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Subsea Leak Detection

– an Overview

Introduction

There is an increasing demand for oil and gas as a source for transportation fuel and energy, driven by the rapidly expanding energy needs of countries with expanding economies.

Affordable energy is a driver of economic growth and there is a close correlation between GDP growth and energy consumption. With the decline of the world's older oil fields, the push to find energy is moving the offshore market into deeper waters (with equipment being placed on the seabed) and into areas not previously explored, including Arctic waters (with long tie-backs).

Furthermore, there is a growing environmental awareness and concern for these important ecological regions. This concern is being translated into legislation which puts the focus on oil and gas companies to minimise the risk and impact of their operations and provide effective and reliable monitoring systems to avoid leaks and spills of harmful fluids.

Subsea pipelines and production systems are becoming a major concern globally as authorities are less tolerant to leaks of polluting material into the marine environment. The ability to detect and also locate any leakage of oil, gas or other contaminant to the surrounding water and environment is of utmost importance to safeguard a sustainable and healthy planet.

The problem

Operation of a subsea production installation is a great challenge and a high risk, with complex equipment and pipelines located at depths of up to 3,000 metres. For Arctic and environmentally sensitive areas, pipeline tie-backs of up to 500 km have been envisioned. Not only are the costs for deep sea installation high, but the risk for the environment is evident. Subsea leaks involving release of hydrocarbons or other chemicals into the sea could lead to environmental damage, fines and withdrawal of permits.

Lost oil production is the most significant financial impact of leaks facing offshore producers. Costs for repairing or replacing subsea equipment are enormous. Subsea intervention is costly and difficult in bad weather or under ice. The challenge is to detect and repair a leak before causing severe financial, environmental and ecological harm, and enable continued operations. In order to obtain permits, operators need to ensure they have a robust and effective plan to monitor leaks in pipelines and subsea equipment.

Although the industry has seen a reduction in reported leaks, there are still gaps to fill concerning the design, engineering and operation of leak detection systems. A lot of the early equipment is ageing. This means more leaks points and a higher risk of leaks and releases.

Leaks in subsea hydrocarbon pipelines and equipment

Reducing hydrocarbon releases (HCRs) is a priority for the offshore oil and gas industry and has been the focus of much effort. Statistics and reported experience find the majority of subsea leaks are at or near templates and manifolds. Critical components include connectors, flanges, seals, valves and welds and small-bore piping. Offshore pipeline technology is being advanced to accommodate Arctic challenges. Although Arctic pipelines are designed not to leak, high-bending strains due to ground movements could result in leaks.

Arctic offshore pipelines are subjected to many environmental loading conditions and potential failure mechanisms include fracture, burst, buckling, and fatigue. Arctic pipelines may be in remote locations and/or under seasonal ice cover; leaks must be minimised. Large leaks can now be detected using computational pipeline monitoring (CPM) systems, but small leaks may go undetected, especially when the pipelines are located in remote environments or under seasonal ice cover. In these cases, external leak detection systems (LDS) can augment CPM for increased, overall leak detection reliability. An effective external LDS can mitigate leak-risk to human life, the environment, reputation, and financials.

Natural gas pipelines deep under the sea are exposed to extreme cold. Salt water and corrosion also attack the transport pipelines. The subsea environment which involves low temperatures as well as high pressures, high water cuts and longer transfer times provide conditions that are ideal for hydrates and wax formation, and other solids deposits. To combat this, Mono-Ethylene Glycol (MEG) is often introduced into the pipelines as an antifreeze and anticorrosion agent. This decreases the hydrate formation temperature below the operating temperature, thus preventing hydrate blockage of the pipeline. The production fluid containing natural gas with associated condensate, produced water, and the injected MEG enters the production facility where the fluids undergo phase separation. MEG is delivered through small diameter pipeline in opposite direction to the production stream from the fixed tanks on the seabed or at topside. MEG sensors are being introduced as a leak detection solution in some parts of the industry, however these sensors have a slow response and need to be in close proximity to the leaking fluid.

Leaks in subsea control fluid lines and equipment

In subsea production, valve manifolds, hydraulic fluid accumulators and subsea control modules are installed on the ocean floor. Hydraulic Blow-Out Preventers (BOP) use specifically formulated water-based hydraulic fluids to control well operation and prevent dangerous blow-outs.

The importance of leak detection in hydraulic pipelines and control equipment is growing as this provides early warning of potential failure, and is required under production permit schemes. Although a number of LDS solutions are used, increasing water depth and long offset production as well as tightening environmental regulations mean that new technological solutions are required.

Environmental

New, precautionary environmental requirements mean establishing confidence that available technology and methods are adequate for new operating environments is essential. Technology development that focuses on avoiding creation of polluting substances rather than applying mitigating technology (such as clean-up or end of pipe treatment) are the priority. There is 'no tolerance' for releases, and major releases could have a significant impact on company reputation.

Technological State of the Art

Rapid and reliable leak detection and location are important aspects for safe subsea hydrocarbon development.

There are three stages to leak detection:

- Monitor
- Detect
- Validate

Installation of effective leak monitoring, detection and validation systems will help operators obtain permits and maintain flow assurance.

Leak Detection System technologies can be classified into internal or external systems. Internal systems use field sensor data to monitor internal pipeline parameters. The systems quickly detect large leaks, but have limited ability to detect small, chronic leaks. Internal leak monitoring system methods include pressure/flow monitoring, acoustic pressure wave analysis, mass balance (MB), pressure balance (PB), statistical methods, real-time transient monitoring (RTTM), extended RTTM, bubble emission method, pressure safety low (PSL) switches, and annulus monitoring in pipe-in- pipe systems.

Systems usually detect large leaks in 30 seconds and small leaks within 24 hours. Some internal detection systems also enable location information to be ascertained.

External systems measure physical properties around the pipelines. These include sensors for vapours, capacitance, temperature differentials, biosystem response, acoustic, fluorescence, optical, and fibre-optic cable methods. Some types are used as fixed point sensors and others are mounted on ROVs/AUVs/towed systems to patrol for leakage.

External leak detection systems can quickly detect and locate small leaks below the minimum thresholds of internal LDS, and provide information for risk mitigation.

Historically, two main methods of external subsea leak detection have been used where obvious visual signs of leaks such as bubbles, large clouds, etc. are not present.

The main methods generally used are: In situ fluorometric measurement AND acoustic listening.

Fluorescence Detection

Until fairly recently, the most successful method of detecting leaks has been the use of fluorescent dyes detected by 'black light' (unfiltered ultraviolet light) with visual observation either directly by diver or by underwater camera.

The major problem with this method is that the dye concentration has to be high to allow visual observation and general visibility must be good. Deploying submersible 'tuned' fluorometers that include an excitation and detection unit and that send data up to the attendant vessel providing a real time visual display has solved many of the problems. These submersible fluorometers are very sensitive and will detect dye at concentration so low as to be invisible to the naked eye or underwater camera.

Because hydrocarbons and some hydraulic fluids have specific fluorescence signatures, they can be targeted by a fluorescence detector. However where subsea control systems or hydrostatic testing are concerned, fluorescent dye is normally added as a component solely for the purpose of leak detection.

Until recently, there was a choice between wide area detection of a leak or accurate location. For example a narrow beam (e.g. from a laser) is long-range, sensitive and accurate, but would require accurate aiming to ensure all possible locations of a leak plume were scanned. It would be possible to completely miss a leak depending on tidal flow etc. If the light beam and sensor field of view is wide e.g. a broadly focused LED lamp, then the sensor would have a wider spatial coverage, but would be shorter range and difficult to pinpoint a leak location.

Neptune Oceanographics has recently introduced their 'Long Ranger' system. The 'Long Ranger' sensors have two forward facing ' tuned' light sources (like two torches) each producing separate beams of excitation light. Fluoresced light generated in the leak fluid is detected by a sensor mounted between the two light sources. A wider angle beam detects the presence of dye and a general direction in relation to the ROV while a narrow intense beam allows a more detailed inspection to determine the leak location.

Because the sensors have wide spatial coverage, quick and easy scanning for leaks is achieved by mounting the sensor on the ROV manipulator and without needing to consider tidal flow direction to 'capture' dye. Leak detection system output is graphically displayed on an onboard PC. This displays data in a colour time series plot in real time allowing the operator to easily see changes in signal that indicate the presence of a leak. The software also allows the user to set alarm levels. The 'Long Ranger' can also detect leaks in risers while working at safe distances and within confined structures where ROV access is not possible or too hazardous.

Problem with the use of tracer dyes

There has already been a move to phase out Fluorescein, the most commonly used dye, as it no longer complies with the latest legislation for discharges at sea. Other tracer dyes such as Castrol's UV clear dye, Champion Clear dye and the Roemex 9022 red dye have been developed and tested to demonstrate their compliance with the latest legislation (often referred to as OSPAR 2007 Compliant) and are now widely used. These tracer dyes fluoresce in the same manner as Fluorescein but at different excitation and emission wavelengths.

Acoustic leak detection

Acoustic leak detection (ALD) systems use hydrophones (underwater microphones) that 'listen' for ultrasound generated by leaking fluids under pressure.

The acoustic signals generated by a leak tend to be at frequencies well above the audible range, i.e. above 20kHz, thus requiring sophisticated sensors and software to reliably determine the difference between leak generated and ambient 'noise'. The major problems with this method are the sounds caused by the attendant (ROV) and other vessels in the vicinity. Thrusters and manipulators are constantly moving during subsea operations causing highly variable acoustic signals to be generated over a wide spectrum.

These signals are additional to any leak-generated sound. It has been difficult, therefore, to differentiate an acoustic leak signal from these other sources and, for this reason, it has not been frequently used as a mobile sensing method. Instead acoustic sensing is commonly used for fixed leak detection sensing, e.g. by mounting hydrophone arrays on subsea equipment. However, modern data handling and spectral analysis techniques have improved the method sufficiently such that in the right conditions the method can be very successful.

Combined sensors

The DNV recommended Practice3 suggests that it is not anticipated that a single technology/principle would be able to detect all of the possible leaks in all possible environments, and that combining two or more types of sensor may provide more confidence in the overall leakage detection system.

It recommends that complementary sensor technologies should be selected to compensate for the respective weaknesses and enable indication of a leak event from one sensor type to be confirmed by positive indications from the other sensor type.

For example a fluorescence sensor can be combined with an acoustic sensor to provide multi-sensor leak detection to enhanced detection probabilities with lower false alarm rates. Neptune Oceanographics have successfully deployed their acoustic leak detection system worldwide for a number of years, often in tandem with their optical fluorescent system. The system, which may be diver-held or mounted in a ROV manipulator, incorporates a directional hydrophone. It is likely that a modular, multi-sensor approach will be the optimum solution as it can be configured to suit local requirements of operators and environments. This will provide a more assured leak detection and location before commencing costly shutdown or further investigation activities.

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