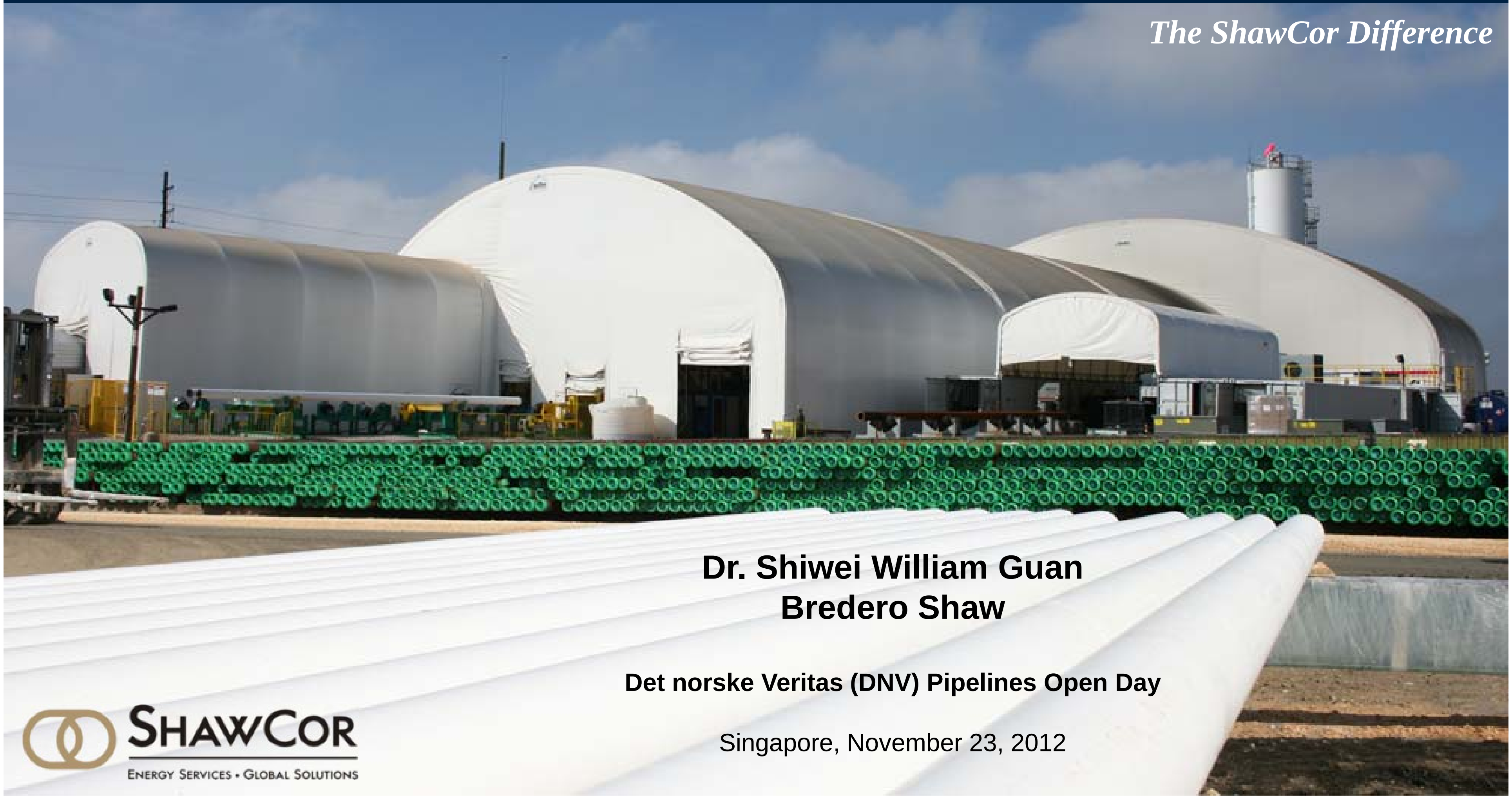
BREDERO SHAW
A ShawCor Company

Subsea And Deepwater Flow Assurance Insulation:

Challenges and New Developments



Dr. Shiwei William Guan
Bredero Shaw

Det norske Veritas (DNV) Pipelines Open Day

Singapore, November 23, 2012

Why Thermal Insulation?

- Subsea tiebacks with multiphase flow require flow assurance
- Thermal insulation is a key tool to ensure reliable operation of subsea flowlines and risers
- ’Dry’ and ’wet’ insulation systems available

Risers
- Single Pipe
- Flexibles

Flow Lines & Field Joints
- Single Pipe (Wet Insulation)
- Pipe in Pipe (Dry Insulation)
- Heated Systems
- Pipe Bundles

Subsea Architecture
- Custom Coating (Wet Insulation)

BREDERO SHAW

Flowlines – Thermal Insulation

- **Insulation is required to maintain temperature of fluid under two conditions:**
  - **Transient Condition**
    - If a field or well is shut down for maintenance, either planned or un-planned.
    - The fluid must maintain temperature. If temperatures, drop then blockages occur and start up is a problem.
      - Key properties are higher density and lower K values to reduce Thermal Diffusivity, store more heat and extend cool down time.
  - **Steady State**
    - Controlled Thermal Loss over Flow System during Normal Production. Maintain temperatures to ensure design flowrates met.
      - Key property is U value

Flowlines – Thermal Insulation

- **Improved seabed stability**
  - Higher density and weight stabilizes the pipe on the seabed
  - Thinner insulation with equivalent U value also stabilizes the pipe as currents have less effect
- **Subsea Tie-backs**
  - Low U values are required for long tiebacks
  - Sometimes wet insulation cannot meet the requirement

Risers – Thermal Insulation

- **Design to withstand continuous dynamic strain without failure**
- **Insulation may be needed to help “dampen” riser motion.**
  - Key properties are a higher density and stiffer insulation material to add weight and stabilize the riser
  - Thinner insulation also reduces effect of subsea currents
  - Riser systems must be capable of accepting a degree of flexing over the lifetime of the field
  - The alternative is to hang weights on riser

Subsea Architecture- Thermal Insulation

- **Concern with subsea manifolds, trees, jumpers, bends is cool down performance**
  - Key properties are:
    - higher density and lower K values to reduce Thermal Diffusivity, store more heat and extend cool down time.
    - Low water ingress for terminations

BREDERO SHAW

Subsea Thermal Insulation: Dry or Wet?

- **'Dry' insulation (Pipe-in-Pipe or PiP)**
  - Achieving low 'Overall Heat Transfer Coefficient' (OHTC) / U values of 1.0 W/m2K or less
  - The most commonly used insulation material is polyurethane foam
  - It is important to ensure that the structural integrity is maintained for both installation and operational loads (thermal insulation, linepipe, centralisers, waterstop seals, and loadshares)
  - Water ingress can cause corrosion and destroy the system
  - Has higher S-lay & J-lay installation costs
  - Limitations on pipe sizes and hence water depth capability:
    Outer pipe to resist hydrostatic pressure;
    Inner pipe to resist high pressures from deep-lying reservoirs

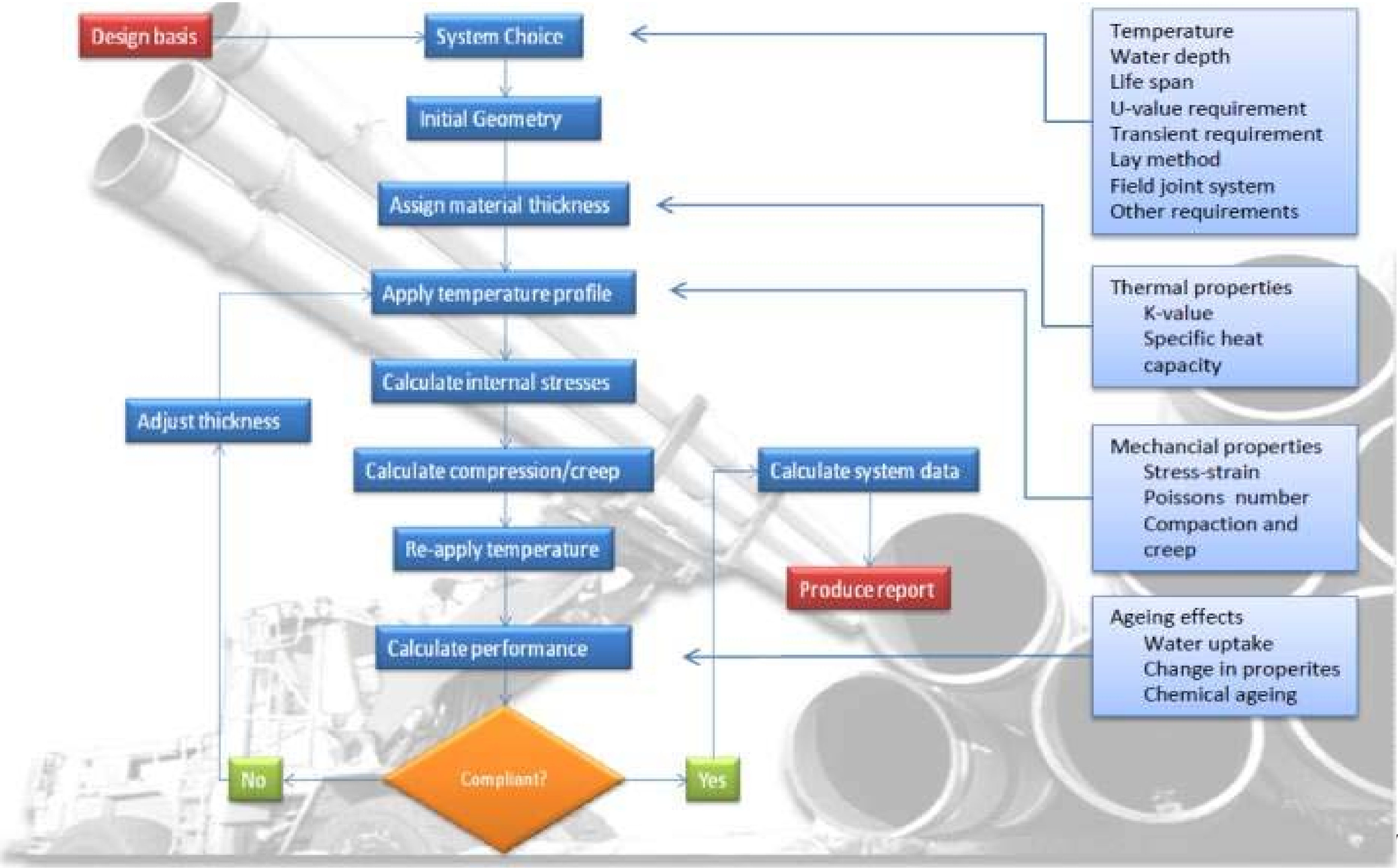
- **'Wet insulation' (Single pipe)**
  - Generally is more cost competitive than PiP
  - The main workhorse has been polypropylenes
  - Polypropylene is currently the standard steel catenary riser (SCR) insulation system

Challenges on Subsea and Deepwater Flow Assurance Insulation

- **Industry Trends**
  - Lower U-values
  - Deeper water
  - Higher temperatures (up to 150ºC)
  - 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
      - Heat loss coefficient (K-value)
      - Transient performance (K-value, Specific heat capacity, Density)
    - Mechanical performance – Response of system to hydrostatic load
      - Immediate (Stress-strain, Poissons number)
      - Long term (Compaction and creep)

BREDERO SHAW

Challenges on Subsea and Deepwater Flow Assurance Insulation



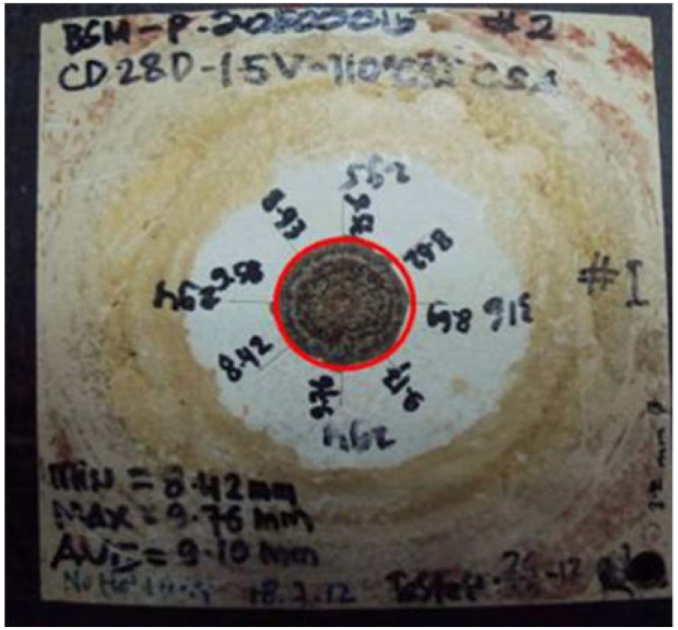
Examples of Difficult Insulation Projects

– **Chevron Wheatstone**	- 110ºC, 237 m, 30 yrs design life, tough spec
– **Statoil Åsgard**	**- 140ºC, 350 m**
– **Statoil Kristin**	**- 155ºC, 350 m**
– **BP Thunder Horse**	**- 132ºC, 2.200 m multi-layer on very heavy pipe**
– **Chevron Blind Faith**	**- 150ºC, 2.000 m, complex composite multi-layer**
– **Woodside Pluto**	**- Complex composite multi-layer on heavy pipe**
– **Shell Kizomba B SHRs**	**- Intricate PiP construction**
– **BP Block 31**	**- Extreme thickness on heavy wall pipe**
– **Total Pazflor**	**- High thickness**
– **BP Skarv**	**- Low U-value, multi-layer coating**

BREDERO SHAW

Challenges on Subsea and Deepwater Flow Assurance Insulation

- **A lack of widely acceptable industrial testing methods and standards for pipeline coatings and insulation materials for the new applications**
  - High temperature cathodic disbondment (CD) testing for temperature of $95^{o}C$ 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
  - Increased demands for simulated service testing to validate thermal and mechanical properties of insulation system



Can it be Both an Insulation and a Weight Coating?

- **Pluto LNG project:**
  - Consists of subsea wells tied into one subsea manifold and one pigging manifold in approximately 830 m water depth.
  - Two 27 km long, 20” (508 mm) flowlines transport the gas to a riser platform
- **A 7 layer coating for Insulation & Weight:**
  - 3LPP + 1 layer of Thermotite® Deep Foam (TDF) polypropylene insulation + 2 layers of a heavy aggregates-polypropylene blend + 1 layer of solid polypropylene
  - The material was successfully extruded to a density of 2000 kg/m3

Pipe End Preservation for Long-term Storage

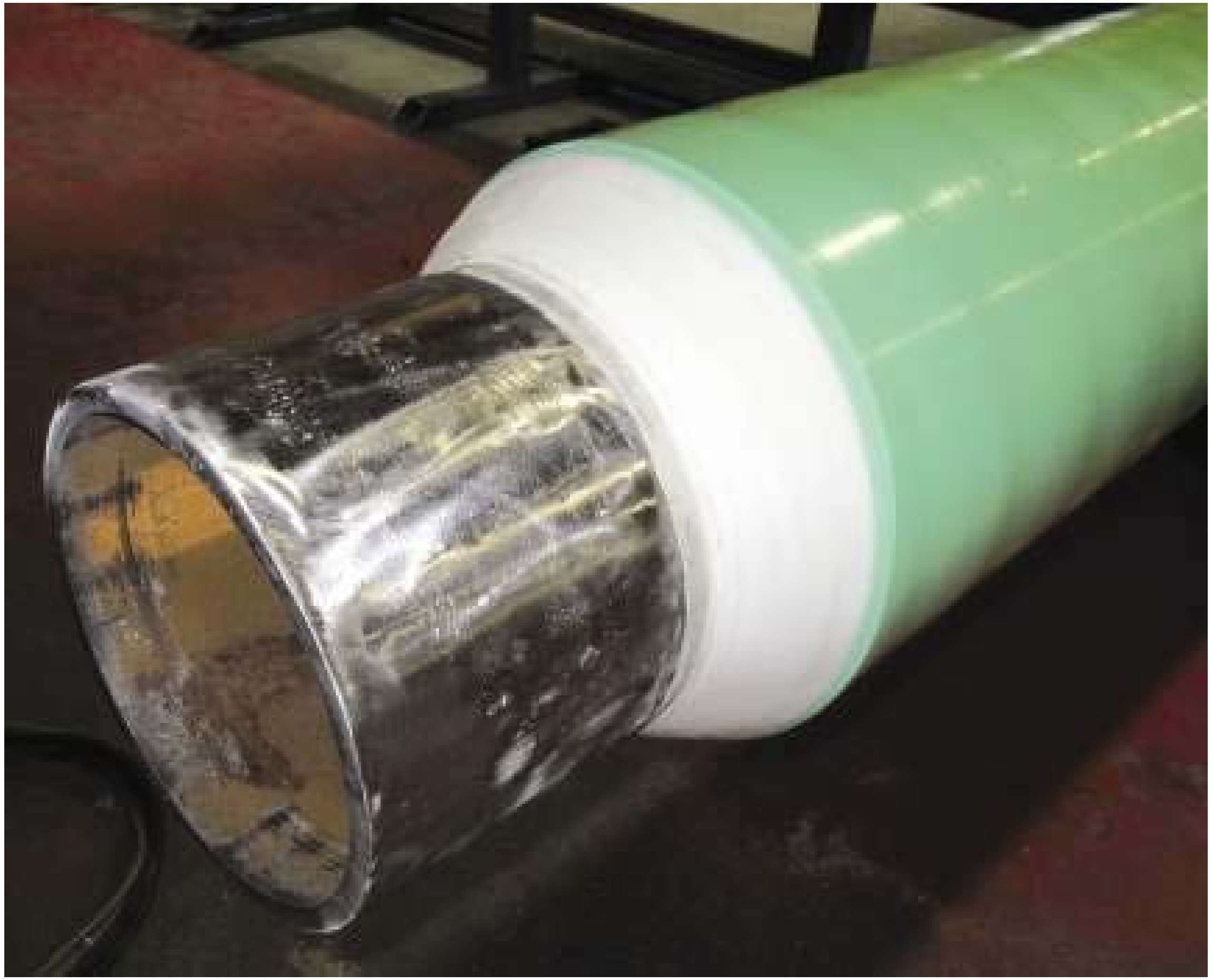

- Coated pipe can be stored in a tropical and marine environment for over 2 years
- Application of a temporary preservation paint/product is common but the removal process brings concerns on schedule, safety, performance and cost

Challenges on Subsea and Deepwater Flow Assurance Insulation

- **Base insulation materials have changed little and are still focused on polyurethane, polypropylene and epoxy foams and syntactics**
- **Limitations of the existing materials**
  - High installation cost
  - High thickness
  - Hydrostatic pressure limitations
  - Subsea stability
  - Temperature limitations

Material	Insulation Type	K-value (W/m.K)	Max. temp. (^{o}C)	Max depth (m)
Pipe-in-Pipe (Dry insulation)				
PUF (Polyurethane foam)	Foam	0.03-0.04	80 / 144	<200 (PE) / 3050 (steel)
Mineral wool	Rock fiber	0.04	700	3050 (steel)
Fibreglass	Spun mineral fibers	0.032	>150 (Steel PIP)	3050 (steel)
Micro-porous silica	Micro-porous ceramic	0.006-0.023	>150	3050 (steel)
Aerogel	Nano size silica	0.014-0.021	650	3050 (steel)
Single pipe (Wet insulation)				
Rubber (Neoprene / HNBR)	Solid	0.26 – 0.28	90 /140	>3000
Filled (Neoprene / HNBR)	Solid	0.12 – 0.14	90 /140	>3000
Syntactic epoxies	Syntactic	0.12-0.17	110	2800
Solid PU (Polyurethane)	Solid	0.19-0.20	90 wet /115 dry	>3000
sPU (Polyurethane)	Polymeric syntactic	0.13	90 wet /115 dry	250
GsPU (Polyurethane)	Glass syntactic	0.14 – 0.17	90 wet /115 dry	2800
PP (Polypropylene)	Solid	0.21 – 0.24	140	>3000
PPF (Polypropylene foam)	Foam	0.13 – 0.2	140	600 (2000 special formulation)
GsPP (Polypropylene)	Glass syntactic	0.17	140	2800

Thermotite® ULTRA™ —Next Generation Subsea Insulation



- Lower k factor than PP
- Lower film thickness for same insulation value
- No glass spheres
- Infinite water depth

BREDERO SHAW

Thermotite® ULTRA™ —Next Generation Subsea Insulation

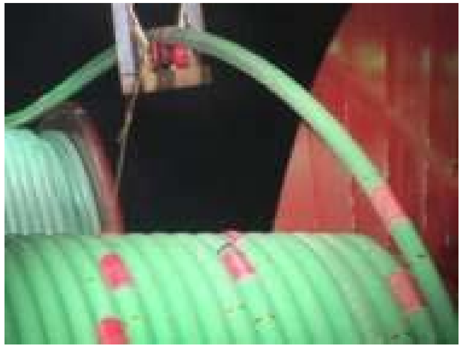
- Thermal insulation and corrosion protection system based on FBE and styrenic alloys.
  - Multi-layer ULTRA system comprised of a base 3 layer:
    - FBE
    - ULTRABond adhesive to bond FBE to ”ULTRA”
    - Solid ULTRA
  - One or more insulation layers of solid or foamed ULTRA
  - ULTRAShield high ductility outer shield

Solids •Density 1030 kg/m^3 •K-value 0.156 W/m.K
Foams •Density 740 – 850 kg/m^3 •K-value 0,115 – 0,145 W/m.K

BREDERO SHAW

Thermotite® ULTRA^{TM} —Next Generation Subsea Insulation


- **Winner of the Spotlight on New Technology Award at the Offshore Technology Conference 2010**
- **Balboa subsea tieback project in GOM: Mariner Energy and Ocean Flow International ("OFI")**
  - 10 km flowline in 975m WD
  - 47.6 mm foam system on 5.5625"X0.500" line pipe
  - Coating completed at Bredero Shaw in Pearland, TX in Q2 2010
  - Reel lay with Ultra Field Joint
- **ENI Goliat: Technip, OD 12" and 40 mm Ultra Foam, 2011**




BREDERO SHAW

ULTRA™ 120 Development

Qualification trials successfully conducted in August 2012 in Bredero Shaw Kuantan Malaysia, witnessed by DnV

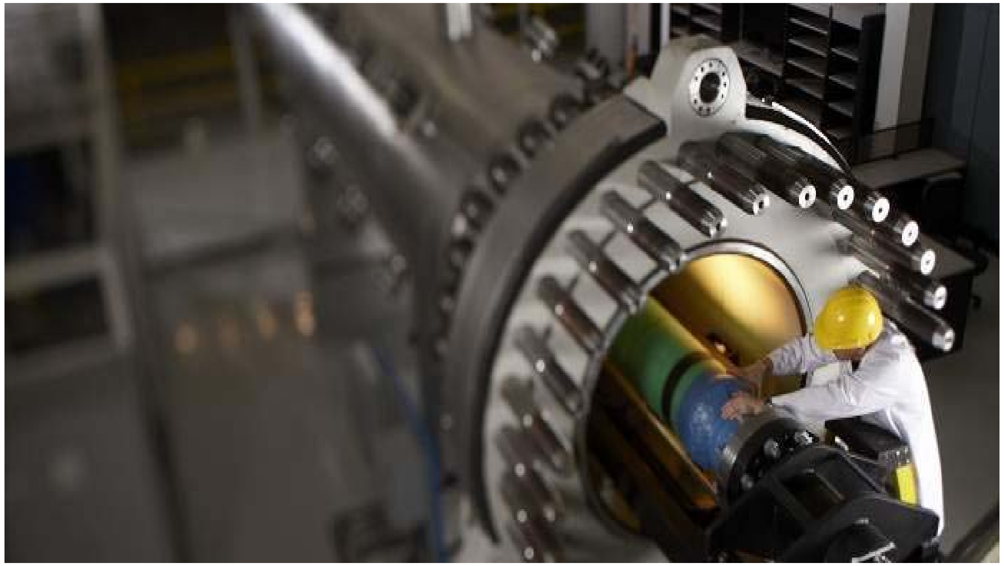
Increase in operation temperature through inclusion of heat barrier between ULTRA foam and FBE, using the extensively tested materials

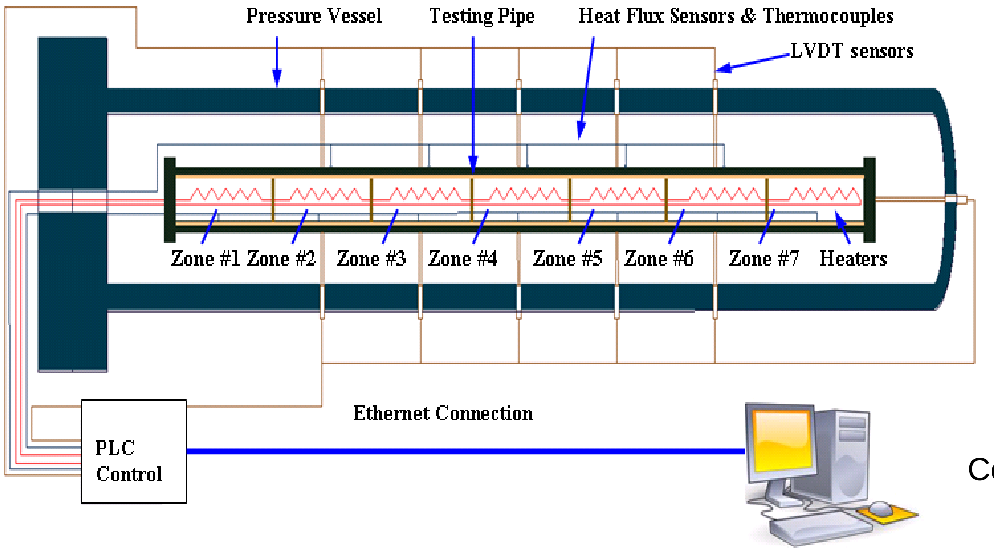
Development included:

- Development of high temperature styrenic adhesive / topcoat
- Development of higher temperature styrenic FJ infill
- Development of application processes

The Industry's Largest Simulated Service Vessel (SSV):

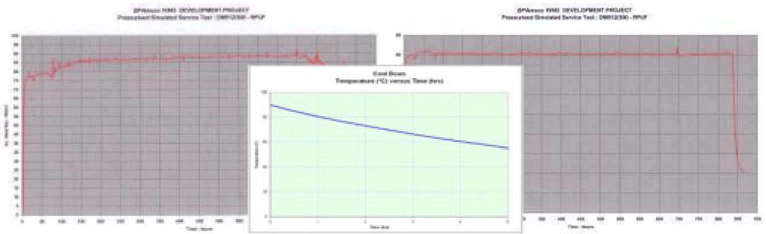
Winner of 2012 OTC Spotlight on New Technology Award





Capability/Property	Specification
Minimum Test Pressure	25 bar (± 2)
Maximum Test Pressure	300 bar (± 5)
Chilled Water Temperature Inside Pressure Vessel	4°C (40°F) (± 2)
Internal Temperature	20°C – 180°C (68°F – 356°F)
Sample Length	6 m (18') max
Vessel ID	1.2m (48"")
Number of Pipe Samples	one pipe
Pipe Inside Diameter	95 mm - 660 mm (4" - 26")
Pipe Outside Diameter (includes insulation)	145 mm - 810 mm (6" - 32")
Coating Thermal Conductivity	0.1- 0.3 W/m K (0.06 – 0.17 BTU / ft hr F)
Overall Heat Transfer Coefficient (U)	1.5 - 6 W/m^2 K (0.3 – 1.1 BTU / ft^2 hr F)

Creep
Cool Down
k factor

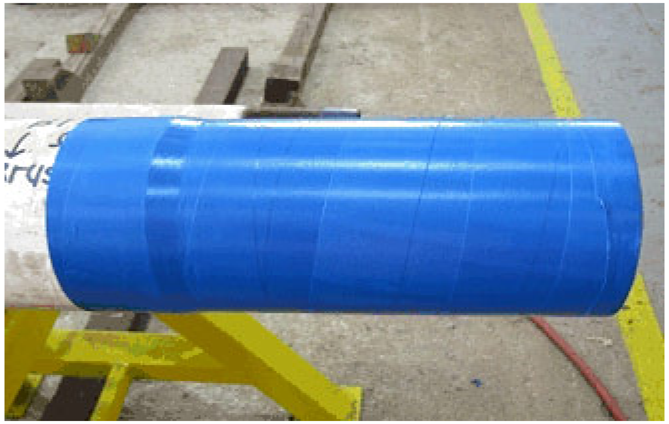


BREDERO SHAW

End Seal Tape for Coated Pipe End Preservation

An easily removable and durable plasticized tape, featuring a modified pressure-sensitive adhesive and a highly flexible backing with excellent abrasion and chemical resistance

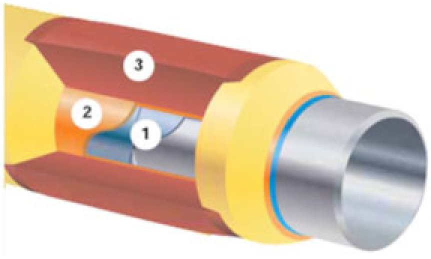
Before and after application

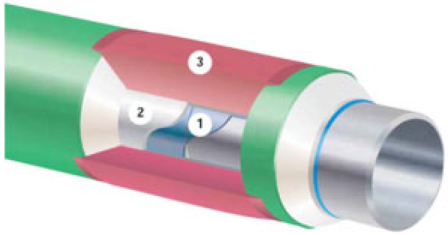


Removal after six months external exposure

BREDERO SHAW

End-to-End Solution including Field Joint Coatings Available in APAC





BREDERO SHAW

Closing Remarks

- As offshore pipeline installation in deepwater and ultra deepwater applications increases, technical requirements for subsea flow assurance insulation will continue along the following directions: longer tie-back, lower U value, deeper water depth, and higher operating temperatures.
- The challenges to the pipeline industry are to improve the conventional systems or to develop new insulation materials/technologies to address the new requirements, and to establish meaningful testing standards and capability to validate the performance of these improved/new insulation systems.
- To meet these challenges and requirements is not an easy task, but has been and will be possible through the joint efforts of all interested parties.