Large Scale Erosion Testing of a Flexible Flowline

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References to “Woodside” may be references to Woodside Petroleum Ltd. or its applicable subsidiaries.
Agenda

• Introduction
• New Technology Identification and Qualification Process
• Qualification Execution (Presented by DNV GL)
  • Rig Design
  • Erosion Test Campaign
  • Benchmarking Assessment
• Conclusion
Introduction

- Woodside is currently developing a subsea tie-back on the North West Shelf
- The concept contains a 12 inch inner diameter (ID) flexible flowline and a 12 inch nominal bore (NB) rigid riser
- The production system will produce gas at elevated velocities (30 m/s in the flowline) due to constraints in existing infrastructure
- The design velocity of the flexible flowline is 40 m/s which was classified as new technology and had to be qualified for the project
Introduction - Flexible Pipe Technology

- The carcass is composed of interlocked steel strips
- The carcass provides collapse resistance to the structure
- The carcass is exposed to bore fluids and solids at high velocity and will erode over time
- 25-50% of strip thickness is a general erosion allowance
- Actual allowable erosion follows from remaining collapse resistance

Source: http://fps.nov.com/
Source: API RP 17B
The qualification process was performed in accordance with Woodside's New Technology Identification and Qualification Procedure (Based on DNV-RP-A203 & API RP 17N)

The following steps are involved in the qualification process:

- STEP 1: Identification and Classification
- STEP 2: Qualification Planning
- STEP 3: Execute → Statement of Release

STEP 1 Determined:
The flexible flowline option is a candidate for qualification and is to be entered into a qualification program.
Tests are constrained by health and safety requirements, test facility limitations, pipe sample availability and time. This results in a difference between test conditions and field conditions as presented below:

<table>
<thead>
<tr>
<th></th>
<th>Laboratory</th>
<th>Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>ID</td>
<td>9.75”</td>
<td>12”</td>
</tr>
<tr>
<td>Minimum Bend Radius</td>
<td>2.5 m</td>
<td>3.3 m</td>
</tr>
<tr>
<td>Density</td>
<td>1.2 kg/m³</td>
<td>44.7 / 28.1 kg/m³</td>
</tr>
<tr>
<td>Carcass Geometry</td>
<td>As per available sample</td>
<td>TBA</td>
</tr>
<tr>
<td>Silica Sand</td>
<td>150µm / 250µm / 550µm</td>
<td>25µm / 100µm</td>
</tr>
<tr>
<td>Proppants</td>
<td>780 µm</td>
<td>780 µm</td>
</tr>
</tbody>
</table>

Benchmarking against erosion prediction models required.
Perform erosion tests at lab conditions (API RP 17B)

Calculate erosion for lab conditions (DNV-RP-O501, Erbend & Computational Fluid Dynamics (CFD))

Compare empirical results against analytical results and derive adjustment factors

Calculate “Field” erosion with revised methodology

Verify project specific collapse resistance of the flexible pipe
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Australasian Oil & Gas Conference 2015
DNV GL – Process laboratory

- DNV GL involved in research and development within the field of sand erosion and sand management since early 1980’s
- Two flow loops with possibility of sand injection: 3-4" multiphase flow loop (air/CO2, oil (stabilised), water and chemicals) and 10" full scale rig (air)
- Test results form the basis of the DNV-RP-O501 “Erosive Wear in Piping Systems”
- DNV GL commissioned by Woodside to perform erosion testing of a 9.75" flexible flowline
Erosion

- Sand is an inevitable by-product during oil and gas production
- Sand production may have a detrimental impact on system integrity and availability due to erosion
- Erosion depends strongly on the particle impact velocity, i.e. bulk flow velocity
- Dependency is given by the material constant \( n \). For steel \( n = 2.6 \)

\[
Erosion \sim K \cdot m \cdot F(\alpha) \cdot U_p^n
\]

Doubling the flow velocity increases the erosion rate by a factor of SIX!
Test facility

Side view

Sand feed unit

Centrifugal fan

Flexible flowline

Filter box 13 m³
3.3 m x 2.5 m x 1.5 m
Test conditions

- 15 days of testing performed in January 2014
- Test fluid: Air at atmospheric conditions (ρ = 1.22 kg/m³)
- Velocity range: 30 – 47 m/s
- Total sand load: 8 tonnes
- 14 tests performed, each test repeated 3 times to ensure repeatability
- 4 particle size:
  - 150 µm
  - 250 µm sand particles
  - 550 µm
  - 20/40 Proppants (780 µm)
Execution of erosion test

- Erosion determined by two measurement techniques
  - Weight loss measurement which is industry standard but not applicable for flexible carcass
  - Carcass cross section thickness determined by microscopy analyses
- Leading edge erosion observed
Erosion – weight loss measurements

- Erosion determined by weight loss measurements at selected cut out windows (0°, 20°, 40°, 60°, 80°)

\[ y = 4 \times 10^{-5}x^{2.5704} \]

\[ R^2 = 0.988 \]
Erosion – weight loss measurements

- All tests repeated 3 times to ensure repeatability and consistency

Cumulative erosion 150 µm sand particles 47 m/s

Erosion as a function of angle – 150 µm sand particles 47 m/s
Erosion – microscopy measurements

- Erosion not uniformly distributed along carcass strip.
- 5 virgin samples measured to get a benchmark of the strip thickness
- Comparison of the measured results against the average virgin thickness clearly shows leading edge erosion
- Leading edge erosion phenomenon has never been considered in the design of flexibles – New to the industry
Benchmarking Assessment

- Objective of benchmarking assessment
  - Compare test results against industry standard calculation methodologies and develop a method for predicting erosion in flexibles
  - Estimate erosion for field conditions

- Benchmarking scope consisted of the following
  - Calculation of erosion with DNV-RP-O501, DNV ERBEND and CFD
  - Comparison of analytical results against test results
  - Extrapolation to field conditions; i.e. higher density, increased bend radius, larger ID and smaller particles (fines with diameter of 25 µm)
  - Sensitivity of carcass geometry variation and reverse flow to determine the effect of changes in carcass (carcass geometry varies per vendor)
Benchmarking assessment

- Comparison of DNV-RP-O501 and DNV ERBEND against test results have shown that the average erosion for silica sand is underestimated.
- Both methods overestimate the average erosion for proppants.
- DNV-RP-O501 and DNV ERBEND do not take into account the erosion at the leading edge.

<table>
<thead>
<tr>
<th>Particle</th>
<th>Method</th>
<th>Average erosion (mm/Te)</th>
<th>Average erosion test (mm/Te)</th>
<th>Ratio Test/Calc</th>
</tr>
</thead>
<tbody>
<tr>
<td>150 μm silica sand, 47 m/s</td>
<td>DNV-RP-O501</td>
<td>0.057</td>
<td>0.077</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>DNV ERBEND</td>
<td>0.055</td>
<td>0.077</td>
<td>1.4</td>
</tr>
<tr>
<td>550 μm silica sand, 30 m/s</td>
<td>DNV-RP-O501</td>
<td>0.017</td>
<td>0.022</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td>DNV ERBEND</td>
<td>0.012</td>
<td>0.022</td>
<td>1.8</td>
</tr>
<tr>
<td>Proppant 40 m/s</td>
<td>DNV-RP-O501</td>
<td>0.036</td>
<td>0.010</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td>DNV ERBEND</td>
<td>0.030</td>
<td>0.010</td>
<td>0.33</td>
</tr>
</tbody>
</table>
Benchmarking assessment

- CFD model (Ansys CFX) contains a short section of carcass geometry
- A very fine mesh was required increasing simulation time
- Erosion is calculated with the DNV GL response model
- CFD was found to predict leading edge erosion
Benchmarking assessment

- Reasonable good agreement for CFD but potential for large fluctuations
- Generally good agreement between DNV-RP-O501, DNV ERBEND and tests
- Correction factors to be applied when calculating erosion in flexibles

![Erosion rate of sample at 20 degrees
Benchmarking 3D CFD and microscopy](image)
Benchmarking Assessment - Results

- Predicted erosion in a flexible flowline using DNV-RP-O501 for field conditions with adjustment and safety factors is presented below.
- The total erosion of 0.50 mm for a velocity of 40 m/s was confirmed acceptable by flexible vendor.

<table>
<thead>
<tr>
<th>Velocity</th>
<th>Total Erosion (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 m/s</td>
<td>0.23</td>
</tr>
<tr>
<td>35 m/s</td>
<td>0.35</td>
</tr>
<tr>
<td>40 m/s</td>
<td>0.50</td>
</tr>
</tbody>
</table>
Conclusions

- The analysed flexible flowline can be operated at 30 m/s and a design velocity of 40 m/s can be accepted.
- Key finding of the test campaign is that localised erosion can be expected at the leading edge of the carcass.
- Commonly used industry erosion prediction tools DNV-RP-O501 and ERBEND are unconservative for flexible pipe and should be adjusted with correction factors based on empirical data.
- CFD was found to predict leading edge erosion but did not reliably predict the magnitude of erosion.
- For the flowline under consideration, the flexible pipe vendor confirmed that the effect of localised erosion on collapse resistance is acceptable.
- The successful completion of the qualification program opens up the use of flexible pipe in gas production service.
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Questions?