Deepwater Flexible Pipes for Sour Applications

Adam Rubin National Oilwell Varco



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Outline

- Sour Cracking of Steel
- Annulus Environment of Flexible Pipes
- Laboratory Test
- Refined Annulus Prediction Model
- Full Scale Validation
- Application



Sour Cracking and H₂S in Flexible Pipes

 Steel in contact with H₂S risks fractures and internal cracking





- 1000 hu
- Observations of no H_2S in venting gas and no sulfide scale in dissected pipes
- No observations of sour cracking of sweet service pipes in souring wells
- Full scale sour test with no measurable H₂S

The Annular Space

- Confined area, a lot of steel 100.000 cm²/m
- Low V/S ratio <0.1 ml/cm²
- A potential corrosive environment



Traditional Mass Balance: In = Out (OS) + Out (VV)



Bore Environment <-> Predicted Annulus Envionment <-> Steel





Consumption of H₂S

- H_2S enters by permeation through the liner:
 - $H_2S + Fe \rightarrow FeS + H_2$
- If supply of H₂S is slow enough
 → Concentration decreased/depletion
 → Tendency to HIC+SSC lowered
- Flow rate into annulus:

 $mH_2S/min/cm^2$ steel surface





10-3

10-4

Laboratory Tests

- Packed cell with armour wire to simulate annulus
- H₂S in CO₂ test gas
- Gas flow: 10⁻³, 10⁻⁴, 10⁻⁵, 5x10⁻⁶, 10⁻⁶ mIH₂S/min/cm²
- Test time: 800-1700 hours
- Monitoring: H₂S, pH, O₂ -continuously
- Test results:
 - H₂S concentration
 - Wire cracking examination





MCE Deepwater Development 2018

Results





Refined "Flow Sour" Annulus Prediction Model



New Mass Balance: In = Consumed +Out (OS) + Out (VV)



Full Scale Validation – Test Pipe

- Standard Sweet 6" deep water pipe:
 - Armour wire: SMYS 1350 MPa
- Bore:
 - $_{\odot}$ Water, saturated with gas: 10% $\rm H_{2}S$ in CO $_{2}$
 - ∘ Pressure: 50 bar \rightarrow 5 bar H₂S
- Tension:
 - $_{\circ}$ 400 tons → 85% yield of tensile armour
- Annulus:
 - Venting pressure: 2barg
 - Calculated H₂S flux: 10⁻⁶ ml/min/cm² steel surface
 - Standard calculated annulus H₂S partial pressure: 177 mbar





Full Scale Validation – Test Setup

- Test time: 1 year
- Continuously monitoring
- Annulus gas sampling every month
- Annulus solution sampling every month







Full Scale Validation - Rusults

- Sampling annulus solutions:
 - pH: Stable along the test 6.3 -6.7
 - H₂S: ~ 0.1 mbar
- Sampling annulus gas:
 - 。60-80 vol% H₂
 - No H₂S detected



- No loss of pipe integrity
- Pipe Dissection:
 - No sour cracking More than 150 m UT scanned for internal cracking

Model Validated

High strength wire showed resistant to a traditionally calculated annulus of 177 mbar!



Application

- "Flow Sour" Annulus Prediction model
- Revied by IVA and incorporated in Type Approval
- Ensures complience with standards
 - H₂S level is still used to select steel armour materials with adequate sour resistance
 - Steel qualification and quality control tested based on ISO 15156 / NACE TM0177 / NACE TM0316
 - Fully in compliance with API 17 J section 6.2.4.2 "SSC and HIC testing"

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Applications – Optimised Designs

- Enabler for free hanging 6"production riser
- 345 bar pressure
- 200 ppm H2S
- 2.500 MWD

- 10" Production Riser
- 345 bar pressure
- 6.700 ppm H2S
- 750 MWD



	Traditional Model	Flow Sour Model	Change
OD [mm]	432	414	-18 mm
Weight in air [kg/m]	287	214	-25%
Weight in sea [kg/m]	137	77	-44%



Questions



Adam Rubin R&D Director | Material Technology adam.rubin@nov.com

