Evaluation of Scenarios Associated to Subsea Gas-liquid Separation in Pre-Salt Fields: Opportunities and Technological Challenges

Denise Diniz

Co-authors: Fabio M. Passarelli
Lidiane M. Rosati
Marcelo L. Gonçalves
Rodrigo P. Resende

Joint Venture Operator

All rights reserved
SUMMARY

❖ WORK MOTIVATION
❖ MAIN CASE STUDY
❖ OPPORTUNITIES AND CHALLENGES
❖ CONCLUSIONS
WORK MOTIVATION

❖ High productivity wells and high original GOR → gas processing plants as a limiting factor for oil production, due to its occupied physical area and weight.

❖ Concept alternatives to deal with high gas flow rates → different scenarios of gas management like subsea separation system and or gas reinjection into the aquifer or gas export.
MAIN CASE STUDY: MERO FIELD
MERO FIELD NW:

→ 170 km from coast;

→ 11 drilled wells;

→ 3 completed wells.
MAIN CASE STUDY – BASE CASE

- Satellite production and injection wells;
- Production wells connected to FPSO by 8” ID production lines and 4” ID service lines (pressure rating of 5,000 psi);
- Injection wells connected to FPSO by 6” ID injection lines (pressure rating of 9,000 psi). Loop for each 2 injection wells, connected by a jumper between their annular side at X-tree;
- Total gas reinjection into the reservoir zones.
MAIN CASE STUDY – BASE CASE

Increasing GOR will constrain oil production

Investigate ways to better manage the gas and optimize recovery

Investigate Gas Behavior and derisk Gas Management alternatives
MAIN CASE STUDY – ALTERNATIVES

→ **Gas Management scenarios**: Increase of oil production due to the reduction of gas flowrates at FPSO through:

- Partial gas reinjection into the aquifer;
- Partial gas export through FPSO + first option;
- Gas export (produced gas) to a gas hub;
- **G/L subsea separation** (1 system per FPU) sending the gas to a gas hub;
- **G/L subsea separation** (1 system per FPU) reinjecting directly the separated gas into an injection well.
MAIN CASE STUDY – ALTERNATIVES

→ 12 reservoir scenarios for Hi-Sep
(No aquifer inj ↔ aquifer inj / Well optimization or not)

- **MERO 2**
  - FEL 3 Approval
- **MERO 3 AND 4**
  - FEL 3 Approval

**Today**
- Hi-SEP on Mero 2 as Qualifier, later 3 & 4
  - (lower maturity)

**Milestone 1**
- **A**

**Milestone 2**
- **B**
  - Hi-SEP on Mero 3 as Qualifier, later 2 & 4
  - (higher maturity)

**Milestone 3**
- **C**
  - Hi-SEP on Mero 3 as Qualifier, later 4
**MAIN CASE STUDY – ALTERNATIVES**

→ **SUBSEA GAS/LIQUID SEPARATION TO A GAS HUB:**

1. **Gas Export**
   - CO₂ and H₂S removal
   - Gas dehydration
   - Capacity: 12 MM Sm³/d
   - Gas Export (CO₂ < 3%)

2. **Reinjection of CO₂ rich stream into aquifer**
   - CO₂ ~ 85%

3. **Produced Gas**
   - Q_gas: 0.5 - 4 MM Sm³/d
   - CO₂: 44 - 60% (flash)
   - H₂O up to 100 ppmV

4. **Reinjection of produced gas dehydrated**
   - (Injection wells)

**Gas Hub**
- Psep = 55 bar

**FPU**
- No CO₂ removal
- Gas dehydration
- Capacity: 12 MM Sm³/d
- Separation pressure: 25 bar

**Subsea Hi-Sep**
- Psep = 200 bar
- Tsep = 70 °C

**Production Wells**

---

*Service line*  
*Production line*  
*Gas Line*
MAIN CASE STUDY – ALTERNATIVES

1. Gas injection into aquifer from gas hub (rich CO₂ stream)

6” and 8” – flexible line / 6.5” – rigid line
Flowline length: 13 and 21 km
Gas export from gas hub to a pre-salt gas route (treated gas)

Flowline length: 20 km
MAIN CASE STUDY – ALTERNATIVES

3. Liquid production from Hi-Sep to FPU

Flowline length: 5 km
MAIN CASE STUDY – ALTERNATIVES

Liquid production from Hi-Sep to FPU

Production with Hi-Sep - MERO 4
Rigid line 8" - TEC 4 W/mK - Tsep - 70°C

- Production Forecast
- Flow Rate Capacity (Hi-Sep)
Gas flow from Hi-Sep to gas hub

Flowline length: 7 km
MAIN CASE STUDY – MERO FIELD

→ SUBSEA GAS/LIQUID SEPARATION & GAS REINJECTION:

Injected Gas:
- Qgas: 2 - 4 MM Sm³/d
- CO₂: 44 - 60% (flash)
- Dehydrated

No CO₂ removal
- Gas dehydration
- Capacity: 12 MM Sm³/d
- Separation pressure: 25 bar

Psep = 200 bar
Tsep = 70 ºC

Service line
Production line
Gas Line

Injected Gas:
- Qgas: 0.5 - 4 MM Sm³/d
- CO₂: 44 - 60% (flash)
- H₂O up to 100 ppmV

Subsea Hi-Sep

Production Wells
Injection Wells
MAIN CASE STUDY – MERO FIELD

1 Gas injection into aquifer from Hi-Sep (separated gas)

Max available BHP - \( Q_{\text{gas}} = 4 \text{ MM Sm}^3/\text{d} \) and \( P_{\text{disch Hi-Sep}} = 620 \text{ bar} \)

Sensitivity Analysis for ID (TEC 4 W/mK)

To respect \( T_{\text{min}} = 35 ^\circ \text{C} \)
MAIN CASE STUDY – MERO FIELD

Injection BHPs at Injection Curves

- GAS INJ MERO 2
- GAS INJ MERO 3
- GAS INJ MERO 4

Q injected gas
2 – 4 MM Sm3/d

<table>
<thead>
<tr>
<th>Hi-Sep Injector</th>
<th>Distance (m)</th>
<th>Reference depth (m)</th>
<th>P_fract at reference depth (bar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRO2</td>
<td>3463</td>
<td>5700</td>
<td>814</td>
</tr>
<tr>
<td>MRO3</td>
<td>4150</td>
<td>5452</td>
<td>785</td>
</tr>
<tr>
<td>MRO4</td>
<td>30</td>
<td>5452</td>
<td>785</td>
</tr>
</tbody>
</table>
MAIN CASE STUDY – MERO FIELD

2. Liquid production from Hi-Sep to FPU

Flowline length: 5 km
OPPORTUNITIES AND CHALLENGES

NPV GAINS (reference: Base Case)

- Base Case: Gas Injection into Reservoir
- Gas Injection into Aquifer
- Partial Gas Export via FPUs
- Gas Export via Gas Hub
- Hi-Sep + Gas Export via Gas Hub
- Hi-Sep + Gas Injection into Aquifer

Oil and Gas Prices

- Scenario A
- Scenario B
- Scenario C
OPPORTUNITIES AND CHALLENGES

→ Reservoir

❖ Uncertainties about injectivity into aquifer.
❖ Investigation of gas behavior from injector wells to producers wells.

→ Topsides

❖ Technical solution to supply extra power demand at FPUs.
❖ Gas hub: limitation on gas capacity due to the high gas inventory with high CO₂ content, weight increment and higher lead time.
OPPORTUNITIES AND CHALLENGES

→ Maturity degree of Hi-Sep Components

❖ Most of the components: TRL = 7
❖ Some of the components: 3 < TRL < 6

<table>
<thead>
<tr>
<th>TRL Scale</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Unproven / Ideal Concept</td>
</tr>
<tr>
<td>1</td>
<td>Concept Demonstrated</td>
</tr>
<tr>
<td>2</td>
<td>Concept Validated</td>
</tr>
<tr>
<td>3</td>
<td>Prototype Tested</td>
</tr>
<tr>
<td>4</td>
<td>Technology Qualified for first use</td>
</tr>
<tr>
<td>5</td>
<td>Technology Integration Tested</td>
</tr>
<tr>
<td>6</td>
<td>Technology Installed and Performing</td>
</tr>
<tr>
<td>7</td>
<td>Proven Technology</td>
</tr>
</tbody>
</table>

Probability Of Success (PoS)
CONCLUSIONS

→ Technical View (1/2):

❖ Gas injection lines: the adoption of 8” ID commits with the maximum discharge pressure at Hi-Sep, not achieving the fracture pressure, for the base case scenario of injectivity index.

❖ For a pessimistic scenario of injectivity index (mainly into aquifer), the oil production gains may be reduced due to the limited gas reinjection flow rates (higher BHPs).

❖ Need of LDHI continuous injection for gas injection / export lines (hydrate prevention during shutdowns), product that still depends on experimental analysis for validation.
CONCLUSIONS

→ Technical View (2/2):

❖ Possibility of optimization on reinjection capacity considering the reducing of temperature discharge at Hi-Sep (some gain in scenarios when the equipment is closed to injection X-tree).

❖ Uncertainties must be mitigated regarding the aquifer injectivity.

❖ Maturity degree of some subcomponents for Hi-Sep is low and depends on the successful de-risking phase.

❖ Technical solution has to be developed to supply extra power demand at FPUs.
CONCLUSIONS

➔ Strategic View (1/2):

❖ Reducing gas production uncertainties at Mero field scale via field production is a must to validate all FPUs forecasts and the production gains associated with gas management.

❖ Gas injection into aquifer is an attractive alternative, due to its oil gains for providing gas debottlenecking, compared to current base case scenario.

❖ Hydrocarbon gas export scenarios, evaluated over a wide range of oil production gains and economic parameters, showed erosion of value when compared to gas reinjection.
CONCLUSIONS

→ **Strategic View (2/2):**

- Gas liquid subsea separation reinjecting the produced gas, which implementation depends on its maturation, has the highest gas debottlenecking impact on oil production leading to significant gains and value creation.
Thank You!
Questions?