Use of fibre sensors for temperature measurement in subsea infrastructure to monitor flow-loop cool-down

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Abstract. The interest in using optical sensors as replacements for typical electrical sensors in the oil and gas industry has increased as the potential benefits and reliability of such technologies become more established. Presented here are the results from initial tests using optical temperature sensors to monitor the effectiveness of subsea tree insulation to retain heat within the flow-loops of a Christmas Tree to prevent hydrate formation during system cool-down. Initial tests were carried out to compare the optical fibre sensor performance with traditional electrical thermocouples. Suggestions for future development and future tests are also presented and discussed.

1. Introduction
The use of insulation within the oil and gas industry to provide heat retention capability in the event of a flow-line shutdown is important to reduce the risk of hydrate formation within the flow-loops in the subsea infrastructure. Such formations can produce potential blockages in the flow-loops and are generally avoided where possible to maintain flow assurance. During system cool-down the elevated temperature of the Christmas Tree will begin to equalize to the ambient subsea temperature and insulation is provided to ensure that hydrate formation temperatures are not reached for a minimum of eight hours. It is important for operators to understand the time taken for such temperatures to be reached to ensure they manage the production field correctly to avoid the risks of hydrate formation. Hydrates are important for an operator to avoid since they can reduce the flow rate of the oil/gas, hence having a negative impact on profitability. Of equal importance is that they can introduce safety risks if formed in critical components in the production infrastructure (i.e. formation in safety valves could prevent these valves closing in the event of well blow-out etc.). An example of a subsea tree with associated insulation on the flow-loops and critical components is shown in figure 1.

The control of subsea production systems and their associated equipment has increased demand for communication bandwidth and brought about the concept of using optical sensing technologies in applications currently dominated by electrical sensors. Optical fiber can provide a high-speed, noise immune, and environmentally stable communication link coupled with the added benefit of providing a range of optical sensor heads to measure temperature, pressure, flow, leak detection, etc. Fibre optic temperature sensors have been developed and researched for a number of years with their characteristics being well established and understood [1-4] suggesting they could provide an alternative sensing technology for harsh subsea environments.
Optical sensors offer significant advantages for such subsea applications due to their small package size and robustness to the harsh subsea environment since systems are required to be specified for 25 years in such applications. Although electrical sensors can provide similar results they are susceptible to corrosion and require suitable insulation from the harsh marine environment to prevent degradation. If multiple electrical sensors are to be placed under insulation on subsea structures electrical cabling would become cumbersome due to the requirement to shield the sensors from the environment, compromising the effectiveness of the insulation and potentially degrading performance. The robustness and small size of the optical fibres require no additional protection, making them more suitable for multiple temperature measurements under such insulation, with no loss of insulation performance. This would result in a compact system, suitable for the field lifetime of 25 years that could be used for continuous monitoring of the flow-loop temperatures to optimise production flow and maintain safety.

![Figure 1 Example of a subsea tree with associated insulation (shown in white).](image)

Presented here are the initial results of a study to determine the suitability of using optical sensors to monitor the effectiveness of insulation used on subsea Christmas trees to retain heat and ensure minimal rate of cool down. These optical sensors have the potential added benefit of having much lower thermal mass (and therefore won’t bias the measurement when compared with electrical sensors); they are EMI noise immune which means they can be used in subsea applications in the presence of the numerous pumps and subsea equipment being employed.

2. Sensor Operation
The fibre sensors used in this work were T1 temperature probes from Neoptix and interrogated using the Omniflex multi-channel monitoring system. The T1 temperature sensor is made from a GaAs semiconductor crystal at the end of a length of optical fiber as illustrated in figure 2. The end of the probe is then bonded with a dielectric mirror and the entire assembly is then coated in Teflon for protection in harsh environments. The opposite end of the probe is terminated with a ST fibre connector which is used for connection to the Omniflex interrogator. A broadband light source is injected down the fibre where some light is absorbed by the GaAs crystal and then reflected by the dielectric mirror. The wavelength of absorption is dependent on the temperature of the crystal and can be accurately characterized to gain a measurement of temperature. These probes provide point
temperature measurements which can be targeted at areas of interest around production equipment and infrastructure. These sensors would be suitable for subsea deployment where the design life is 25 years. The harsh environment surrounding subsea structures would cause corrosion and failure if electrical sensors are used whereas the components of the optical probe (crystal, dielectric mirror) will be immune to corrosion and are in general more resistant to the subsea environment making them more suitable long term deployment.

![Figure 2 Probe construction.](image2)

3. Experimental Procedure
A section of flow-pipe was insulated with typical production subsea insulation to retain heat and prevent conditions where hydrates may form in the flow-loops. A fibre optic temperature sensor was mounted inside the insulation and bonded to the exterior of the flow pipe and a second sensor placed on the exterior wall of the insulation layer as shown in figure 3. Comparison thermocouples were also mounted on the interior of the insulation to provide information on the thermal performance of the experimental system. The thermocouples data was acquired by a National Instruments NI9211 module with USB carrier with the results logged using Labview. Figure 4 shows the physical setup in the laboratory.

The pipe was filled with water and heated to 80°C (which is typical temperatures realised in some producing wells) and data acquisition started once a steady temperature was reached. A thermocouple was placed in the water contained in the pipe to monitor the internal water temperature and the top of the pipe sealed to retain the heat. Data was collected for 16 hours with the sensors monitoring the temperature changes over time with no manual intervention. The time taken for the water contained in the pipe to reduce to ambient temperature will give an indication of the thermal efficiency of the insulation material and provide valuable information for oil and gas operators who rely on such insulation during the operation and control of their fields.

![Figure 3 Experimental set-up and location of sensors during tests.](image3)
4. Experimental Results

Data collected from the fibre temperature sensors along with comparative data from thermocouples are shown in figure 5. This shows the temperature measurements taken with each of the sensors plotted as a function of the actual time of measurement. The experiment was run overnight from 15:30 to 07:00 as shown on the x axis in figure 5.

Figure 5 shows the results from the fibre optic sensors placed on the internal wall of the insulation and the external wall of the insulation. The temperature measurement on the external sensor begins at ambient temperature and rises as the heat from the pipe is conducted through the insulation. The temperature then falls and equalises with the internal fibre sensor as the assembly cools down to ambient conditions. The temperature measurement internally to the insulation reaches ~78°C and then falls to almost ambient temperature. Results show that the time taken for the internal temperature within the insulation to fall by 50% to ~40°C was 8 hours with a further 6 hours to fall to ambient temperature.

The thermocouple results are also shown in figure 5 and illustrate that the temperature along the length of the pipe in the experimental system falls as position up the pipe increases (i.e. more heat is lost at the top of the experimental system than in the centre). The overall temperature readings agree well with the measurements gained using the fibre sensors where both sensors are co-located on the same section of pipe. This illustrates that results from the fibre based system are comparable with those gained from the electrical sensors in such an application which illustrates that it does have the potential to replace such electrical sensors in these applications.
5. Conclusions

Initial attempts at using fibre temperature sensors to monitor flow-loop temperatures during system cool-down have shown that optical sensors have the potential to replace electrical equivalents. Such optical sensors could be mounted continuously along the flow-loops on subsea structures and provide valuable control information for efficient running of an oil or gas field which should increase efficiency and reduce the risk of hydrate formation or workover being required.

The results presented in section 4 show that the temperature measurements gained using the fibre system match the thermocouple results well. Further work will be required to continue testing of fibre sensors for temperature measurement of Christmas Tree flow-loops with further tests being carried out during production to mount a multiplexed temperature sensor system under the insulation layer and measurements of temperature taken with underwater ambient conditions.

These tests illustrate that fibre sensors could provide an alternative solution to temperature measurement for subsea monitoring and can be used in noisy environments where subsea machinery is present. Such sensors could also be used in surface applications where this is a risk of explosion when using electrical equivalents since such optical sensors are passive devices and can be remotely interrogated. As the adoption of fibre sensors in the oil and gas industry increases, the number of potential applications for process control and monitoring will increase, providing a large potential market for such sensor systems.

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