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Comparsion Study of Subsea Leak Detection Technologies

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Abstract

An offshore leak detection technology for identifying hydrocarbon leakages under subsea conditions is an area of interest for many oil and gas companies. The human and environmental consequences of offshore leakages and spills have been the reason for oil and gas companies to study and develop detection technologies that can locate, with high sensitivity and fewer limitations, leakages. The purpose of this paper is to identify the state-of-the-art in subsea leak detection technologies. Comparisons based on the advantages and disadvantages of those technologies are also presented. Additionally, the limitations of subsea leak detection technologies were identified, along with potential solutions to those limitations.

Keywords: Subsea, Leak, Detection, Pipelines; Sensors.

1. Introduction

Offshore oil and gas production has made a major contribution to the world's oil and gas needs since the revolution of subsea production systems began in the 1940s [1]. The increased demand for new, economical and safe subsea hydrocarbon production and transporting systems, such as templates and pipelines, have been the focus of many oil and gas companies. However, one of the major challenges associated with subsea production systems is monitoring and minimising hydrocarbon (HC) leakages. The need for leak detection technologies for subsea production systems has become a more recent focus of the offshore oil and gas industry [2][3]. Until recently, leak detection has been undertaken by visually monitoring the sea surface for any hydrocarbon spills. Today, the technologies employed are more advanced, where water proof sensors are being used for oil and gas detection either by continuous monitoring or by surveying and inspection. The aim of this paper is to review subsea leak detection technologies (SSLDTs) employed by oil and gas companies and to identify limitations of SSLDTs with potential solutions to those limitations with the aim of reducing offshore leaks.

2. Subsea Leak Detection Technologies

Leak detection in subsea environments is becoming very important in the oil and gas industry. As more new deep-water oil fields are being discovered, the need for subsea production and transporting systems, such as tie-backs, templates and multiphase flow pipelines, is increasing [4][5] . In addition, the concern about hydrocarbon leakage from such systems is increasing due to high risks to the environment and the safety of operators [6]. There are a number of leak detection technologies available in the market, with each providing different methods of detection. However, due to the fact that subsea leak detection technology is a new area of development, some of these technologies still do not meet oil and gas industry regulations [1][6].

2.1. Leak Detection Approaches

There are two common inspection approaches to hydrocarbon leakage in the offshore environment. These approaches can be classified according to their physical principals, as follows [3][7] :

a. Non-continuous inspection approach The inspection is done by either visually observing the sea surface condition for any traces of oil and/or gas or by attaching sensors to movable sensor carriers. Visual inspections, usually carried out once a year, may be undertaken by using boats or helicopters, with the latter especially useful for observing long distance oil and gas transporting pipelines [3]. However, detecting hydrocarbon visually is limited to observing hydrocarbon floating on the sea's surface, which means that, depending on the water depth in which the source of the leak has occurred, hydrocarbon may have been leaking for hours or even days before detection. In terms of movable sensor carriers, remotely operated vehicles (ROVs) or autonomous underwater vehicles (AUVs) are commonly used [8]. While both types of non-continuous approaches provide relatively simple ways of detecting hydrocarbon leakages, attaching sensors is more reliable [3][7].

b. Continuous inspection approach The inspection is done by installing permanent leak detection sensors for continuous monitoring of subsea installations and pipelines [7].The detection is done by using different types of external detection sensors, such as point sensors and area coverage sensors. For internal detection, methods such as mass- and volume balance are used [3].

2.2. Classification of Existing SSLDTs

Subsea leak detection technologies have been classified as internal-based technologies (IBT) and external based technologies (EBT). These two technologies are sometimes referred to as software- or hardware-based methods. IBTs are those that measure the changes in the characterisation of flow parameters, such as pressure difference, flow rate and fluid volume. On the other hand, EBTs use different detection principles to detect leakages in the surrounding area of subsea installation systems and pipelines [7]. Based on the technology mechanism used, EBTs can be further classified into the following methods: active acoustic, passive acoustic, optical camera, fibre optic, capacitance, fluorescent, bio-sensor, methane sniffer, non-dispersive infrared spectrometry (NDIRS), and semi-conductor [1].The internal-based technologies can be further classified into computational methods, such as mass/volume balance, pressure point analysis, and real time transient modelling (RTTM). Figure 2.1 shows the classifications of subsea leak detection methods.

2.2.1. External-based Technologies

As defined above, external-based technologies are those methods that monitor the surroundings of subsea systems and pipelines by using either non-continuous or continuous inspection approaches. The EBTs described below are area coverage and point sensor-based technologies. The main difference between the two is that area coverage-based technologies can more easily determine leak location than can point sensor technologies [1].

a. Active Acoustic Method (AAM)

The AAM is a sound-based method in which sonar sensor is used to detect leaked oil droplets or gas bubbles in a subsea environment. The AAM has been used successfully in the North Sea with non-continuous leak detection approaches [1][9]. The AAM can also be used in continuous monitoring of subsea pipelines by installing the active acoustic sensors outside the subsea structures or pipelines [9]. However, the AAM is uneconomical in continuous monitoring of long distance transporting pipelines. In addition, the performance of this technology depends on water depth and the size of the gas bubbles.

b. Passive Acoustic Method (PAM) The PAM is another type of acoustic based method that uses microphone sensors to pick up pressure waves caused by hydrocarbon leaking under pressure in subsea structures [1][9]. The main difference between AAM and PAM leak detection technologies is that the PAM works only by receiving sound waves, whereas the AAM works by both emitting and receiving sound waves. This means that the PAM is not dependent on using reflective media in detecting leaks [1].

c. Optical Camera Method (OCM) The OCM is a type of optical monitoring method in which a video camera is used as a sensor to detect hydrocarbon leakages [10]. The OCM is commercially available and it is very suitable to use with ROVs. Area coverage is also possible with OCM. However, the optical camera method is affected by seawater conditions such as turbidity.

d. Fibre Optic Method (FOM) FOM is a method

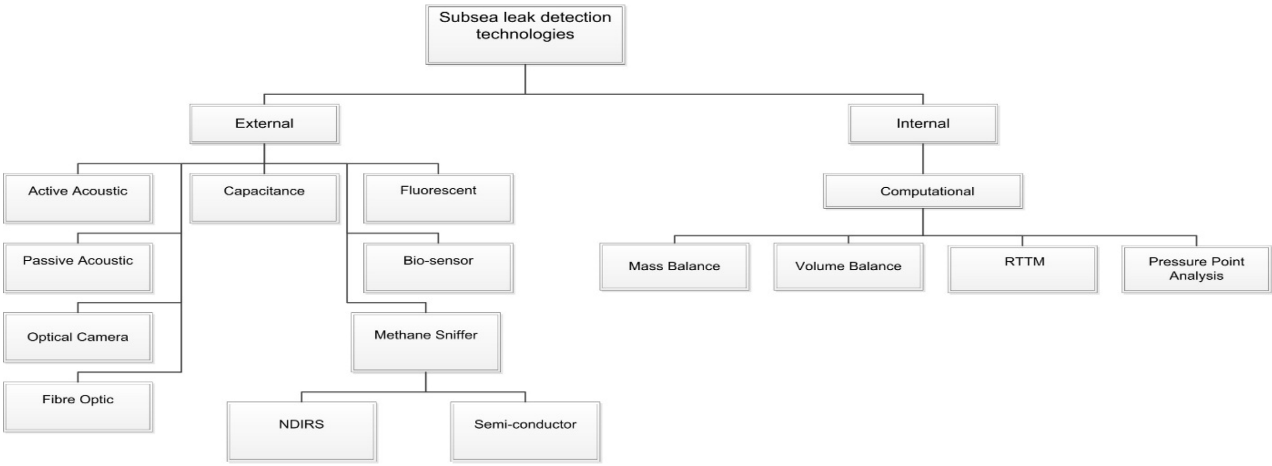

Figure 2.1: Classification of subsea leak detection methods.

that uses fibre optic cables to monitor changes in physical and chemical properties surrounding subsea pipelines [11]. In this technology, fibre optic cables are installed alongside subsea pipelines. Due to the fact that this technology does not require power or electronic cables, the FOM has the potential to be used in detecting deep water subsea transporting pipelines [11][12]. FOMs are commercially used onshore.

e. Capacitance Method (CM) CM is an electronic-based method that uses the difference in dielectric constants between sea water and oil and/or gas to detect leaking subsea production systems. Capacitance detection sensors have been available since the 1990s [4].

f. Fluorescent Method (FM) The fluorescence method is defined as a method that uses different light wavelengths to detect leakage through fluorescent material that have been added to fluids in subsea structures. The fluorescent method is very sensitive in detecting fluorescence in crude oil with ppm detection levels [13][14].The fluorescent method is commercially available and has been successfully used with ROVs in non-continuous monitoring of subsea structures. However, permanent monitoring of subsea structures using FM is still immature.

g. Biological Sensor Method (BSM) The biological senor method is a method that uses the response of living organisms to detect hydrocarbon leakage. One of the primary requirements of this technology is the need for direct contact with the leaking hydrocarbon. Therefore, the closer the sensors are from the structure to be monitored, the better the detection sensitivity of this technology. However, seawater current can affect the sensitivity of this technology. The BSM has been tested in shallow water; however, testing the technology in deep water is still under development [1].

h. Methane Sniffer Method (MSM) The methane sniffer method is defined as a method that measures methane concentration in seawater to detect gas leakages. There are two types of process that can be used when employing the methane sniffer method: semi-conductor and NDIRS. The two processes are based on measuring methane as it is diffused over a membrane and to a detector. Both processes are point sensor-based and locating leakage is not possible [1][4].

2.2.2. Internal-based Technologies

Internal-based technologies are those methods that rely on internal changes in fluid characteristics such as pressure, temperature, flow rate, etc. These methods are also referred to as 'computer methods'. The data collected through employing these methods are analysed by computer software. Below is a description of different internal based methods.

a. Mass Balance Method (MBM)

The mass balance method uses mass conservation law to detect leakages [1]. Leaks from subsea pipelines are detected when (M_1) does not equal (M_o). In other words, the difference between mass input and mass output does not equal the total fluid mass.

b. Volume Balance Method (VBM)

The volume balance method is also based on the principle of mass conservation law similar to the MBN. A leak is detected when the volume of fluid entering a system is not equal to the volume exiting the system [9]. This simple process is widely used in oil pipelines.

c. Real Time Transient Model (RTTM)

The RTTM uses different types of conservation law equations in detecting leakages. These equations include mass, energy, momentum and the equation of state [9]. The real time transient model is based on detecting leakage by comparing the measured data and predicted data of the fluid flow [10]. However, the cost of instruments and of training users, due to the complexity of the models, make this technology very expensive.

d. Pressure Point Analysis (PPA)

Pressure point analysis is a simple and fast method for detecting subsea leaks in pipelines, on the basis that a leak will occur when there is a pressure drop along a segment of the pipeline [9].This leak detection technology has been used successfully in different applications, such as multiphase flow and transporting subsea pipelines [10].

2.3. Comparisons of SSLDTs

From the information presented above, subsea leak detection technologies have been compared based on the following categories:

- Sensitivity: the ability to detect hydrocarbon (liquid or gas) whether the leak is small or large
- Leak location detection: the ability of a technology to estimate leak location
- Availability: is the technology available to continuously monitor subsea structures?
- Detectable media: What types of media can the technology detect? E.g., liquid, gas, or both?
- Maintenance requirement: technical performance of a technology and the level of technology maintenance requirement
- False alarms: the number of false leak alarms that are triggered when there are no leaks in the subsea structures
- Cost: how expensive is the technology in terms of capital and operational expenditure?

A comparison of subsea leak detection technologies is summarised in table 1.

It can be clearly noted that there is no single technology that achieves a high performance level in all categories. This is because every technology is different in physical principle and therefore can achieve superior results in one category and fail in another. It can also be ascertained that all subsea leak detection technologies have a common problem: false alarms. The frequency of false alarms is dependent on the technology in use. However, external- and internal-based technologies give false alarms for different reasons, for example, false alarms due to the seepage of gas from the seabed [1]. Visual observation is the only method that can detect hydrocarbon with low false alarms, as this method relies on the user actually seeing the leak, rather than depending on sensors which may be prone to external influences.

2.4. Limitations of SSLDTS and Suggested Solutions

The limitations of each SSLDTs are listed below, along with suggested techniques for bridging these limitations.

2.4.1. Limitations of External Leak Detection Technologies

a. Active acoustic method

- This method is sensitive to sound signal-shadowing, caused by subsea installations. To overcome this problem, more than one active acoustic sensor should be installed. In this way, false alarms caused by shadowing of the sound signal can be reduced by referring to the other installed active acoustic sensors. However, in addition to the high cost of detection methods in general mentioned above, the particularly expensive process of installing more than one or two sensors may prove to be a further financial limitation when considering this method.
- The active acoustic method generates large data, which affects the efficiency of data transfer. Developing computer software that can a) collect data more easily, and b) minimise this data without reducing its effectiveness, would be desirable, and would allow data to be transferred more efficiently.

Table 2.1: Comparisons of subsea leak detection methods

Leak detection technology	Sensitivity	Leak location detection	Availability	Detectable media	Maintenance requirements	False alarms	Cost
Visual	Yes	Yes	No	Liquid & gas	Medium	Low	High
Active / Passive acoustic	Yes	Yes	No	Liquid & gas	Medium	High	High
Optical Camera	Yes	Yes	No	Liquid & gas	Medium	Medium	High
Fibre Optic	Yes	Yes	Yes	Liquid & gas	Medium	Medium	Medium
Capacitance	Yes	No	Yes	Liquid & gas	Medium	Medium	Medium
Fluorescent	Yes	Yes	No	Liquid & gas	Medium	Medium	High
Biological Sensor	Yes	No	Yes	Not dependent on chemical compound	NA*	NA*	NA*
Methane Sniffer	Yes	No	No	Methane	Medium	Medium	Medium
Mass/ Volume Balance	No	No	Yes	Liquid	Low	High	Low
Real Time Transient Modelling	Yes	Yes	Yes	Liquid & gas (multiphase)	High	Medium	High
Pressure Point Analysis	Yes	No	Yes	Liquid	Medium	High	Medium

Where: Yes & Low = good ; No & High = not good; Medium = average; NA = Not Applicable

- Field experience and laboratory results show that false alarms are a common problem in active acoustic leak detection sensors. A complete elimination of false alarms is not possible, because of the subsea environment in which these sensors work, for example, marine life such as fish shoals causing false alarms, where keeping fish away from sensors would be both impractical and difficult. However, reducing false alarms can be achieved by following the suggested techniques discussed at the end of this paper.

b. Passive acoustic method

- Small leaks from subsea structures can be challenging to detect using the passive acoustic method. This is because the sound from small leaks is not strong enough to reach hydrophones. This, however, can be solved by identifying hot leak spots and installing hydrophones close to these locations.

- Background structure and production noises are another limitation of passive acoustic technology. False alarms caused by noises can be reduced by following the suggested techniques at the end of this paper.

c. Optical Camera Method

- The sensitivity of optical cameras is controlled by water conditions, such as turbidity. Therefore, the best way of solving this is to use a different type of detector, combined with optical camera sensors. This solution is further explained below.

- Biological growth on the optical lens is another limitation of this method. This can be solved by regular maintenance, depending on the level of biological activity around the installed optical camera detector.

- The requirement for a yellow background for oil detection is also a limitation. Whether or not this background is required should be decided prior to the start of any detection process, since in order to maximise efficiency in terms of time, cost, etc, installation should take place at the same time that optical camera sensors are installed.

- Field experience shows that using optical camera sensors can produce false alarms. However, false alarms can be reduced by following the suggested techniques discussed below.

d. Fibre Optic Methods

- The distributed acoustic sensor, as used in one fibre optic method, is sensitive to background noises. This can be reduced by using more than one sensor.
- The distributed acoustic sensor also requires direct contact with leaking material. As with the passive acoustic method, this limitation can be solved by installing sensors near hot leaking spots.
- Vessel anchoring is another limitation that could affect fibre optic cables. This can be solved by providing an appropriate form of protection, such as feeding cables through a pipe. Another possible solution is to create a map with all installed fibre optic cables highlighted, which should be referred to prior to any vessel anchoring activities.

e. Capacitance Method

- Installing a leakage collector above the structure to be monitored affects access to the capacitance sensor if maintenance is required or if the sensor needs to be replaced.
- As is the case with the optical camera method, sensitivity to water currents and turbidity can be solved by employing a type of leak detection method that is not prone to water conditions.
- Sensitivity to biological growth can be solved by regular maintenance.
- False alarms are known to be experienced using the capacitance method.

f. Fluorescent Method

- The optics used in this method are sensitive to biological growth, which can be solved by regular maintenance.
- Sea water current is another limitation. This can be solved by installing more than one sensor alongside the subsea structure to be monitored.
- Reduced visibility, due to the use of high fluorescence dye concentration, can be a problem.
- False alarms can be experienced when using the fluorescent leak detection method.

g. Methane Sniffer Method

- Water current was found to direct leaked gas away from methane sniffer sensors. This can be solved by installing more than one sensor, for example, one before the subsea structure to be monitored, and one after. This way, whichever the direction of the current, there is a good chance of detecting leaked gas. The number of additional sensors required will, however, depend on the size of the structure.
- As is the case with regard to other methods, false alarms are experienced.

2.4.2. Limitations of Internal Leak Detection Technologies

The most common limitations of internal based technologies include:

- System shutdown. This can be avoided by using external leak detection technologies.
- Expensive and complex pressure point analysis and real time transient models. This can be solved by using less costly and more simple external leak detection technologies.
- False alarms. Although these technologies are based on internal parameters, false alarms are experienced.

2.5. Techniques to Minimise Limitations

This section suggests techniques that should be followed to reduce common limitations of subsea leak detection technologies, such as false alarms.

2.5.1. Combining technologies

It is highly recommended that more than one type of detection sensor is used, which will increase the detection of real leaks, while reducing the number of 'false' leaks. For example, combining point sensors with area coverage sensors will ensure that both broad areas and 'hot spots' are monitored. However, the downside of combining more than one type of sensor is that it can be complex and unfeasible. Choosing the 'correct' combination, for instance, is imperative. Using the above example, the existing limitations of the active acoustic sensors used for area coverage may prove incompatible with the structure's requirements; and a more suitable method, such as that

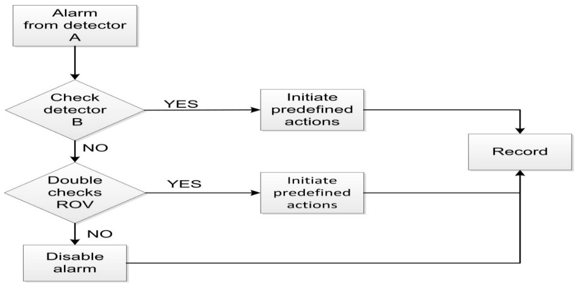

Figure 2.2: Best practice to confirm real leak alarms

which employs fluorescent point sensors should have been installed. Therefore, providing combining technologies is approached with due consideration, this technique is highly recommended. Due to the associated high cost, however, this technique may be best employed in areas that are particularly susceptible to leaks or that may prove especially vulnerable, for instance, environmentally, should leaks occur.

2.5.2. Best practice for confirming real leaks

Figure 2.2 shows a flow chart outlining simple steps to follow should an alarm be triggered:

- Alarm is received from installed detector A.
- Check detector B for confirmation. If a genuine leak is confirmed, predefined actions to deal with the leak should be initiated.
- If detector B indicates that there is no leak, a further check should be performed by sending an ROV to the suspected source of the alarm.
- If the leak is found to be real, predefined actions to stop the leak should be initiated. If the ROV check indicates no leak has occurred, the alarm should be identified as false and then disabled.
- Finally, both false and real leak alarms should always be recorded, since even data referring to 'fake' incidents can be used for future development of subsea leak detection technologies. It has been observed that there is currently a gap in leak detection data details relating to alarms, whereas it may be strongly argued that the best way to improve a technology is by looking at its performance record.

2.5.3. Staff training

Staff should be trained to a high standard in order to deal with subsea leaks. Training methods relying simply on employing manuals containing lists of procedures and protocols is not desirable when it comes to how subsea leaks and the impact on the environment are dealt with. Therefore, an effective training program should include the following:

- Staff should have a good understanding of the integrity of subsea structures and pipelines.
- A map should be made available of potential leak spots, especially if subsea structures are old.
- There should be a strict guide for confirming real alarms from false alarms. (An example is given in Figure 2.2).
- There should be predefined actions to deal with leaks after they occur. Staff should be trained in initiating these actions.
- Following training, staff should be given permission to take decisions quickly rather than waiting for managers to do so. Time can often be critical when responding to leak situations.
- There should be good communication between staff on different shifts; staff should make sure any issues regarding suspected leaks are communicated to members of the next shift during the changeover.

3. Conclusion

Subsea leak detection technologies and their characteristics have been the focus of this paper. Various leak detection technologies and methods have been examined, limitations identified, and solution to minimise these limitations suggested. From the information brought together in this paper and the review of the existing literature the following conclusions can be made:

- A number of different subsea leak detection technologies exist, involving a variety of physical principles and requirements. Therefore, selecting the best technology can be difficult. With this in mind, there is no single subsea leak detection technology that can meet all desirable

requirements of appropriate sensitivity, economic feasibility and freedom from false alarms.

- Combining more than one leak detection technology is a promising solution to some technologies' limitations. However, cost and complexity has to be carefully considered.
- Proposed solutions, such as a 'best practice' guide to confirming real leaks, and staff training, have the potential to reduce false alarms and provide guidance on appropriate and efficient responses to leaks.

Overall, it is concluded that existing SSLDTs need to be improved and developed to meet all functional requirements and operate with minimum false alarms.

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