Subsea Produced Water Separation with SpoolSep:
A Robust and Efficient Pipe Solution for a Wide Range of Deepwater Applications

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AGENDA

- Subsea Oil/Water Separation
- SpoolSep Principles
- Installation and Maintenance
- Qualification tests
- Conclusion
Subsea Oil/Water Separation

- **Subsea Produced Water Separation and Re-Injection**
  - Increase recovery
  - Debottleneck topsides
  - Allow new tie-back to existing facility

- **SpoolSep for Subsea Bulk Water Removal**
  - Made of several horizontal pipes working in parallel
  - Dedicated to deep/ultra-deep waters & high internal pressure applications
  - High flowrates
SpoolSep Principles

Main incentives
- Gravity-based Separation (field proven & robust process)
- Made of long parallel pipes with reduced thickness compared to large pressure vessels to cope with Deep & Ultra Deepwaters
- Higher interfacial areas / lower rising distance for oil droplets (improved efficiency)
- Good slug handling capabilities
- Modular system: based on deepwater spools design
- Flexible design to cope with wide range of inlet parameters

Design principles
- Ensure equal fluid distribution
- Same Process control philosophy as per single vessel
- Provide required residence time for efficient oil/water separation
SpoolSep Principles

Spool outlet: several options
- Independent outlet for each phase
- Oil and gas recombination (stand pipe) + water outlet

Process criteria:
- Phase velocity
- Residence time / Cut-off diameter

Selection of:
- Number of spools
- Spool diameter
- Spool length

Design

Typical Performances

Downstream bulk separator
- Maximum OiW: 1000-2000 ppm
- Maximum WC in oil stream: 15%

Re-injection requirements
- OiW: 20-100 ppm
- TSS: 1 to 10 ppm
- Solid particle size: 1-50µm

Inlets & Outlets in the same area

Multiphase production from wells
Water Injection Pumps (O/W interface control)
Oil and Gas exported to surface (MPP) or separately
Subsea Station Design

- **Subsea Station Architecture**
  - 1 or 2 foundations
    - 1 for the station with all the process
    - 1 smaller for pipes support (if needed)
  - 1 subsea station with connecting all the equipments
    - All active parts gathered on same structure
    - Standard integration and test principle

- **Separation spools modules**
  - Within typical spool size envelop
  - Optimization of layout with compact connection
  - Retrievable by IMR vessels
Separation Spool Module

- **Spool Outlet**
- **Separator Inlet**
- **Feed Line**
  - OD 8” typ.
- **Pipe separator**
  - OD 18” to 50” typical
- **Overall length**
  - 10 to 70 m typical
- **Height**
  - 4 to 6 m
- **Separator Outlet**
- **1 off 3-bores clamp connector**
- **Or**
- **1 off dual-bore clamp connector**
- **+ 1 off single bore clamp connector**

Feed Line (Overview):
- **Separation Spool Module**
- **Spool Inlet**

Aker Solutions
Installation and Maintenance

- Typical subsea module handling
- Optimized connection for easier ROV operation
- Standard installation sequence
- Easy Spool recovery
Qualification Tests

- **Phase 1: Design Feasibility**
  - Fluid distribution & level symmetry
  - Gravity separation efficiency
    - Tests loop built with 4 spools at reduced scale (200mm ID, 18m long)
    - Model oils/Tap Water/Air Flows at ambient conditions for visualization
    - Variation of operating conditions: flowrates / WC/ GVF/ shear level
  - Sand settling & flushing characterization

- **Phase 2: Design improvements & process criteria validation**
  - Comparison of several geometries to further improve performances
    - Tests on each spool arranged with specific outlet
    - Internals
Qualification Tests

- Characterization of Horizontal Flow Patterns

- Gas/Liquid Flows
  - Slug Flow
  - Stratified Smooth Flow
  - Stratified Wavy Flow

- Liquid/Liquid Flows
  - Stratified Flows
  - ST & MI
  - DO/W & W
  - DW/O & OW

- Symmetrical behaviour whatever the flow regimes
- Assessment of flow regimes impact on performances and level control requirements
- Definition of velocity criteria to ensure separated phases with required quality
Qualification Tests

- **Validation of Flow Distribution / Level Symmetry & Stability**

  - Equal fluid distribution and balanced phase composition inside each spool
  - Symmetrical behavior of spools: validation of the base principle for level control philosophy
  - High level stability at separation conditions

- **Design Criteria for SpoolSep Sizing**

  - Assessment of design criteria for the range of 100 to 2000 ppmv Oil in Water contents

  ➤ Tests have confirmed separator operability giving design criteria to achieve required performance
Qualification Tests

- **Sand transport depends on:**
  - Liquid velocity and viscosity \( (Re) \)
    - Critical velocity, \( V_c \)
    - \( V_c \) increases with increased viscosity
  - Sand granulometry
    - \( V_c \) increases with increased particle size
  - Carrier fluid flow pattern
    - At low velocity, no impact of gas (if stratified flow)
    - At high velocity, easier transport under slugging flows
  - Pipe slope has a significant impact on sand transport

- **Sand handling optimization (no need for internals)**

- **Tests conditions:**
  - Pre-installation of a sand bed in a 110 mmID pipe
  - 2 particle sizes: \( d_{50} \) 64µm & 248µm - 2650 kg/m³
  - Oil or water wetted sand
  - 2 sand bed heights (10%-30% HU)
  - Flowing with different fluids
CONCLUSION

- As part of Subsea Processing systems, the SpoolSep brings robust solution to PWRI applications in deepwater
- Each separation spool can be installed and retrieved easily by subsea connectors
- Confirmation of stability and symmetry of flows within separation spools
- Reliable design to achieve required performances for water re-injection
- Better understanding of criteria for efficient sand transport by fluid flowing
- SpoolSep design flexibility (spool number, diameter and length) allows to accommodate wide range of requirements and conditions
- On-going JIP with TOTAL & PETROBRAS