some new improvements have overcome this limitation, high power consumption, operation is not fail-safe.
	Thermal conductivity	Same as above	Wide measuring range	Non-specific (cross-sensitive), unsuitable for gases with thermal conductivities (Tc) close to one. Gases with Tc < 1 are more difficult to measure. Output signal not always linear.
	Photoacoustic Infrared (IR)	Same as above	High sensitivity, linear output, simple to use, not subject to poisoning, long-term stability	Not suitable for hydrogen detection
	Fixed-point IR (absorptive)	Same as above	Immune to poisoning by contaminants, fail-safe operation, absence of routine calibration, can operate in the absence of oxygen or in enriched oxygen, can operate in continuous presence of gas	Gas must pass by the sampling path so as to be detected, the gas to be detected must be infrared active (e.g. a hydrocarbon), gases that do not absorb IR energy cannot be detected, highly humid and dusty environments can increase the maintenance cost of IR detector, routine calibration to a different gas is impractical, a relatively large amount of gas is required for response testing, ambient temperature limit of detector use is 70^oC, not suitable for multiple gas applications, the IR source is not replaceable in the field, but in the factory.
Open path (line or perimeter) detection	Open-path IR (absorptive)	Boundaries with public areas and between fire areas or equipment, along rows of items and perimeters	Same as above and long line coverage.	Same as above
Area detection	Ultrasonic (or acoustic)	General process areas, loading/offloading facilities, gas turbines, flow stations, tank farms etc.	Very high detection rate of pressurized gas leaks, versatility (detects pressurized leaks irrespective of gas type), unaffected by ambient conditions (fog, heavy rain and others), minimal maintenance, absence of consumable parts, robust, fail-safe, insensitive to gas dilution and changing wind direction, wide area coverage, gas must not be at the device for detection.	Unsuitable for low pressure leaks, under certain conditions influenced by artificial or natural ultrasonic sources, requires estimation of background noise levels before installation, cannot determine concentration of gas, cannot pin-point leak source.
	IR gas cloud imaging	Large gas clouds monitoring in unmanned platforms, pipelines	Wide field of view and detection coverage, no gas calibration is required in the field, highly immune to spurious alarm sources, simultaneous detection of multiple gases.	Detectability of gases is poor when the contrast with the background is poor, heavy fog and rain reduces detection range, suitable only for large leaks - not a small leak detector.

4. REQUIREMENTS FROM NORWEGIAN REGULATIONS AND STANDARDS

Gas detection in the Norwegian offshore petroleum industry is being regulated by some standards and regulations briefly described in Tables 3 and 4.

Table 3: Requirements from Norwegian regulations

Provisions Relevant to Gas Detection	Norwegian Guidelines	Related Standards
Safety barriers: Safety functions being regarded as barriers against hazards and accidents	Sections 3 and 8 of the Facilities and 4 and 5 of the Management Regulations in PSA Guidelines	
Design of safety functions: Requirements for design of safety functions	Section 8 of the Facilities Regulations in PSA Guidelines, OLF 070 Guideline	NS-EN ISO 13702, NORSOK S-001 and IEC 61508
Design of fire and gas system: Requirements for design of fire and gas detection systems	Section 8 of the Facilities Regulations in PSA Guidelines, OLF 070 Guideline	NS-EN ISO 13702 with Appendix B.6, NORSOK S-001 Chapters 12 and 13
Disconnection: When it becomes necessary to disconnect safety functions, the requirements shall be applied.	Sections 8 of the Facilities and 26 of the Activities Regulations in PSA Guidelines	
Performance requirements: Performance requirements shall be established for all safety barriers on an installation	Section 1 and 2 of the management regulations in PSA Guidelines, OLF 070 Guideline	IEC 61508
Availability: The requirement for available status shall be fulfilled.	Section 8 of the Facilities Regulations in PSA Guidelines	NORSOK I- 002, Chapter 4
Independence: The fire and gas detection system shall come in addition to systems for management and control and other safety systems.	Section 32 of the Facilities Regulations in PSA Guidelines	
Interface: The fire and gas detection system may have an interface with other systems as long as it cannot be adversely affected as a consequence of system failures, failures or isolated incidents in these systems.	Section 32 of the Facilities Regulations in PSA Guidelines	
Limiting consequences: Relevant safety functions shall be activated when there is a demand on the detection system	Section 32 of the Facilities Regulations in PSA Guidelines	
Not Permanently Manned Facilities: They should also have a dedicated gas detection function for the area around and on the helicopter deck	Section 32 of the Facilities Regulations in PSA Guidelines	
Visual perception of detection: Detection of gas should be shown by means of a light signal that is visible at a safe distance from the facility.	Section 32 of the Facilities Regulations in PSA Guidelines	
Gas detection for mobile units: For mobile facilities that are not production facilities, and that are registered in a national ships' register	Section 32 of the Facilities Regulations in PSA Guidelines	DNV-OS-D301 Chapter 2, Section 4, subsection D

The role of gas detection as stipulated in NORSOK S-001 (subsection 12.1) shall encompass the continuous monitoring of flammable or toxic gases. The standard focused primarily on hydrocarbon (HC) gas detection (including H_2 as relevant), H_2S gas detection, CO_2 gas detection and CO gas detection wherein it sets alarm limits for each of these. For hydrocarbon gas detection (including H_2 as relevant), i.e. flammable gas detection, the alarm limits (both low and high) are fixed in relation to the types of detectors in use whether point detectors or IR open path detectors. It is possible to use a single alarm limit

Table 4: Requirements from Norsok S-001 Standard

Provisions	NORSOK S-001 Requirements	References
Role	Continuous monitoring of flammable or toxic gases.	subsection 12.1
Interfaces	Link between gas detection system and ESD, BD system, ISC, ventilation, PA and alarms system and fire fighting systems.	subsection 12.2
Required utilities	Uninterrupted Power Supply (UPS) and instrument air supply (if aspiration system is applied) are required in gas detection system.	Subsection 12.3
Detection design coverage	Speedy and reliable detection before gas cloud reaches critical concentration/size.	subsection 12.4, subsubsection 12.4.1
Leak detection	All potential flammable gas leak points shall have flammable gas detection.	subsection 12.4, subsubsection 12.4.2
	Herein, the smallest gas cloud with the least unacceptable consequence shall be the basis for confirmed gas detection.	Same as above
	In naturally ventilated area, a smaller leak rate for warning (alarm) is enough and is typically 0.1 kg/s.	Same as above
	In mechanically ventilated areas, detection of smaller leaks shall be subject to expert judgment.	Same as above
	Deploying detectors shall be based on an assessment of gas leak scenarios in relation to potential leakage source and rate, dispersion, density, equipment arrangement, ventilation and the probability of small leak detection therein.	Same as above
	The basis for selection and placement of detection in each area shall be documented.	Same as above
	Open path detectors are preferred where the layout enables good coverage by them.	Same as above
	Detection principle to apply shall be subject to considerations for environmental conditions and availability of protection for detectors.	Same as above
	Catalytic detectors shall not be used unless other detectors do not perform as required.	Same as above
Detection location	Sufficient detectors shall be located by natural passageways along flow direction, in different levels in an area or module, in potential gas traps and in the air inlets of heat sources and accessible without scaffolding.	subsection 12.4, subsubsection 12.4.3
Detection characteristics and calibration	The detector characteristics and calibration shall guarantee good estimation for gas concentration (point detectors), gas amount (open path detectors) or leakage rate (acoustic detectors)	subsection 12.4, subsubsection 12.4.4
Detection actions and voting	The detection system shall activate all actions according to the Fire and Explosion Strategy (FES).	subsection 12.4, subsubsection 12.4.5
Detection levels	Detectors used shall give alarms as soon as possible and within the recommended alarm limits/settings. Detection, failure of further action on demand and system defect shall be reflected in central control room (CCR) as alarms. Use alarm limits and outputs for annunciation as stipulated by standard.	subsection 12.4, subsubsection 12.4.6
Detection response time	Maximum response time of detection shall be defined so as to ensure fulfillment of total reaction time for each safety function. Apply recommended response times unless reduction is needed	subsection 12.4, subsubsection 12.4.7
Detection logic solver	Logic solver compliance with the intended use and safety integrity requirement shall be demonstrated.	subsubsections 12.4.8 and 9.4.6 and IEC61508
Fire and gas independence	The fire and gas detection system shall operate as an independent system.	subsection 12.4, subsubsection 12.4.9
Survivability requirements	The gas detection system shall not be dependent on local instrument rooms with location less safe than the central control room.	subsection 12.5
	Equipment critical to effectuation of system actions shall be protected against mechanical damage and accidental loads until all actions from the detection system have been activated.	subsection 12.5

for hydrocarbon gas detection, but this must be the low alarm limits. The alarm limits for area detection systems (e.g. ultrasonic/acoustic detectors) are left to the operators to decide and adjust on the basis of the background noise peculiar to their operating environment. However, guidelines on the use of IR gas cloud imaging, a type of area detection, has yet to be treated by the standard. This is probably due to its being a new technique that has yet to be applied extensively in the Norwegian industry. Furthermore, the alarm limits for toxic gases are defined in the standard based on the effect of toxic gas in relation to concentration or exposure time and these vary for H_2S gas detection, CO_2 gas detection and CO gas detection.

5. COMPARATIVE STUDY OF PERFORMANCE STANDARDS FOR GAS DETECTION WORLDWIDE

The performance standards for gas detection do specify the performance levels to which gas detectors should be tested and operated, and several variations of these exist across the geographical regions of the world. The variations are probably as a result of diversity of regulatory agencies. Some of the standards available in different countries have little differences, whereas the differences between some are significant. However, they all have a common goal which is the prevention of accidents.

In North America, as regards flammable gas detection performance specifications, FM 6310/6320 (used mainly in the US) is similar to C22.2 152 (used mainly in Canada) and both of them are closely related to ANSI/ISA 12.13.01-2000 [4]. As regards offshore toxic gas detection, the ANSI/ISA 92.00.01 is widely used worldwide [4] and emphasizes on repeatability, step-response and recovery as part of requirements for toxic gas detection performance tests with the worst case accessory attached [2]. The ANSI/ISA 12.13.04 recommends instrument measurements in LEL-m (lower explosion limit meters) or ppm-m (parts per million meters) for flammable gas open-path detection [2]. It also recommends several rigorous tests covering solar immunity, simulated fog/mist and water vapor, partial obscuration of optics, long range operation with 95% obscuration of optics, vibration and temperature extremes and long term stability, either while under stress or before and after stress [2]. The ANSI/ISA 92.00.04 also demands measurement in ppm-m (only) of the toxic gas in the optical beam of the open-path toxic gas detector as well as a misalignment test [2].

In Europe, the national standards are becoming harmonized with the European standards and the IEC standards. For example, as regards both point and open-path flammable gas detection performance specifications, the IEC 60079-29 series have been adopted by many European countries [4]. The same also applies for IEC 45544 series which are dedicated to toxic gas detection [4]. The IEC/EN 60079-29 series recommends that a detector for flammable gas should be used where the accumulation of a combustible air-gas mixture can pose a hazard to life and assets. Furthermore, such a detector is required to sound alarms, show visual warnings or initiate mitigative actions. In addition, IEC/EN 60079-29 and IEC/EN 45544 series advise on considering the effects of variations in temperature and humidity of the gas marked for detection.

In Norway, NORSOK standards which are developed by the Norwegian petroleum industry are widely in use. They are a range of standards intended to serve as references or bases upon which relevant Norwegian regulatory bodies can prescribe statutory requirements and evaluate their compliance. In addition, NORSOK standards serve as replacements for oil company specifications and they normally make necessary additional provisions to recognized international standards in order to address some needs peculiar to the Norwegian petroleum industry [17]. The NORSOK standard that treats gas detection is NORSOK S-001 (Technical safety) which has been described to some extent earlier. NORSOK S-001 is an all-in-one standard generally covering point, open-path and area detection of both flammable and toxic gases. This is unlike the other standards that are separated such that each covers not more than one of the following aspects: flammable-gas point detection (IEC/EN 60079-29-1 and ANSI/ISA 12.13.01), toxic gas point detection (IEC/EN 45544 series and ANSI/ISA 92.00.01), flammable gas open-path detection (IEC/EN 60079-29-4 and ANSI/ISA 12.13.04), toxic gas open-path detection (IEC/EN 45544 series and ANSI/ISA 92.00.04) and area detection of flammable or toxic gas.

A table briefly juxtaposing performance specifications for toxic-gas point detection across Norway, Europe and America is shown in Table 5.

Table 5: A brief comparison of performance standards for toxic-gas point detection

Toxic gas detection specifications	**NORSOK S-001**	**IEC/EN 45544 series**	**ISA 92.00.01 to 92.06.01, FM 6341, NFPA 70**
Gas concentrations		0, 20%, 50%, 90% of full scale	10 to 100 ppm H2S
Temperature range		-10 to 40^{o}C	14 to 122^{o}F (–10 to 50^{o}C)
Relative humidity range		20% RH, 50% RH, 90% RH	15 to 90%
Response time	T90 < 2 seconds	T50 < 60 seconds, T90 < 2.5 minutes	T20 < 10 seconds, T50 < 30 seconds
General alarm limits	Maximum is 10 x 10-6 /20 x 10-6 (low/high for H2S), maximum is 5000 x 10-6 /15000 x 10-6 (low/high for CO2), maximum is 30 x 10-6 /200 x 10-6 (low/high for CO)	70 Db(A) at 0.3 meters from apparatus	
Accuracy/Linearity		0.3% (for 0.5 STGC to 10 STGC) to 0.5% (for 0.1 STGC to 0.5% STGC)	10% of applied gas concentration or 3 ppm

6. CONCLUSION AND RECOMMENDATIONS

According to recent statistics, a significant percentage (about 44%) of gas releases remain undetected in spite of the application of the detection technologies in use [19]. The main objective of the paper has been to present a state-of-the-art knowledge of gas detection for offshore application.

This paper has given more insights into the various aspects of applicable gas detection and will be useful to students and practitioners in offshore petroleum related fields. The paper has reviewed literature, standards and guidelines in relation to gas detection in the offshore oil and gas industry. It has covered the description of the various gaseous releases, the applicable detection technologies and their pros and cons as well as standards and guidelines being applied in the offshore industry in Norway and worldwide. In addition, a comparative study of performance requirements across international boundaries has been done.

Based on the aforementioned, it can be inferred that no single detection technology is a complete solution to offshore gas detection. There is the need to link various technologies together in order to achieve complete coverage and enhanced redundancy. In this way, detection layers of protection (barriers) will be established and made independent. This will enhance the prevention of major accidents characterized by fire, explosion and toxic release. Besides, the associated flammable and hazardous gases, of which exposure is inevitable, need continuous monitoring since the processes generating them are continuous.

Furthermore, it has been seen that no single detection standard across the world areas can be regarded as "'the standard of everything about gas detection offshore"'. Hence, there is the need for continuous improvement as regards the harmonization of standards.

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