Development of an Ultra-High Pressure Deep Water Riser/Flowline – Challenges and Progress

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Innovation in Extreme Environment Technologies: High Pressure & Temperature
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Unbonded Flexible Pipe

Pipe consists of concentric layers of metallic wires, tapes and extruded polymers.

End fittings are custom designed. Each layer of the pipe individually terminated. Designed to assure a leak tight connection.

Withstand severe environmental loads and thermal cycling. Stronger than pipe in burst and axial tension. Allow for the venting of permeated gases.

Designed to form a structure that addresses the specific loads, environmental requirements and characteristics of the transported fluids.

Reeled for Transportation

Important layers – carcass; fluid barrier; pressure armour; tensile armour; anti-wear layers; external sheath (insulation; condition monitoring; annulus control).
Pipe Outlines and Key Design Considerations

**Riser**

**Structural integrity**
- Tension – weight
- Pressure / bending
- Temperature
- Dynamic service - fatigue

**Riser interaction**
- Installation
- Clashing
- Interference
- Entanglement

**Specific analyses**
- Global analysis
- Local analysis
- Armour stress analysis
- Gap span
- Corrosion fatigue
- End fitting analysis

**Pipe Connection**

**Touch down point**
- Abrasion
- Local armour buckling (bird-caging)

**Flowline**

**Structural integrity**
- Pressure/bending -static service
- Temperature

**Fluid medium**
- Oil & gas (mixture)
- Increasingly sour
  - H₂S, permeated gas
- Rapid depressurisation

**Market Demand**
- Design Pressure (kpsi)
- Water Depth (km)
- Operating Temp (°C)

Graphs showing trends from 1980 to 2020 for various parameters.
Flexible pipes for high pressure & deep water
Only need a flexible tube (fluid barrier) !!!

1. Carcass (Flexbody™)
Prevent buckling of polymer tube under external pressure
Limits water depth
Limits the diameter

2. Pressure Armour (Flexlok™ / Flexpress™)
Prevent bulging of polymer tube under internal pressure.
Limits design pressure
Limits the diameter
Can be multi layer
Need Sacrificial layer for high pressure

3. Tensile Armour (Flextensile™)
Prevent extension of polymer tube under weight/axial load.
Limits water depth
Several wires
Multi-layered
Fatigue resistance (sweet/sour)

4. Anti-wear Layers (Flexwear™)
Prevent rubbing between metal layers
Limits pressure
Fatigue durability
Annulus Conditions

5. End Fittings - Leak free fluid barrier seal
Termination of carcass, pressure armour and tensile armour wires

6. Installation Requirements

Key design features
Strength, durability & integrity
Temperature performance,
Aging behaviour, Fluid compatibility

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Aim of the Project

Development of a 4 inch (100 mm) diameter riser/flowline for 20kpsi (1200 bar) design pressure and 3 km water depth to operate at 100°C maximum temperature and to transport gas/fluid under mild sour conditions

Key Technical Challenges

• Maintaining the integrity of the polymer barrier
  Withstand rigorous service temperature and pressure.
  Compatibility of barrier with service fluids under high pressure
  Ensuring barrier integrity during service life, thermal cycling, shut-down
• Design of a suitable carcass to resist wet collapse at ultra-deep water
• Selection of metallic hoop armour layers to resist high internal pressure
• Limiting the weight of the pipe and achieving necessary axial stiffness/strength
• Evaluation of layer interaction in two pressure armour layer design
• Development of end fittings with proven seal integrity
• Completion of FAT and offshore field tests without any detrimental effect on pipe
• Achieving necessary bending requirements and packaging
• Ensure damage free dynamic interactions between metal layers
• Safeguard integrity of the pipe under rapid depressurization conditions
• Satisfy Industry design standards (ISO 13628-2)
Design of Fluid Barrier

Material - Depends on service temperature: below 60°C – PA or PE and above 60°C PVDF (or PEX/PPS)

Design Criteria (API 17J) - Static (flowline) require ±7% few cycles + 7% strain for 25 year service (PVDF)  Dynamic (riser) require ±7% few cycles + cyclic ±3.5% strain performance.

Additional Requirements – Manufacture / storage / FAT/ installation  Operation (normal / extreme / abnormal)

Developing HP & HT Barrier - Challenges

Polymer crazing at high hydrostatic stress

Rapid Gas Depression (RGD)

Crazing can occur in places of high local Plastic strain if not controlled through design, materials or mitigated through treatment.

Blistering can occur in some materials if depressurisation rates exceed certain limits.
Developing HP & HT Barrier – Barrier Integrity (Fatigue)

Removing Inner wear layer is considered to be beneficial in high pressure pipes as this facilitates easier additional treatment of the barrier layer to prevent crazing (using GE patent pending technologies). This requires proper design of the polymer barrier for service integrity.

Polymer creep into armour gaps

Polymer flow into carcass gaps

Acceptable profile shapes have been identified and the manufacturing procedures and controls have been established and implemented to ensure production of acceptable barrier profiles.
Carcass Capability (Limits Inner Diameter of the Pipe)

Carcass prevents inward collapse of the fluid barrier due to external pressure, typically resulting from operating water depth. (API 17J defines utilisation of 0.85 based on yield strength)

New material options and design improvements

- New materials (higher yield strength)
- Increased Collapse Resistance (modification to section)
- Improve prediction capability - modelling work hardening
- Corrosion resistance
- Additional barrier support
- Elimination of flow induced vibration

Based on the API assessment procedure the collapse capacity predicted for 100mm / 4-inch pipe is 3.5 km sea water depth. Actual qualification test data shows that a 150 mm/6-inch pipe can withstand 4 km water depth (before safety factors are applied for design purposes).

Based on wet collapse test data safe carcass design available for over 3 km water depth.
Pressure Armour Capacity

Function of the pressure armour is to resist internal & external pressure and give strength in the hoop direction during manufacture, installation and operation. Provide a guard against creep extrusion of the polymer.

HP Design Criteria

Based on available carcass design for 3 km water depth maximum pipe internal diameter is limited to 150 mm. Due to manufacturing limitations the pressure armour wire thickness needs to be below 12 mm. Single pressure armour (8 mm and 10 mm) insufficient to achieve design pressure of 15kpsi

**Dual pressure armour required** - 8 (+8) mm wire scan give 15 kpsi
10 (+10) mm wires can give 20 kpsi
Tensile Armour Capacity

Multiple helically formed wires - Support axial load (mainly due to weight). Pairs of contra-wound layers to give torsional stability. Lay angle optimised during pipe design to balance axial capacity and hoop strength, giving additional support to the pressure armour layer.

The high strength requirements coupled with the suspended riser length result in a very heavy structure and corresponding high topside loads.

Tensile wire buckling resistance is also a consideration. The minimum bend radius of the pipe depends on water depth.
Buoyancy Requirements of HP Deep Water Pipes

**2 Tensile Armour Design – New Materials**  
(2 x 90 tonnes buoyancy)

- Top Tension
- Allowable Tension  
  (~Installation Limit)
- Top Tension with stepped buoyancy

**4 Tensile Armour Design**  
Current Materials  
(2 x 214 tonnes buoyancy)

New Armour Materials

Alternatives to the current carbon-manganese steels:

- Required Properties,
  - Mechanical strength, weld and corrosion properties
  - Confirm potential ‘improvement’ in capability using design software
  - Ability to form and deliver suitable wires to the required profile
  - Ability to wrap and weld using available manufacturing machines
  - Technical and economic feasibility.
High Pressure End Fitting

End fitting is an essential component of flexible pipes enabling their connection between moving structures and pipes to make complete pipe infrastructure.

**Key Functions** -
- Effective barrier seal
- Termination of all layers
- Anchoring tensile armour
- Transfer of external loads

**Barrier Seal**

Before swaging

Outer taper of seal ring engages with the inner taper of the end fitting body.

Seal ring is plastically deformed creating highly localized contact pressure at the contact edge.

After swaging

Maximum contact pressure at the interface changes with applied internal pressure

Maximum contact pressure must be greater than leak criteria to maintain a seal

New end fitting designs proven to work above 30 kpsi
Anti-Wear Tapes

Anti-wear tape layers are used to prevent direct contact between the reinforcement layers. The contact stresses in HP pipes are significantly high, leading to an increased risk of fretting or contact fatigue of the metallic wires.

In flowlines these tapes are subjected to static non-uniform compression whilst in risers these may be subjected to compression loading with dynamic slip.

New Tape Material
- High performance materials
- Interlayer interaction – friction, wear, damage mechanisms
- Wear models – prediction of service life
- Environmental effects – temperature, annulus conditions
- New experimental facilities
Composite Pipe Design

Composite Smoothbore  Composite with metal Carcass

200 mm/ 8 inch ID Pipe. 15% OD reduction
Reduction of Mass/Top Tension A B
60% 55%

Composite Armour - Optimized fiber angles and thicknesses to meet design requirements
Bonded Liner/Barrier - PVDF - with high chemical resistance; reduced permeated gas risks
Thermoplastic Matrix - PVDF - qualified material
Carbon Fiber - Not susceptible to environmental stress corrosion; chemically resistant

Flow Induced Pulsation

Flow induced pulsation can affect the dynamic performance of the pipe. This is pronounced when transporting gas in deep water pipes.

New design technology has been used to develop pulsation free carcass profiles (GE patents pending)

Condition Monitoring

the MAPS® wire stress and wire break monitoring and inspection systems, integrated fibre optic sensors embedded within the pipe structure, and topsides equipment for the monitoring of polymer and pipe annulus condition.
Summary - Key Challenges & Progress

High pressure ultra-deep water flexible pipe

- Validate dynamic performance
- Managing weight and strength
- Integrity of polymer barrier
- Passing FAT and offshore field tests
- Burst/design pressure ratio

Future Developments

- Packaging and bending limits
- Manage interaction between layers
- Rapid depressurisation (multilayer barrier)
- Achieve seal performance
- Integrity of end fittings

New Technology Developments

- Manage tensile capability
- Prevent collapse (carcass)
- Resist internal pressure (Flexlok)
- Comply with design standards
- Burst/design pressure ratio

Existing Technology

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END - Any Questions?

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