Fenja Development Automated Flow Assurance System and Associated Real-time Advisory Modules

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Outline

• Fenja Field Overview

• Flow Assurance Challenges in Fenja

• Fenja Digital Twin

• Operational Automated Advisors

• Integrity and Safety Automated Advisors

• Conclusions
Fenja Development Options

- Fenja was discovered in 2014
- Located offshore Norway about 35 km southwest of the Njord Field
- Field is developed with two subsea templates and subsea wells tied back to the Njord A facility
- Well fluid will be commingled at the subsea template prior to being routed through a single pipeline to the Njord A
Flow Assurance Challenges in Fenja Development

• Multiphase production via a single long tie-back pipeline length (35 km) in cold arctic environment

• Wax and Gelling Risk
  o High Wax Content,
  o Wax Appearance Temp: 39°C,
  o Pour Point Temp: 27°C

• Hydrate Risk
  o Hydrate Formation Temp: 18°-24°C,

• Liquid Management
  o Host facility constraints

• World’s longest ETH PIP as the primary layer of protection for Wax & Hydrate
Why Active Heating is Required for Wax Management?

- The active heating system constitutes the only layer of protection against gel blockage in the pipeline after shutdown.
- The length of gelled section is dictated by the oil content in the pipeline after shutdown and depressurization

<table>
<thead>
<tr>
<th>Flowline Condition</th>
<th>Total length of Blocked Sections (m)</th>
<th>Number of Sections</th>
<th>Length of Longest Individual Sections (km)</th>
<th>Gel Strength at 4°C (Pa)</th>
<th>Differential Pressure to Break the Gel (bar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shutdown</td>
<td>16000</td>
<td>12</td>
<td>5</td>
<td>180</td>
<td>223</td>
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<tr>
<td>Shutdown</td>
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<td>12</td>
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<td>434</td>
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<tr>
<td>Depressurized</td>
<td>8000</td>
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<td>4</td>
<td>180</td>
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<tr>
<td>Depressurized</td>
<td>8000</td>
<td>12</td>
<td>4</td>
<td>350</td>
<td>259</td>
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</table>
Why Active Heating is Required for Hydrate Management

- Hydrate Management Challenges
  - Depressurization is identified as a challenge during early field life production
  - Low Pressure start-up is technically infeasible

Liquid volume > available topside liquid surge handling volume

Pipeline does not reach hydrate safe pressure

<table>
<thead>
<tr>
<th>Case</th>
<th>Restart Time (to nearest 1 hr before CDT)</th>
<th>Final Pressure [bara]</th>
<th>Max DTHYD [°C]</th>
<th>Pipeline Inlet Final Temperature [°C]</th>
<th>Hydrate Safe Pressure (@ 0°C) [bara]</th>
<th>Time to Hydrate Safe Pressure [h] @ Pipeline Inlet</th>
<th>Accumulated Liquids [m³]</th>
<th>Accumulated Gas Mass [m³]</th>
<th>Minimum Temp D/S 'LEAK' [°C]</th>
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<tr>
<td>Jan-21</td>
<td>50</td>
<td>18.06</td>
<td>6.9</td>
<td>1.12</td>
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<td>257</td>
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<td>44</td>
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<td>-2.46</td>
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<td>Apr-23</td>
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<td>14.59</td>
<td>4.5</td>
<td>0.23</td>
<td>-1.31</td>
<td>NOT POSSIBLE</td>
<td>211</td>
<td>0.28</td>
<td>162.8</td>
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<td>Jun-25</td>
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<tr>
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<td>7.99</td>
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<td>-5.12</td>
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<td>8.7</td>
<td>45</td>
<td>130.6</td>
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</table>
Fenja FAS & Automated Advisory Modules

• Fenja Digital Twin is designed not only to enable continuous monitoring, but also to provide advisories and operational guidelines for key operations:

• **Fenja FAS Modes of Operation**
  • Real-Time Mode
  • Look-Ahead Mode
  • What-if-Mode
  • Replay Mode

• **Fenja Advisory Modules**
  • No-touch time (NTT)
  • Warm up and keep warm operations
  • Leak detection
  • Sand Transportation & Risk of erosion
  • Slugging and surge handling
  • Emulsions
Fenja Digital Twin Data Flow Diagram
No Touch Time Advisor

- Predictive simulation using online look-ahead mode
- Performs a predefined shut-in sequence using real-time field conditions
- Simulates into future to predict NTT for key locations
- Alarm/warning raised if temperature drops below hydrate and pour point temperatures alarm/warning threshold
- It runs automatically without any human intervention and provides updated information in real-time
Warm-up and Keep Warm Advisors

- It provides guidance for ETH pipeline operations. It has two distinct features:
  1) Keep warm: simulate minimum power requirement to stay outside hydrate risk
  2) Warm up: simulate time required to warm up the pipeline for restart

- Using real-time field conditions, simulates into future to predict time and power required for ETH operation

- It runs automatically without any human intervention and provides updated information in real-time

Power (green), Min Temperature in Pipeline (Red)
Leak Detection Advisor Working Principles

- Digital Twin simulates the system behavior without any leaks
- Field measurements that deviate from the real-time model in case of a leak
- **Leak Signatures** that generate a warning and subsequently an alarm when the signatures indicate a change in the operating point outside the **Expected Operating Region (EOR)**

<table>
<thead>
<tr>
<th>Label</th>
<th>Status</th>
<th>Active</th>
<th>Threshold</th>
<th>Signature</th>
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<td></td>
<td></td>
<td></td>
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<td>18-FT-7463-QWST</td>
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<td>0.00</td>
</tr>
</tbody>
</table>

Example of leak signatures at OP1 wellhead
Leak Detection Test Setup and Results

• Testing Setup:
  o To replicate a leak scenario, a FIELD model was made
  o Two models (FIELD and Digital Twin RTM) run in parallel and independently

• Testing Outcomes:
  o Reliable operation with high uptime
  o False alarms are rare
  o Small Leak (1% of pipe dia.): 1 hour
  o Moderate Leak (>3% pipe dia.): 15 mins
  o Time to detect a leak depends on various factors, such as operating conditions in the field, leak size, leak location, etc.

Sum of leak signature value (red)
Threshold value (blue)
Sand Deposition and Erosion Risk Advisor

• Instant warning if any of the network sections are experiencing erosional issues

• Advisor monitors the erosion risk at key locations:
  • Production choke downstream piping
  • Production jumper outlet
  • Pipeline outlet
  • Production riser outlet

• Erosion risk static curves can be updated automatically based on field sand production data:
  • Average sand density and particle diameter
  • Average sand production rate (either manual or from sand detector measurements)

Different erosion risk boundaries based on different correlations
Green color dot shows current operating data
Conclusions

• Fenja Digital Twin is deployed to optimize operations and improve surveillance.

• By integrating the automated advisors with the real-time surveillance, this solution will achieve an increased level of accuracy, consistency and avoiding human errors.

• These automated advisors help identifying operational risks (wax, gelling and hydrate formation) in advance.

• Keep Warm & Warm-up advisor provide guidance to optimize the power consumption during various operations.

• A novel leak detection solution incorporating signature and regions definitions ensures "Top-of-the-range" leak detection for long multiphase tie-back pipeline.

• This solution promotes interaction among the various disciplines involved in operations into a single platform.
Acknowledgement

- I would like to express my deep appreciations to Neptune Energy and Schlumberger management for permitting this presentation in Digital Forum 2022.