Permanent Underwater Leak Detector

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Abstract
A new optoelectronic sensor for the real time monitoring of key components such as valves and connectors within the subsea production equipment for leaks of hydraulic fluid is reported. The sensor is capable of detecting low concentrations of such fluids, allowing the early detection of small leaks, and the ability to monitor the evolution of the leak-rate with time, hence providing an important new tool in complying with environmental requirements, enabling early intervention and optimising subsea production.

1. Introduction
There are hundreds of subsea hydrocarbon production installations currently in situ globally. As the focus of exploration in the oil and gas industry moves into deeper water, the number of subsea installations will continue to grow. The control and monitoring of the subsea equipment is therefore increasingly being done remotely over ever greater distances. Consequently there is a growing requirement for improved systems for both controlling and monitoring components of the subsea hydrocarbon production system.

A subsea hydrocarbon completion system is typically made of a combination of major components, such as Xmas Trees (XT), manifolds and Subsea Processing Systems (SPS), as illustrated in Figure 1. The XT is attached to a wellhead situated on the seabed. The XT consists of a combination of different flow lines, chokes and valves that allows the operator topside to directly control the production flow from the reservoir. The XT is also used for injecting chemicals down hole and as a facilitator for the operator during well work over. If multiple XT's are used in a field, a manifold can be integrated into the completion system to control the production from the XT's. In systems where an SPS is used, the production fluid is separated before being lifted to the surface. The Manifold and SPS are used by the operator to increase the production efficiency from the reservoir and as a cost saving measure; the manifold reduces the number of long flow lines required, the SPS removes unwanted fluid, which causes back pressure, and therefore increases production rates.

As field development moves into deeper water the subsea equipment has to withstand conditions which are more extreme. The regulatory authorities are tightening legislation to prevent the release of polluting materials into the marine environment, and the control and monitoring of installations is becoming more remote. With these factors in mind, there is an increasing demand for an effective and reliable monitoring system capable of detecting, characterising and quantifying leaks from subsea installations.
When designing subsea equipment there are rigorous standards that must be adhered to, however there are locations on subsea equipment which have a higher probability of a leak occurring, such as a valve or flange. A typical location is depicted in Figure 2, which shows a cross over valve (XOV on the picture) in a Xmas Tree. Effective techniques to monitor such components for leaks are therefore highly desirable, both to enable operators to comply with environmental legislation and to enhance overall customer operation. Existing approaches to such permanent leak monitoring have been based on acoustic [1], capacitive [2] and video inspection [3], all of which have been of limited effectiveness. The principle drawbacks of such systems relate to the physical size of the sensor restricting their ability to be located on critical components, cost and background interference, for example noise from production activities often rendering acoustic systems ineffective. There is thus a need for a new and improved sensor for leak monitoring of critical components of subsea systems.

Figure 1: Subsea Completion System

Figure 2: Cross over valve on a Christmas tree
2. Subsea optical fibre permanently installed leak detector

The approach described in this paper to overcome the limitations of existing leak detection sensors centres on the use of the intrinsic fluorescence of the hydraulic fluids within the subsea system. The new sensor is based on an optical fibre probe capable of detecting leaking materials from subsea XTs and SPS in real time. The small size of the sensor probe makes it highly suited for locating directly onto key locations on the XT/SPS, such as those shown on Figure 2. In contrast with existing permanent leak sensors, which work by detecting secondary features such as noise, the fluorescence approach will provide direct detection of the leaking material. Further, the system will offer the potential to assess the quantity of the material leaking. This will allow the potential to not only detect leaks, but monitor their growth, via the amount of material being discharged. This may allow informed decisions on the appropriate time for repair of the leak to be made and the likelihood of component failure to be assessed.

The optical fibre leak sensor comprises an optoelectronics module connected to one or more optical fibre probes. The optical probe comprises a cable containing an excitation and detection optical fibre, which connect with an optical fibre coupler to form the sensing probe, as shown schematically in Figure 3. This 2 fibre geometry within the probe allows individual sensor fibres to be located at opposite side of a key component to be monitored, thus enhancing the probability of detecting any leak. Excitation light from a 12 mW LED centred on 400nm, is launched into the excitation fibre. The excitation light emerges from the far ends of the fibres in a cone determined by the numerical aperture of the fibre and the refractive index of the sample. A fraction of the resultant fluorescence induced in the sample is collected by both of the fibre ends. The collected fluorescent light is conveyed back down the optical fibres via the coupler to a spectrometer configured to detect light at the appropriate fluorescence wavelength, the output of which is connected to a data logger or computer. In operation the measured signal at the central fluorescence wavelength is logged.

![Optoelectronic sensor set up](image)

**Figure 3: Optoelectronic sensor set up**
4. Hydraulic Fluid Fluorescence

MacDiarmid HW443 R, a typical hydraulic fluid used in subsea systems, was used in the initial testing of the leak detector system. This hydraulic fluid is used as part of the control system of an XT. Pressurised control lines, contained in the umbilical, transport the fluid from topside to the subsea equipment in order to control the choke and actuators, which in turn control the production flow. As a first step in producing a leak sensor for this fluid, the fluorescence spectra of the fluid was examined using the optical fibre fluorescence sensor running in full spectral analysis mode. The measured fluorescent spectrum for this fluid for excitation with a 400nm centred LED is shown in Figure 5. From the figure it can be seen that the fluid exhibits a fluorescence spectrum in the range 540nm to 640nm, with the spectral peak found at approximately 582nm.

![Figure 4: Fluorescent Spectrum from HW 443 R](image)

The system was then configured to log the 580nm fluorescence from the sample and the response to different concentrations logged, the results are shown in Figure 5. For these tests the original stock MacDiarmid HW443 R was diluted in various amounts of water. From this figure it can be seen that the system has a linear relationship between the magnitude of the detected signal and the concentration over the concentration range 1- 100% examined, with the system readily capable of detecting the 1% solution. This lower concentration detection capability coupled with the small size of the sensor head and the ability to locate the sensor directly on the component to be monitored makes the system highly suited to detecting leaks on such subsea components.
5. Conclusion

The optical fibre based sensor has been shown to be capable of detecting in real time a typical hydraulic fluid used in subsea control lines. The system has been shown to be able to detect hydraulic fluid concentrations ranging from 100% to 1% of the original stock, hence allowing the detection of both large and small leaks. The detection range when combined with twin sensor head sensing geometry and small physical size of the heads, lends itself to the tree design where the sensor can easily be located onto key components. The twin sensor head design increases the detection area around the component, therefore enhancing the of leak detection. From the initial results it appears that optical fibre sensor described may provide a viable solution for permanent subsea leak detection on XT and processing systems.

6. References

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