An optical sensor for the detection of leaks from subsea pipelines and risers

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Abstract. An optical sensor for the rapid detection of detect leaks of oil, hydraulic fluids or leak detection chemicals from underwater pipelines and risers is reported. The sensor is designed to be deployed on ROVs or AUVs for the rapid survey of underwater pipelines and risers. The system employs ultra-bright LEDs to project a sensing light beam into the water to allow real time detection of ppm concentration plumes of material leaking from pipelines or riser in real time. Typically the system is deployed on an ROV which inspects a pipeline at a height of 2-3m.

1. Introduction

Subsea pipelines, risers and umbilicals are vital components in offshore hydrocarbon production, transportation and processing. Globally there are many thousands of miles of such installations containing crude oil, hydraulic fluids and production chemicals. Ensuring the integrity of these installations is a major challenge for the industry, which with the increasing environmental awareness and legislation is becoming ever more important. In particular it is important to minimise leaks of polluting material such as crude oil and hydraulic fluids into the marine environment. In operation subsea pipelines risers and umbilicals are subjected to a range of potentially damaging factors including elevated temperatures and pressures, abrasive components such as sand in the production fluids, salt water, ship anchors and tectonic movements of the sea bed. Given the harsh marine and internal production flow environments experienced by such installations it is not surprising that component failures leading to leaks are an all too common occurrence.

Most oil company operators run an annual inspection of their subsea installations as part of a routine maintenance procedure. A key objective of such inspections is the early detection of leaks. In addition changes in the pressure detected within a pipeline section, which may indicate a potential leak, can also instigate inspections. The deployment of inspection ships and subsea remotely operated vehicles for such inspections is very expensive. There is thus considerable interest in techniques that can be employed both as part of planned inspections and for those actioned by suspected leaks and which offer the potential to significantly reduce the inspection time.

Fluorescence forms the basis of one of the most widely used and effective approaches to subsea installation leak detection. This often involves the use of a fluorescent tracer or label that is added to the subsea structure, such as a pipeline. However in many applications, such as those involving hydraulic lines, the hydraulic fluid may itself contain a fluorescent component. For pipelines containing oil the intrinsic fluorescence of the oil can be used to aid the detection of a leak (1-3). A number of methods for detecting the leaking fluorescent fluid for these situations have been developed. These include visual observation by a diver or via cameras, sometimes aided by a Black
light. Such observational techniques are however only useful for very large leaks. Subsea fluorimeters provide a more sensitive detection system and offer the potential to reduce the quantity of dye needed to effect leak detection. Although highly sensitive, with ppm detection levels being typical, existing subsea fluorimeters are almost exclusively point sensors that are only able to perform measurements in a small volume of water immediately adjacent to the instrument, typically within a few centimetres (4-8). For subsea inspection this means that the fluorimeters have to be placed in the plume of fluorescent fluid emanating from a leak in order for it to be detected. Consequently the ROV on which such a fluorimeter would be deployed during an inspection has to be brought very close to the subsea structure. As well as increasing the risk of damage to the ROV and pipeline, such manoeuvring impedes the speed of the inspection. There is thus considerable interest in new leak detection devices that overcome these problems and allow increased inspection speeds.

In this paper a subsea fluorimeter that allows remote detection of fluorescent material is described along with results from testing of the system when deployed on an ROV for leak detection.

2. Remote Fluorescence Sensor
To provide enhanced and faster leak detection during inspections using ROVs or autonomous underwater vehicles (AUVs) it is necessary to have real time ppm detection capability over a large volume of water at a range of several meters from the instrument. Such a sensing volume and range will allow the subsea vehicles, on which a sensor is deployed, to remain at a safe distance from the underwater structures to be inspected and hence to be manoeuvred at higher speed.

![Figure 1: Schematic of the subsea fluorimeter for leak detection](image)

The remote sensing subsea fluorimeter system developed to allow enhanced detection of leak plumes of ppm concentration at ranges of 2-5m is shown schematically in figure 1 (9). In the system remote sensing of plumes of fluorescent material emanating from underwater structures, is performed using an LED array (470nm), interference filter (470nm, bandwidth 40nm) and lens arrangement located within the excitation unit, to project a cone of amplitude modulated light onto and around the subsea structure. This light is at a wavelength close to the absorption band associated with the fluorescence emission of the leaking material or a fluorescent tracer injected into the structure. The excitation unit also contains electronic control circuitry for controlling the supply of electrical current to, and for stabilising the optical power of, the LED array. These components are located in a water-tight corrosion-resistant subsea housing which has a depth rating of 2000m and an optical window at one end.

A similar subsea housing is used for the separate detector unit. The detection unit comprises a lens system for collecting the fluorescence produced in the excitation cone, followed by a spectral filtering system (520-570nm) to select only the fluorescence from the target fluorescent species and a photo-detector. The resulting signal from the photo-detector is processed using a digital signal processing unit which provides an output corresponding to the intensity of fluorescence detected. As the
measured fluorescence intensity is related to the concentration of the target material in the water occupied by the excitation beam, the system is able to provide an immediate indication of likely leak locations. The system also allows a concentration map of the detected target fluorescence to be generated. In this way as an ROV navigates along, for example a subsea pipeline, an altitude of typically a few meters, with the excitation cone of light directed onto the pipeline, it may be efficiently monitored for leaks.

The signal processing unit output signal is transmitted to the topside data logging system via a communications interface located within the detection unit. The processing system also includes a feature to allow for measurement of the output characteristics of the excitation system and perform relevant corrections. The topside data logging software provides a visual indication of the fluorescein concentration and logs all the data. The software also allows alarm thresholds, corresponding to concentrations of fluorescent material that would be higher than background and indicative of a location close to a leak, to be set. When used on a ROV this feature can be employed to provide a simple audio alarm whenever the unit detects high concentrations. This allows the operator to fully focus on flying the ROV and not have to be distracted by watching for concentration levels. This in turn makes the inspection both safer and faster.

3. System Testing
The remote sensing capability of the subsea fluorimeter is illustrated in figures 2 and 3. Figure 2 shows measured response of the system for a 500ml target of 1ppm fluorescein (Acid Yellow 73) in water for varying ranges in air. In the graph the background signal has been normalised to zero. From the figure it can be seen that the system is able to detect this target in real time at ranges up to 9m. Figure 3 shows the measured variation in the output signal with distance in water for the same 1ppm 500ml fluorescein (Acid Yellow 73) target. From this figure it can be seen that the system is capable of detecting this low concentration target at ranges of 3.5m in water in real time.

![Graphs showing response of the subsea remote sensing fluorimeter system](image-url)

**Figure 2**: The response of the subsea remote sensing fluorimeter system for a 500ml target of a 1ppm concentration of fluorescein (Acid Yellow 73) in water at increasing ranges in a) air and b) water.
The current excitation source and detection filters are suitable for a range of fluorescein based leak tracers and fluorescein labelled hydraulic fluids. With suitable selection of alternative filters in the detection system a still wider range of common leak detection and hydraulic fluids can be effectively detected.

The utility of the system for leak detection applications on subsea risers with an ROV was tested in a series of tests in an ROV testing facility comprising a water filled tank approximately 13m in diameter and 15m deep. A 15m length of 12inch pipe was suspended vertically in the centre of the tank to mimic a riser. Two 500ml targets of fluorescein dye in water, one of 1ppm and one 100ppm concentration were attached to the pipe to simulate leak plumes. The remote sensing fluorimeter was mounted on a test ROV, as shown in figure 3. The ROV was then manoeuvred around the tank at varying ranges from the pipe section and the fluorimeter beam directed at the pipe. Figure 4 shows a typical result when the ROV was at a range of 3m from the pipe section and manoeuvred up the pipe section. As can be seen from the figure a pronounced peak is produced when the light cone coincides with the 500ml target. The secondary peaks observed in the trace are due to turbulence induced oscillations in the attitude of the ROV.

Figure 3: The subsea remote sensing fluorimeter mounted on an ROV for testing
The results of the tests described above demonstrate the capability of the subsea remote sensing fluorimeter to detect very low concentrations of fluorescein remotely from the unit itself. This ability to effectively, stand-off from subsea structures, while rapidly and accurately detecting fluorescence from target materials, such as fluorescein, facilitates subsea inspections, as it allows the ROV or AUV to be manoeuvred quickly and safely over the structure to be inspected, with minimum chance of collisions. The remote sensing ability is also a useful tool in probing complex subsea structures, were it would be extremely difficult, if not impossible to use conventional subsea fluorimeters. The large volume of water over which instantaneous detection is performed further enhances the suitability of the system, as it both increases the probability of detecting the fluorescein plume emanating from a given leak and also reduces the skill necessary to ensure that the beam is directed at the target. The system has been subsequently been successfully deployed on a number of subsea integrity and leak detection surveys in the North Sea, Gulf of Mexico and Atlantic.

4. Conclusions
The capability of the subsea remote sensing fluorimeter system to remotely detect extremely low (ppm to ppb) concentrations of fluorescein and a range of other common leak detection chemicals and hydraulic fluids, combined with the large volume of water over which the measurement is performed, makes the system highly suited to subsea inspections with ROVs or AUVs. The system has been successfully used in real subsea survey applications and has been found to be effective, user friendly and to dramatically reduce inspection times and hence costs.

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