Fiber Optic Cable Pipeline Leak Detection Systems for Arctic & Cold Region Applications

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Outline

- Who we are
- Experience with Arctic leak detection systems
- Arctic pipeline leak detection challenges
- Fiber Optic Cable DTS and DAS
- Principles of operation
- Key technology gaps
- Arctic Leak Detection JIP
- Summary
Significant undiscovered oil & gas reserves remain in the Arctic
Demand for oil and gas will continue to drive Arctic development
Unique Arctic environment presents technical challenges
Reliable Arctic operational strategies are needed to reduce risk
Rapid and reliable leak detection is an important aspect of safe and economic hydrocarbon development in offshore Arctic/cold regions
Pipeline Leak Detection Systems

- Conventional flow-based pipeline monitoring systems (mass balance, transient pressure wave, acoustic detection)
- Airborne and marine surveillance
- Leak detection procedures under winter sea ice
- External monitoring systems (FO cables, LEOS, point source monitors)
- Remote sensing systems (airborne infra-red, radar, satellite, visual, smell)
- Other systems based on pipeline configuration

Preferred Subsea Leak Detection System Features

- Continuous operation
- Rapid detection of sub-1% leaks
- Independent of flow conditions
- Cost-effective, constructible & installable
- Minimal false alarms
- Long (>15 miles) pipeline coverage without intermediate power requirements
- Installable in Arctic conditions
- Proven performance in Arctic conditions
Arctic Pipeline Leakage – Potential Causes & Consequences

Causes

- Unique Loading Conditions
  - Buried Pipelines
  - High bending strains
  - High differential Temperature
  - Ice gouging, thaw settlement, strudel scour, etc.
- Pipeline connections, valves, fittings, etc.
- Structural degradation
  - Corrosion, erosion
  - Fatigue cracking
- Other issues
  - Span, VIV, buckling, rupture

Consequences

- Safety
- Environmental
- Economical
- Negative reputation

Exacerbated by remoteness

Structural Degradation - Corrosion

Compressive pipe buckle failure
INTECSEA Experience with Leak Detection Systems

Beaufort Sea Pipeline Projects:

BPXA Northstar (installed 2000)
- Oil Transmission lines: Mass Balance, Pressure Balance, LEOS
- Gas transmission lines: Mass balance, Pressure Balance

Pioneer Oooguruk (installed 2007)
- 3 Phase Production flowline: Pressure Balance, PIP annulus monitoring
- Water injection flowline: Mass Balance, Pressure Balance
- Gas Injection Flowline: Mass Balance, Pressure Balance
- Seabed erosion: Distributed temperature sensing (DTS)

Eni Nikaitchuq (installed 2009)
- 3 Phase Production flowline: PIP annulus monitoring, PSL
- Water injection flowline: Mass Balance, Pressure Balance
- Gas Injection Flowline: Mass Balance, Pressure Balance
- Seabed erosion: Distributed temperature sensing (DTS)
Arctic Leak Detection Challenges

- Buried pipelines conveying multiphase flows
- Seasonal ice cover
- Installation and maintenance challenges
- Subsea equipment and power requirements
- Uncertain minimum thresholds of detection for buried lines
- Remote maintenance, performance monitoring and control
- Potential for false alarms
- Background noise reduction
- Uncertain operational reliability in Arctic
- Temperature and slack line issues
Distributed Temperature Sensing (DTS)
- Oil leakage leads to local rise in temperature
- Gas leakage leads to local cooling
- Raman band systems
- Brillouin band systems
- FOC itself acts as the sensor and data link

Distributed Acoustic Sensing (DAS)
- Acts as a hydrophone
- Captures acoustic signature (i.e. vibration) generated by leaking fluid
- Signal/frequency separation
- Rayleigh band systems
- No need to contact fluid with FOC sensors
When a short pulse of light is emitted, a proportion of the outgoing signal is scattered back to source due to impurities or defects in fiber microstructure.

**Distributed Temperature Sensing**

**Raman DTS System**
- Backscatter signal intensity-based system
- Measures local change in temperature

**Brillouin DTS System**
- Converts temperature effects on cable into frequency shifts of backscattered light
- Insensitive to the fiber attenuation changes over time and distance

**Distributed Acoustic Sensing**

**Rayleigh DAS**
- Measures minute strain effects on sensor
- Strain is caused by acoustic vibrations
- Acoustic waves modulates the backscattered signal.
- Cable pick up the acoustic signals, and when a distinguishable signature is detected, an alarm is triggered.
FOC Distributed Sensing Leak Detection System Components

Typical DTS Cable
1. HDPE outer sheath
2. Galfan high strength steel wire
3. Gel-filled metal loose tube SS 316L
4. Bend insensitive optical fibers

Typical DAS Cable
1. PA Outer sheath
2. Stainless steel 316 L metal tube
3. Inner interlocking system
4. Multilayer acoustic coupling layer
5. Bend insensitive optical fiber
Technology Gaps

- False alarm reduction
- Reliability of systems
- Minimum thresholds of detection
- Long pipeline application
- Cable positioning
- Leak size quantification
- Technology readiness
- Few Arctic project applications

Northstar Pipeline (BP Alaska)

Ooguruk Pipeline (Pioneer Natural Resources)
INTECSEA JIP

- Testing of Fiber Optic Cable Distributed Sensing Leak Detection Systems for Arctic and Cold Region Applications
- Managed by Petroleum Research Newfoundland Labrador (PRNL)
  - Not-for-profit corporation that funds and facilitates collaborative R&D on behalf of Newfoundland and Labrador’s offshore oil and gas industry.
- Lead by INTECSEA
- Governmental and Industry funding
- Phased Development
  - Phase 1: finishing 2014
  - Phase 2: 2015 -2016 (planned)
- No comprehensive full scale testing has been reported in the public domain for FOC subsea Arctic applications
- Purpose of this JIP is to help close the technology gap
Test detectability limits
- Determine minimum thresholds of detection (leak rate and response time)
Help advance the technology readiness level
Simulate cold-region environmental testing
Identify/quantify false alarm rate
Phase 1 Objectives
- Planning, design and costing to establish the basis of the testing program (in Phase 2)
- Develop experiment setup, test matrix and procedure,
- Phase 2 test organization and execution plan,
- Cost and schedule
- This will allow Phase 2 to proceed with greater confidence in the execution, cost and schedule associated with the FOC LDS experiment program
Phase 1 Objectives

- **Design**
  - Test Tank Design
  - Overall Experimental Setup

- **Planning**
  - Test Procedure
  - Execution Plan

- **Cost**
  - Develop Cost and Schedule for Phase 2

Phase 2 Testing
Outline desired test parameters

Particular consideration is given to testing of a long FOC length (40km), moderate test pipe length (20m) and a low ambient temperature (4°C / 1°C)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipeline Length</td>
<td>2m – 20m</td>
</tr>
<tr>
<td>Water Depth (max/min)</td>
<td>100m / 1500m (simulated)</td>
</tr>
<tr>
<td>Pipeline OD</td>
<td>12” (324mm)</td>
</tr>
<tr>
<td>Concrete Weight Coating Thickness</td>
<td>25.4mm (1”)</td>
</tr>
<tr>
<td>Fluid Type (oil/gas)</td>
<td>Water and Nitrogen</td>
</tr>
<tr>
<td>Pipeline Design Pressure</td>
<td>5800psig</td>
</tr>
<tr>
<td>Pipeline Operating Temperature</td>
<td>0 to 50°C</td>
</tr>
<tr>
<td>Ambient Temperature</td>
<td>4°C (with potential of testing 1°C)</td>
</tr>
<tr>
<td>Burial</td>
<td>Non-buried and 1m burial cases</td>
</tr>
</tbody>
</table>
Test Hierarchy & Procedure

- Testing hierarchy:
  - Liquid → Temp → Pressure → Leak Size
  - Gas → Pressure → Temp → Leak Size

- Test procedure:
  - Installation of test setup
    - Insulation/isolation
    - Soil preparation
  - Test matrix (varying pressure, temperature, leak size)
  - Test procedure, monitoring and control equipment
  - HSE considerations
Study was completed on potential test facilities/space selections.

Study Methodology:
- Facility identification (within JIP project area)
- Selection criteria (size, cost, boundary effects)
- Identify required modifications (i.e. insulation to minimize boundary effects)
- Facility ranking

Identified 2 facilities
- Facility 1: Requires purpose built tank (allows testing of 2m long pipeline segment)
- Facility 2: Existing tank (allows testing of 18-19m long pipeline segment)
Tank sizing based on the following:
- Acoustic boundaries requirements
- Leak simulation (i.e. appropriate sizing of pressure rated tubing)
- Burial / non-burial test conditions

Required instrumentation and control based on fluid type

Proposed system is able to control:
- Pressure
- Flowrate
- Temperature
- Leak size

CFD Model - Acoustic Contours of Pipeline Leak
Test Facility Selection

- **C-CORE**
  - Requires purpose built tank
  - Can test 2m long test pipe

- **Foxtrap**
  - Existing tank
  - Can test 18-19m long pipe
Vendor Identification
• 14 vendors were identified

Outlined Required System Criteria
• Water depth, fluid type, pipeline length, etc.

Literature Review
• Through internet search and past project experience
• Questionnaire provided to vendors

Level I Screening
• Determine relevancy to JIP

Level II Screening
• Investigation of system performance
Determine optimal positions to ensure baseline for detection performance can be achieved, as well as detection envelopes can be established

Positioning based on:
- Leak conditions
  - Buried/non-buried, gas/water leak
- Vendor recommendations

**Testbed Geotechnical Evaluation**
- Identify appropriate soil material, density and saturation requirements, and soil placement/replacement strategy
- Identify testbed material as representative of Arctic and cold region soil conditions
- Identify potential local vendors
Phase 2 Objectives

- Conduct detailed engineering and procurement
- Execute the leak detection test program
- Determine detectability and detection envelope of selected/leading DTS as well as DAS systems
- Further prove the technology (and enhance TRL or reduce TRC) for Arctic and cold region applications
- Perform system installation, maintenance and repair requirement assessment
- Evaluate system reliability and false alarm rate
- Recommend proven systems (DTS/DAS) for field test and/or pilot project implementation
Novelties

- Long cable (up to 40 km)
- Low ambient temperature (as low as 4°C / 1°C)
- Large test tank (20m x 10m x 2.5m)
  - Accommodation of boundary conditions
  - Buried pipeline
- Integrated (DTS/DAS) leak testing
- Small chronic leak detection capability testing
- Replicate coated conditions
  - Concrete vs. bare pipe
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