Validation of the Performance of Offshore Pipe Insulation Systems

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Outline

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- Challenges of Offshore Insulation Validation
- Bredero Shaw's Thermal Design Process
- Simulated Service Vessel Testing
- The New ShawCor Subsea Test Facility
  - Best-in-Class Testing Capabilities
  - Unique Testing Process Control
  - Validation example – Predicted and measured data
- High Temperature Cathodic Disbondment (CD) Testing
- Summary

Background

- Validation prior to deployment of the pipeline is needed to avoid high remediation costs of any failures

- Testing of insulation under conditions similar to those on the seabed is essential to validate the design of the insulation system

- Validation of the end-to-end system including linepipe and field joint coatings is critical since the field joint coating material is often different from the linepipe coating material

Background

- ***EXISTING INSULATION SYSTEMS*** :
  Since testing of the insulation needs to be completed on the project pipe prior to deployment, testing of the insulation after the pre-qualification testing (PQT) is often on the critical path

- ***NEW INSULATION SYSTEMS:***
  For novel insulation solutions, simulated service testing and other tests are required to ensure their suitability for the project

- ***INSULATION APPLICATION:***
  Extensive tests during PQT and the application of the insulation are required to ensure quality of the insulation

Trends in Offshore Projects

- Lower U-values
- Deeper water
- Higher temperatures (up to 150^{o}C)
- Longer tie-backs
  - Maximize the number of satellites that can be tied back to a host
  - Encompass sufficient reserves to improve economic viability
  - Burial and electric heating are current solutions
- Tougher design and qualification requirements
  - Thermal performance
    - *Steady-state performance (Heat loss coefficient s: U-value or OHTC)*
    - *Transient-state performance (k-value, Specific heat capacity, Density)*
  - Mechanical performance – Response of system to hydrostatic load
    - *Stress-strain*
    - *Long term (Compression and creep)*
- Newer and tougher QC performance requirements during insulation application

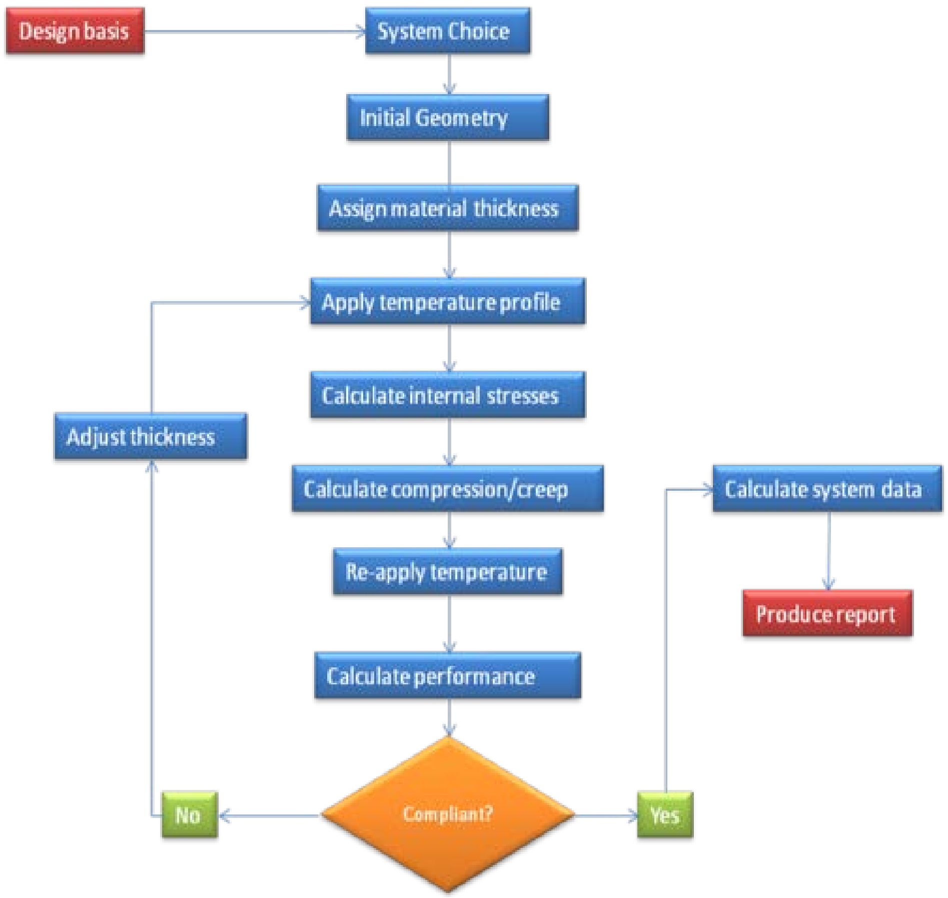
Challenges of Offshore Insulation Validation

- Availability of an SSV testing facility to meet the project schedules and scope
  - Increased demands for simulated service testing to validate thermal and mechanical properties of insulation system

- Lack of widely acceptable industrial testing methods and standards
  - High temperature cathodic disbondment (CD) testing for temperature of 90^{o}C or above, when high temperature FBE coating raw material is also relatively new to the industry
  - Hot water soak testing for insulation system
  - Thermal shock testing for insulation system

Bredero Shaw's Thermal Design Process

- Implemented in 1-D algorithms.
- Easily ported to 2-D axio-symmetric / 3D models
- Material relationships time, stress and temperature dependent
- Accurate prediction of
  - Internal stresses
  - Densification
  - Dimensional change
  - Temperature profile
  - K-value profile
  - U-value / OHTC.



Simulated Service Vessel Testing

- Insulation system subjected to thermal and hydrostatic loadings

- Allows for verification of:
  - Thermal performance over period of test and system integrity
  - Compression / creep model & temperature / density / k-value relationships, and
  - Prediction of cool-down time

The New ShawCor Subsea Test Facility

Spotlight on new TECHNOLOGY

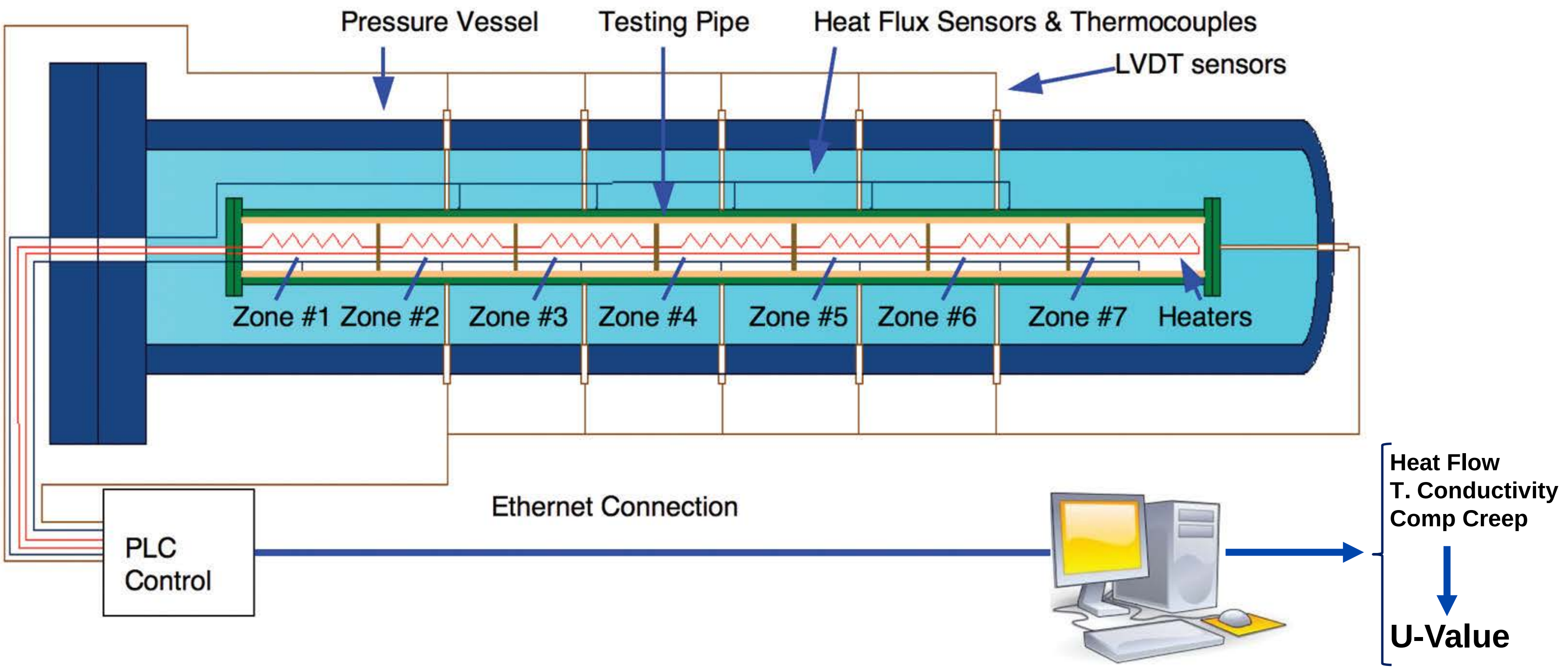
The Industry's Largest Simulated Service Vessel

SSV Capability

Parameter	Specification
Maximum Test Pressure	300 bar (3,000 m equivalent)
Chilled Tap Water Temperature inside pressure vessel.	4ºC (40ºF) (+/-2)
Internal Pipe Temperature	20ºC to 180ºC (68ºF to 356ºF)
Inside diameter of test vessel	1.2 m (48 in.)
Sample Length	6 m (18 ft.)
Number of test samples	One (up to three materials)
Pipe Outside Diameter	145 - 810 mm (6 to 32 in.)
Pipe Inside Diameter	95 - 660 mm (4 to 26 in.)
Range of Coating Thermal Conductivity (k)	0.1 - 0.3 W/m K
Range of Heat Transfer Coefficient (U)	1.5 - 6 W/m^2 K

Best-in-Class Testing Capabilities

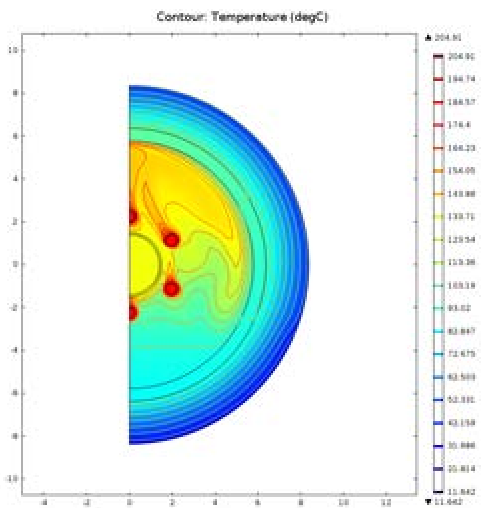
Allows for Accurate Assessment of the Performance Capability of an Insulated Pipe System Under Precisely Controlled Conditions



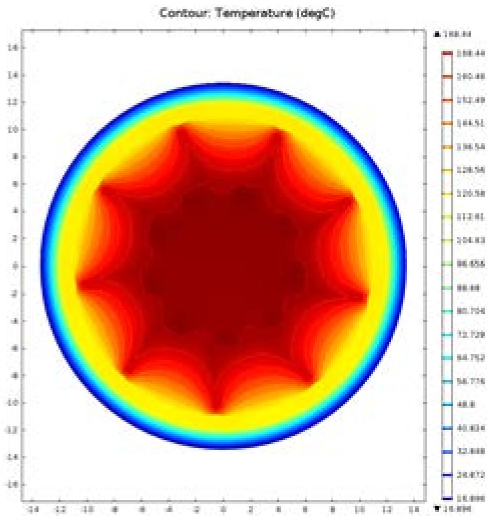
Best-in-Class Testing Capabilities

- The SSV testing capabilities are continuously improved
- A new electrical heater design was developed, implemented and evaluated through application of Finite Element Analysis (FEA) simulation

Pipe Temperature with Different Electrical Heater Designs For the Simulated Service Test



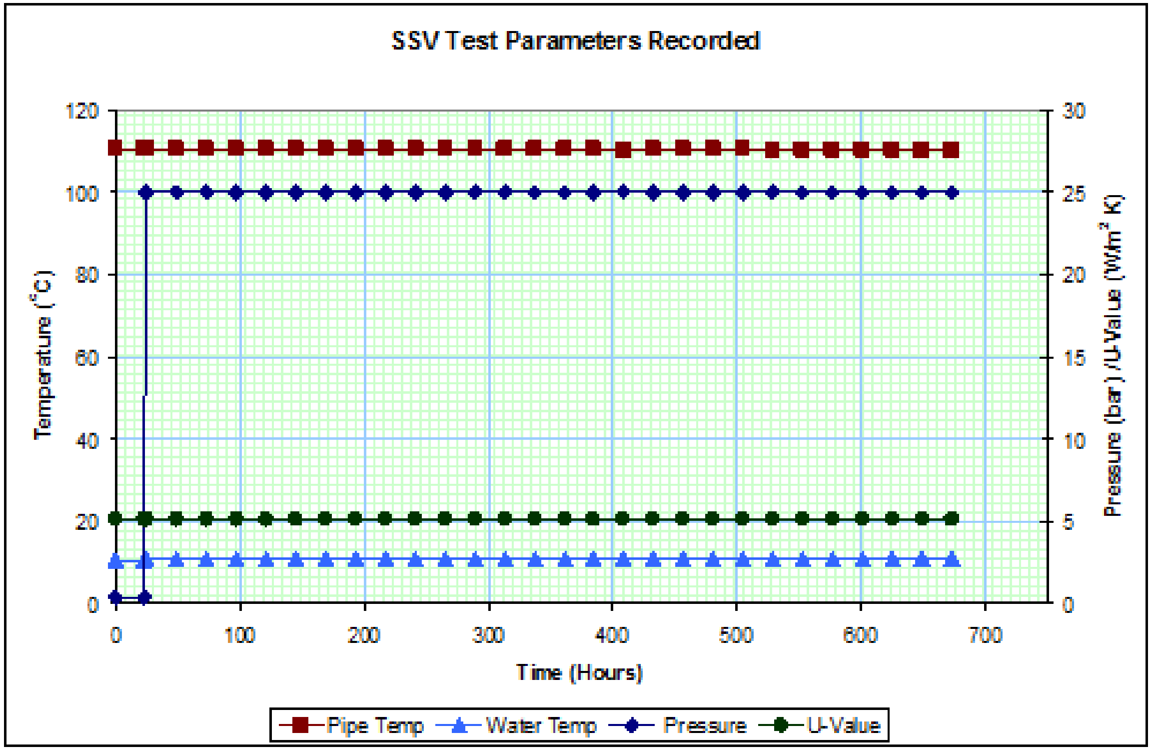
Before heater design optimization



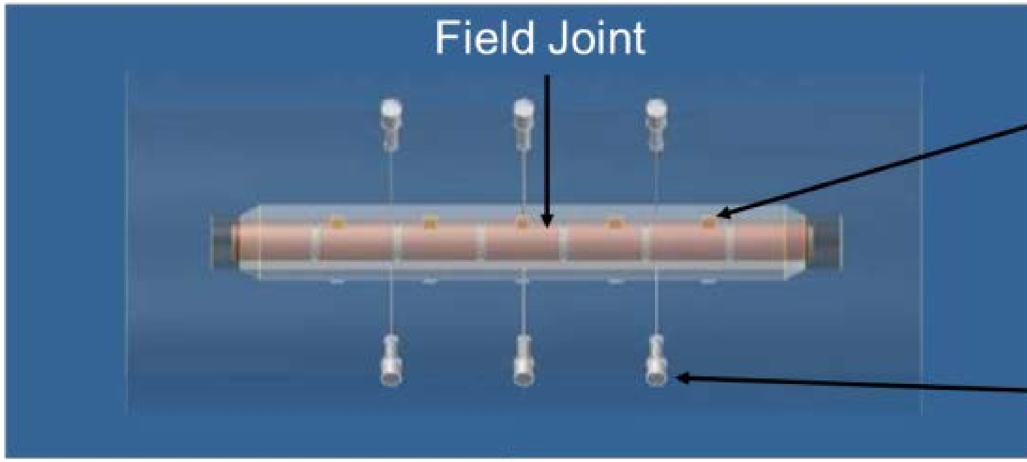
After heater design optimization

Unique Testing Process Control

- Water temperature: 4 ±1°C
- Pressure is held within 1 bar of target
- Pipe wall temperature is maintained within 1 °C
- Heat flow is constant, once stabilized
- As steady state is reached quickly, test duration can be reduced in some cases to 14 days for systems with low compression



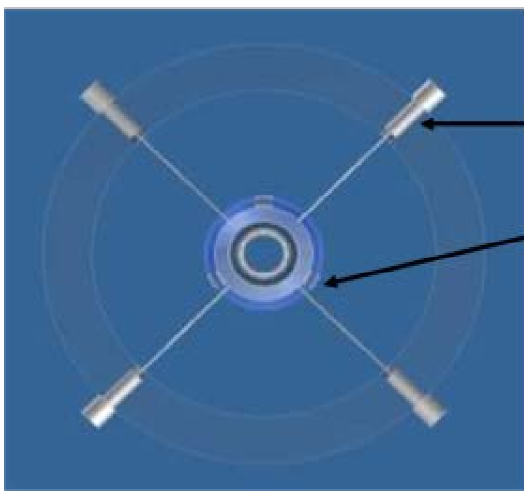
Unique Testing Process Control



Heat Flux Sensor & Thermocouple

LVDT

Sensor layout



LVDT

Heat Flux Sensor &Thermocouple

Multiple sensors provide more accurate determination of U Value

Unique Testing Process Control

U-Value Calculation

- Measurements of heat flow and internal and external temperature are made in 20 locations over the 6 m pipe
- Based on these measurements, an average U-value for the insulation is calculated daily, and communicated to customer
- When the test is completed, the U-value and the 95% confidence interval for the U-value are calculated
- Performance of linepipe and field joint insulation coating is thus validated prior to deployment of pipe

Remote customer access to real-time testing data

Unique Testing Process Control

SHAWCOR TO BE SURE

Ts Reading	Zone LVDT (mm)	Ti (°C)	Ts (°C)	Ub (W/m^2K)
7.5	0.87	119.6	7.5	4.48
8.5	0.87	124.1	8.5	
7.9	0.87	123.0	7.9	
7.2	0.87	119.5	7.2	4.55
7.8	0.87	123.7	7.8	4.33
7.3	0.87	123.5	7.3	4.53
6.6	0.87	121.4	6.6	4.45
8.7	0.87	125.8	8.7	4.38
8.0	0.87	127.6	8.0	
6.1	0.87	120.0	6.1	4.53
8.2	0.87	123.7	8.2	4.53
8.7	0.87	123.4	8.7	4.50
6.7	0.87	120.9	6.7	
8.6	0.87	124.7	8.6	4.53
9.0	0.87	124.6	9.0	4.73
6.4	0.87	119.3	6.4	4.47
8.4	0.87	124.0	8.4	4.37
8.4	0.87	124.1	8.4	4.34
Average	0.87	122.92	7.78	4.48
StDev.	0.00	2.34	0.89	0.11

Sample U-Value Calculation

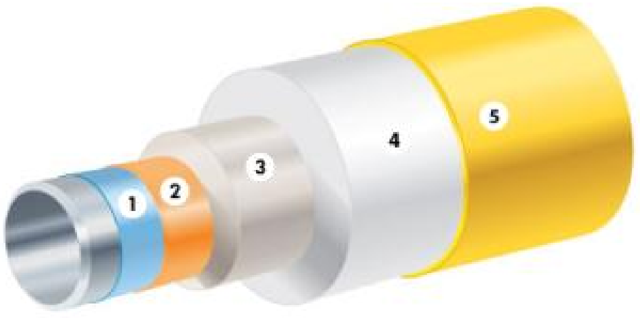
- *Accurate U values can be calculated after 14 days of testing (for systems with low compression)*
- *Statistical analysis used to determine U value and uncertainty in U value*

Final U value

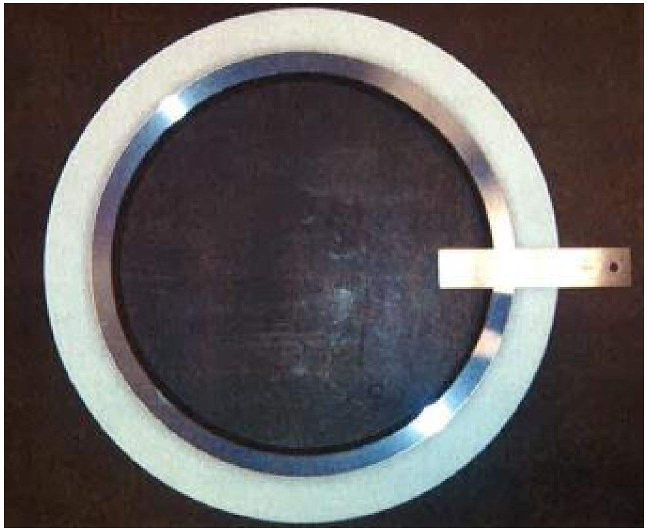
Uncertainty in U value

Predicted & Measured Data

- An offshore gas flowline project in Australia
- Design temperature 110°C
- Water depth 237 m
- 14” (355.9 mm) x 17.8 mm pipe with a 40.2 mm thick 5LPP Foam
- 28 day SSV testing duration, 25 bar, 110°C
- Predicted data
  - Expected U-value: 5.19 W/m²K on OD early life
  - Expected Cool-Down time: 11 hours 24 minutes from 110°C to 21.4°C
- Actual measured data
  - Measured U-value: 5.13 W/m2K ± 0.16
  - Measured Cool-Down time: 11 hours 50 minutes ± 56 minutes
  - Compression (mm radius): 0.3 mm ± 0.1

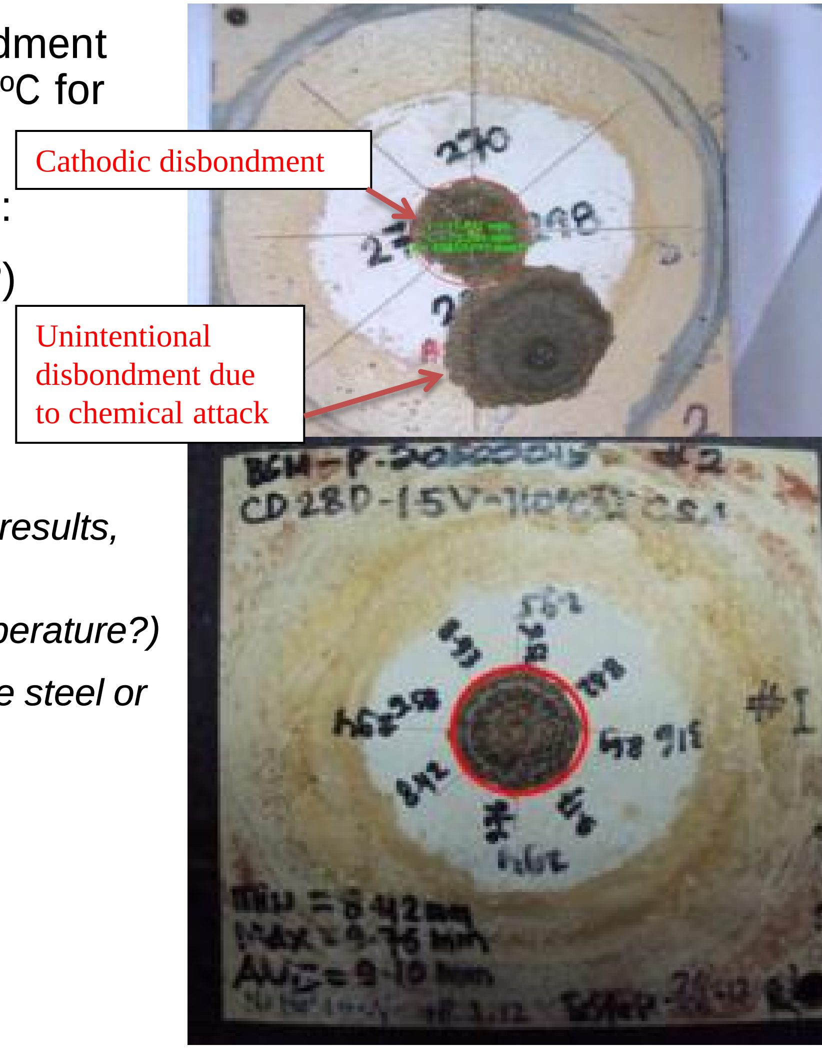


1. Fusion Bonded Epoxy 2. Adhesive 3. Solid PP 4. PP Insulation5. Outer Shield



High Temperature CD Testing

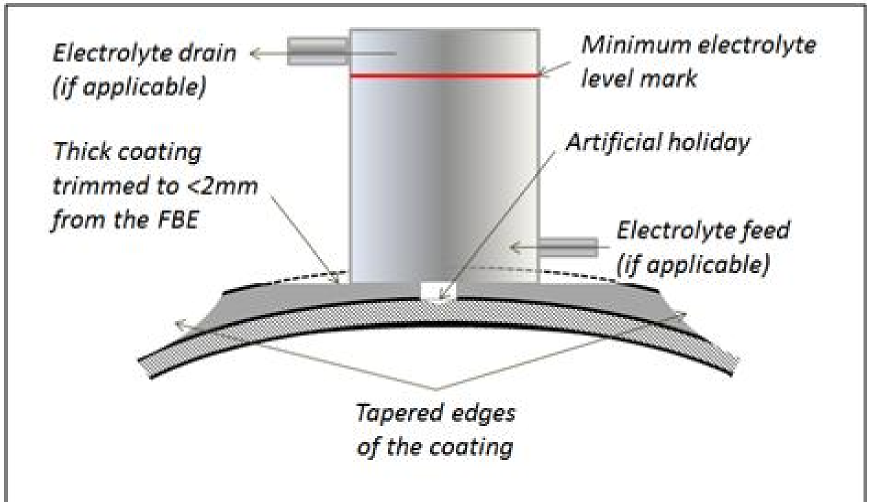
- No broadly accepted standard for cathodic disbondment (CD) testing for testing temperatures above 90-95^{o}C for offshore insulation validation
- Several key factors with many different arguments:
  - Testing duration (24h, 48h, 7d, 28d or longer?)
  - Testing potential (-1.5V or -3.5V?)
  - Testing temperatures:
    - *Hyprochlorite attack – an artificial laboratory phenomenon but significantly affecting the test results, becomes more severe at high temperatures*
    - *Electrolyte temperature (90^{o}C or seawater temperature?)*
    - *Sample testing temperature (measured from the steel or the electrolyte side?)*
    - *Higher water vapour permeation and pressure*
  - Testing on FBE standalone or a full insulation system?
  - Coating film thickness, particularly FBE



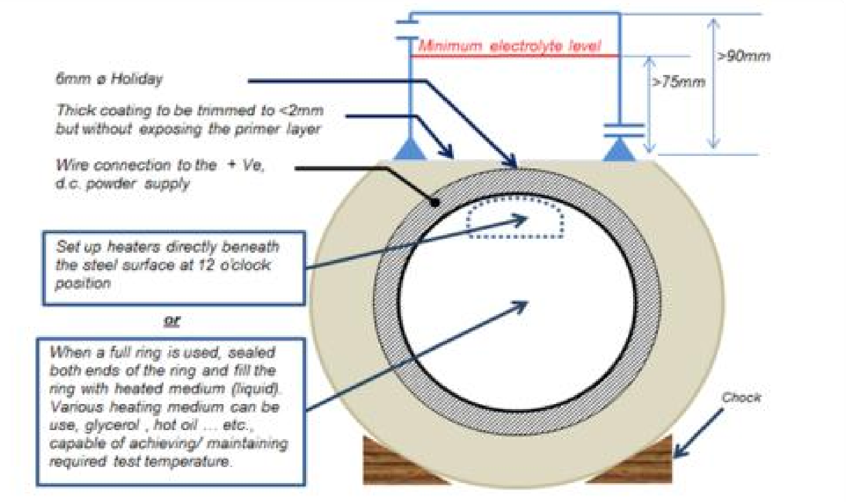
High Temperature CD Testing

A Proposed Testing Protocol

- Testing on a full insulation system is preferred to validate the performance of the real production-produced insulation system
- Attached cell method:
  - Set up A (Panel) or Set up B (Ring for thick insulation)
- Testing duration and potential:
  - 24 h @ -3.5V, 14 d and 28 d @ -1.5V for material qualification and PQT validation
  - 24 h @ -3.5V for production QC validation
- Testing temperatures:
  - Electrolyte temperature (30±5^{o}C or project seawater temperature)
  - Sample testing temperature (Maximum designed/operating temperature measured from the steel)
- Consistent and stable CDT results were obtained



Set Up [A] - (Attached Cell Panel Method)



Set Up [B] - (Attached Cell - Ring Method)

Summary

- Validation gives the design engineer and owner confidence that the offshore pipeline insulation system will meet project requirements when it is installed
- The ShawCor Subsea Test Facility provides a more advanced SSV testing
  - Samples up to 6 m long with diameters up to 910 mm (36") with insulation to accommodate insulated project pipe including the field joint during one test cycle
  - Test schedules are controlled to eliminate delays and are readily adjustable to accommodate the client's project schedule.
  - Unlike traditional testing vessels, the ShawCor SSV performs direct measurements of temperature and creep in seven separately controlled testing zones with real-time data acquisition
  - Precise control of the test environment leads to very stable heat flow during a test
- A new HT-CD testing protocol has been proposed for testing temperatures above 90-95^{o}C for offshore insulation validation, achieving consistent and stable CD results for PQT and production QC testing during insulation project