Flow Assurance Challenges in Deepwater Brazil Pre-salt

Adriana Teixeira

Petrobras

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Flow Assurance Challenges in Deepwater Brazil Pre-salt

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Outline

1. Brazilian pre-salt
2. CO_2
3. Wax
4. Hydrates
5. CO_2 separation and injection
6. Final remarks

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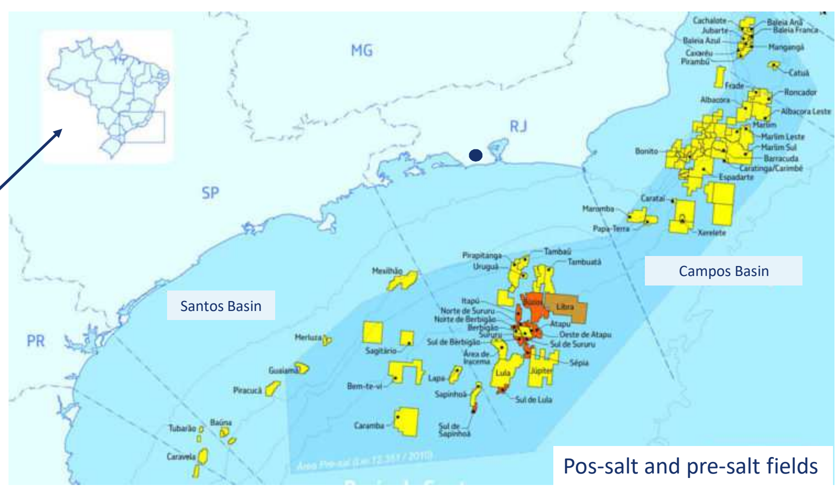
1. Brazilian pre-salt

1. Brazilian pre-salt

a) Location



Pos-salt and pre-salt fields

https://petroleohoje.editorabrasilenergia.com.br/indicacao-de-areas-por-agentes-economicos/

1. Brazilian pre-salt

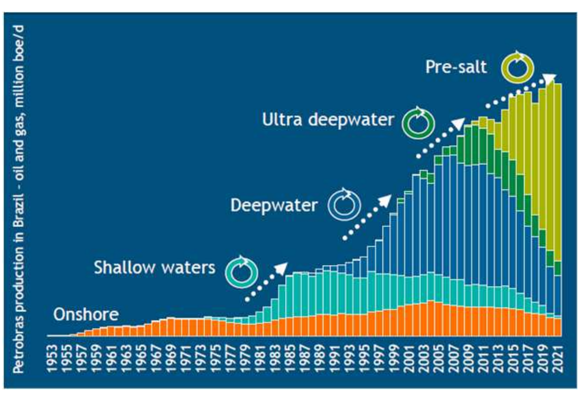
a) Location

OTC 2015 - Petrobras

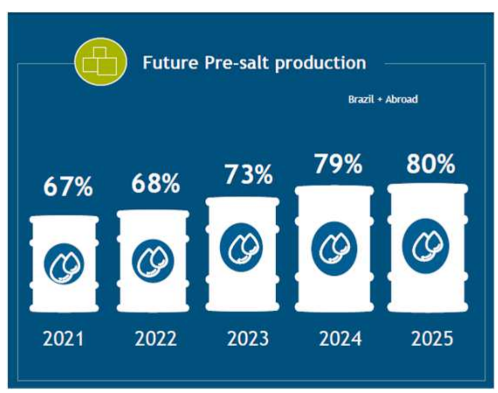
https://www.youtube.com/watch?v=dJMlsTw2BU4

1. Brazilian pre-salt

b) Petrobras production



Cumulative production until jun-2021



2015: 700 kbpd
2021: > 2000 kbpd

https://www.investidorpetrobras.com.br/en/presentations-reports-and-events/presentations/

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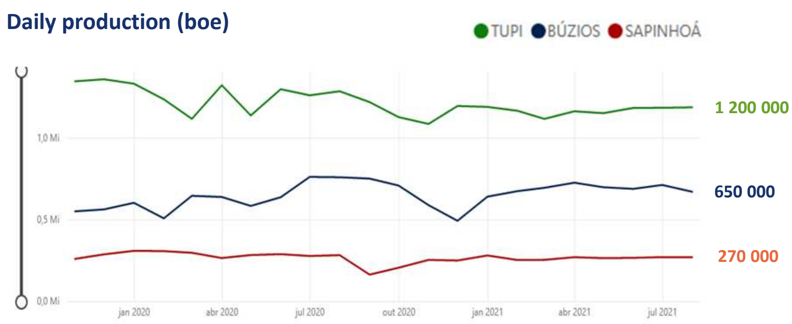
1. Brazilian pre-salt

b) Petrobras production



https://www.gov.br/anp/pt-br/centrais-de-conteudo/paineis-dinamicos-da-anp/paineis-dinamicos-sobre-exploracao-e-producao-de-petroleo-e-gas/paineis-dinamicos-de-producao-de-petroleo-e-gas-natural

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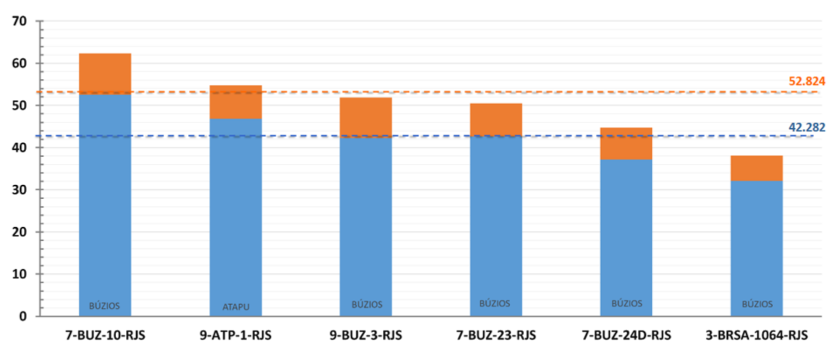
1. Brazilian pre-salt

b) Petrobras production

Daily production (kboe)
Nov 2020



https://www.presalpetroleo.gov.br/ppsa/conteudo/psemn_jan21_ref-nov20_c_co.pdf

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1. Brazilian pre-salt

c) Reservoir

- Area: 140 000 km^2
- Distance from coast ~ 300 km
- Total depth ~ 6000 m
- Carbonates

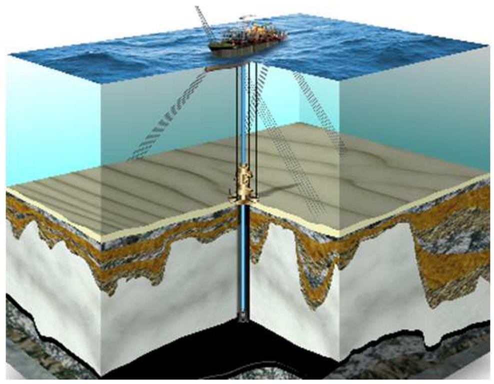
Production:

Gas:

- Injection
- Exporting lines

Oil:

- Offloading



https://www.presalpetroleo.gov.br/ppsa/o-pre-sal/caracteristicas

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1. Brazilian pre-salt

d) Fluids characteristics

Characteristics

- 26 - 32º API
- TAN 0.1 mgKOH/g
- High GOR ~240 m^3/m^3
- High CO_2: 1 - 50%
- H_2S ~ 200 ppmv
- High salinity produced water (> 100 000 ppm)

- Natural flow / Gas lift
- WAG method (EOR)

Some Flow Assurance Challenges:

- High GORs
- High flowrate production
- Scale risk ($CaCO_3$ / $BaSO_4$)
- Asphaltenes deposition
- Wax deposition, gelification and yield stress
- Hydrates – WAG; shut-in/startup operations
- Modelling accuracy (thermodynamic and flow models)
- Pipelines integrity (corrosion; SCC-CO_2)
- Reliable chemicals injection systems

- **(Petrobras)** Naveiro, J. T. and Haimson, D., Sapinhoá Field, Santos Basin Pre-Salt: From Conceptual Design to Project Execution and Results, **2015**, OTC 26320.
- **(Petrobras)** Noville, I. et al, Flow Assurance in Buzios Field: Key Challenges and Implemented Solutions, **2021**, OTC-31277-MS.
- **(Petrobras)** Silva, V. et al, Buzios Drainage Strategy: A Combination Of Reservoir Characterization,Risks Mitigation And Unique Contract Features, **2021**, OTC-31170
- **(Petrobras)** Mattoso, M. P. and Pimenta, M. G., Buzios FPSO Experience: Standardization and Perspectives for Our Next Generation of Pre-Salt FPSOs, **2021**, OTC-31074

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Webinars

2. CO_2

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2. CO_2

Webinars

Challenges:

- **Modelling of high CO_2 content fluids**
  - Need to improve thermodynamic and flow simulators models to accurately predict fluids behavior during production.
  - Experimental data are important to validation and tuning of models.
- **Corrosion and integrity problems [SCC – CO_2 (CO_2 Stress Corrosion Cracking)]**
  - Better comprehension on CO_2 corrosion effects in flexible pipelines
  - **(Baker)** Brandão, M. et al, Flexible Pipes Subjected to SCC CO2, Review and Means to Increase Reliability on Service Life Applied to Brazilian Pre-Salt Fields, **2021**, OTC-31135
- **Scale formation**
  - CO_2 + high salinity brines may elevate the scale potential in reservoir and in pipelines. Need to understand the roles of fluids composition / reservoir interactions / inhibitors performance to do a correct scale management.

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2. CO_2

Challenges:

- **Asphaltenes precipitation**
  - CO_2 may destabilize asphaltenes both in reservoir and production pipelines. Fluids characterization is again important to correctly address prevention and mitigation risks.
- **Wax**
  - Need a better understanding on the influence on WAT, yield stress and deposition. Modelling.
- **Hydrates**
  - More studies on the influence on hydrate formation process (kinetics, agglomeration).
- **Emulsion Stability**
  - Better understanding on the destabilization of water-in-crude oil emulsions when CO_2 is present.

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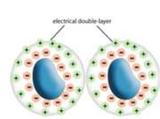
2. CO_2
Emulsions

Characteristics:

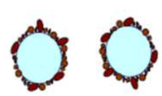
- w/o or o/w emulsions
- Some are very stable (but termodynamically unstable)
- Dispersed microdroplets (0.1 to 100 µm)
- Natural surfactants (asphaltenes, acids, ..)

Stability mechanisms:

- Droplets electric repulsion
- Characteristics of the interfacial film
- Steric stabilization
- Solids stabilization



Electrostatic



Solids
(wax, asphaltenes, ...)

Multiphase flow in pipelines:

- Viscosity increase (↑ dP)
- Production decrease
- Chemicals (flow improvers)
- Good effets on
  - wax deposition
  - corrosion potential
  - hydrate blockage risks

Topside

- ↑ treatment T
- ↑ residence time
- ↑ chemicals

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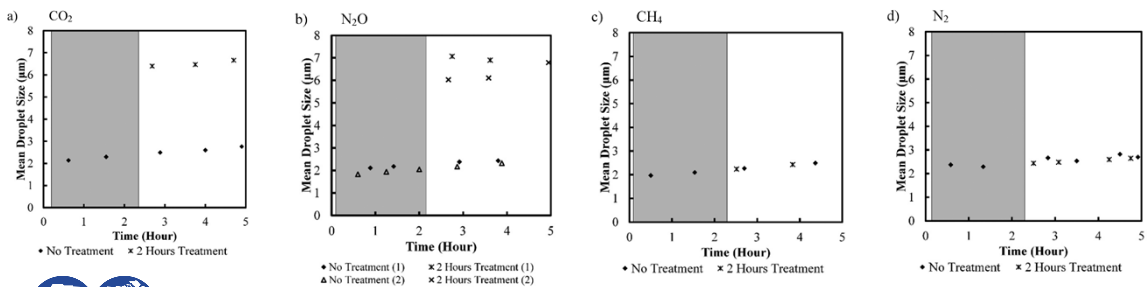
2. CO_2
Emulsions

Webinars

CO_2 effect on emulsions stability:

- 50 bar and 25 °C (30% WC - crude oil/water)
- Water DS measured after depressurization
- Gas solubility seems to have a destabilizing effect

gas	solubility in water (50 bar, 25 °C)	solubility in crude oil (50 bar, 25 °C)
CO_2	1.74 mol/L	3.80 mol/L
N_2	0.03 mol/L	0.73 mol/L
CH_4	0.07 mol/L	1.09 mol/L
N_2O	1.20 mol/L	7.60 mol/L



SPE International

(UWA) Ling, N. N. A. et al, NMR Studies of the Effect of CO_2 on Oilfield Emulsion Stability, Energy Fuels **2016**, 30, 5555–5562

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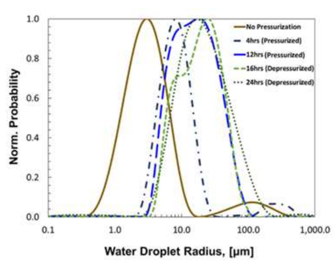
2. CO_2
Emulsions

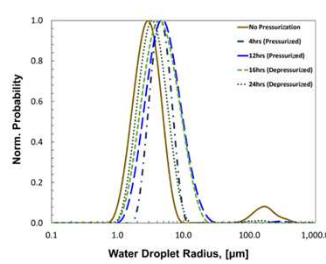
Webinars

CO_2 effect on emulsions stability:

- 50 bar and 25 °C (30% WC - crude oil/ water)
- Water DS measured during and after depressurization
- 1% NaCl seems to have a stabilizing effect for tested crudes



water-in-crude emulsion



brine-in-crude emulsion

SPE International

(UWA) Azizi, A. et al, Emulsion Breakage Mechanism Using Pressurized Carbon Dioxide, EnergyFuels **2019**, 33, 4939–4945

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2. CO_2

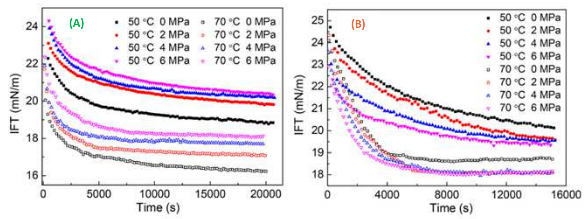
Emulsions

CO_2 effect on emulsions stability, IFT and interface viscosity:

- Emulsion stability under pressure
- IFT and interface viscosity: high pressure drop tensiometer

Increasing CO_2 content:

- Emulsion stability: Oil A and B decrease.
- Interfacial elasticity: Oil A and B decrease.
- IFT: Oil A increase and Oil B decrease.



(China U.P.) Sun, G. et al, Effects of Dissolved CO2 on the Crude Oil/Water Interfacial Viscoelasticity and the Macroscopic Stability of Water-in-Crude Oil Emulsion, EnergyFuels **2018**, 32, 9330–9339

Main observations: CO_2 can minimize emulsion problems!

- Emulsion stability was lowered in diferente studies

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3. Wax

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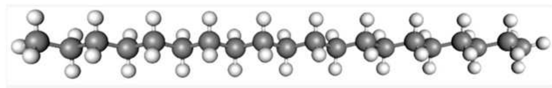
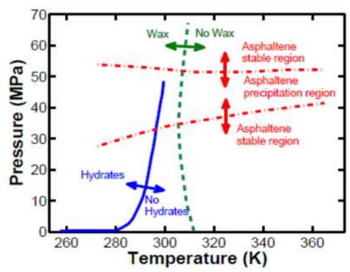
3. Wax

Webinars

Wax or paraffins: mixture of oil soluble alkanes

- Normal / branched / cyclic alkanes
- Solubility in oil decrease with temperature decrease
- May precipitate or deposit on the walls (T gradient)
- May form gels (yield stress problems)
- Production: insulated lines minimize/avoid deposition





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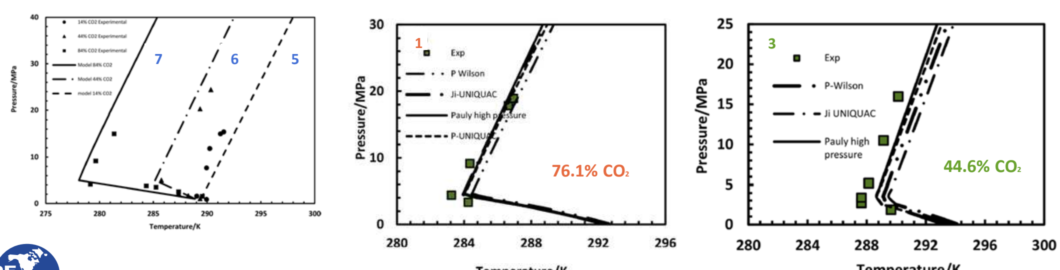
3. Wax

Webinars

CO_2 effect on WDT:

- Thermodynamic equilibrium, Model systems
- Increase of CO_2 decreased WDT (good!)
- Visual rocking rig

component	sample 1	sample 3	sample 5	sample 6	sample 7
n-dodecane ($C_{12}H_{26}$)	0.128	0.293			
n-hexadecane ($C_{16}H_{34}$)	0.093	0.212	0.860	0.560	0.160
n-docosane ($C_{22}H_{46}$)	0.010	0.026			
n-tricosane ($C_{23}H_{48}$)	0.001	0.004			
n-tetracosane ($C_{24}H_{50}$)	0.007	0.019			
carbon dioxide (CO_2)	0.761	0.446	0.140	0.440	0.840



SPE International

(HWU) Eniolorunda, O. V. et al, Phase Equilibria of waxy live oil systems containing CO2, experimental measurements and thermodynamic modeling, Energy Fuels **2021**, 35, 3731–3741

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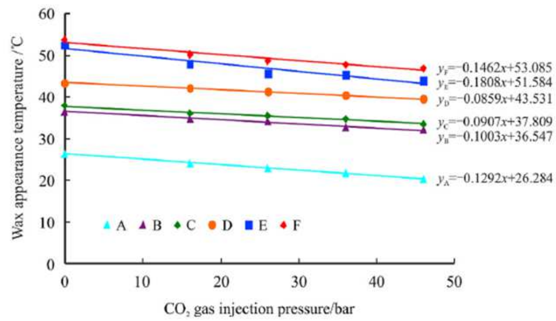
3. Wax

Webinars

CO_2 effect on WAT

- Decrease with increasing CO_2 content / pressure
- Need to consider effect of gas solubility in oil
- DSC method



SPE International

(U. Lisboa) Souza, A. M. et al, Wax deposition mechanisms and the effect of emulsions and carbon dioxide injection on wax deposition: Critical review, Petroleum 6 (**2020**) 215–225

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3. Wax

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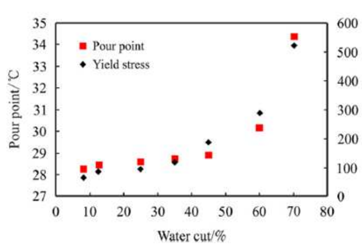
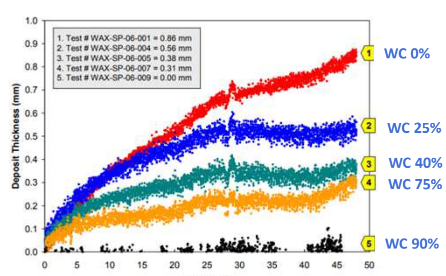
Water effect on:

- Yield stress - Increase, due to aggregation of the waxy crystals and water.
- Deposition - Deposits thickness decrease with increasing WC.





SPE International

- **(U. Lisboa)** Souza, A. M. et al, Wax deposition mechanisms and the effect of emulsions and carbon dioxide injection on wax deposition: Critical review, Petroleum 6 (**2020**) 215–225
- **(U. Tulsa)** Bruno, A. et al, Paraffin Deposition During the Flow of Water-in-Oil and Oil-in-Water Dispersions in Pipes, **2008**, SPE 114747

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3. Wax

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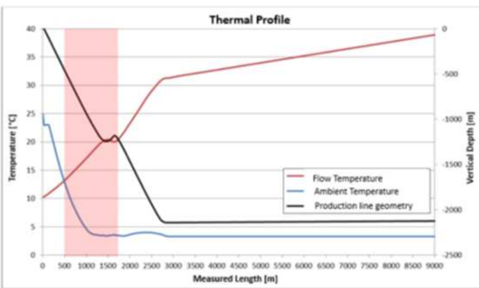
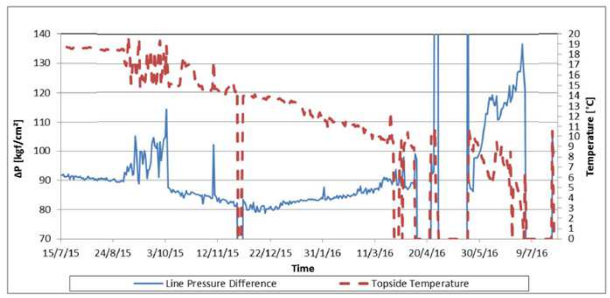
Wax deposits removal in a pre-salt field

- High GOR and 9 km tieback – low T in riser
- Riser T below the critical T for wax deposition



- Increasing dP in production line
- Decreasing arriving T at topside



Pressure difference along production line and topside temperature.

SPE International

(**Petrobras**) Andreotti, T. et al, Wax Removal Procedure Used in Pre-Salt Oil Well, **2017**, OTC 28120

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3. Wax

Webinars

Wax deposits removal in a pre-salt field

a) Pigging – less effective (7 pigs – foam with different densities and plastic covered): few wax quantity removed

b) Static diesel soaking (8h / 24h) – better than pigging: 15 liters of wax + a lost pig (diesel pump at 720 m^3/d)

c) Dynamic diesel soaking – best method: 55 liters of wax (gas at 400 000 sm^3/d)

a)

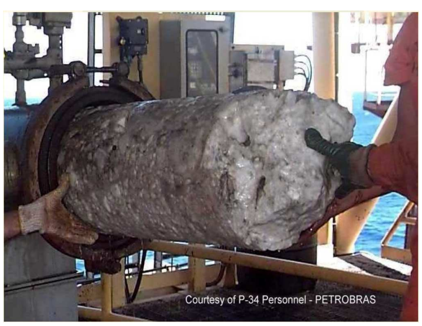
b)

c)

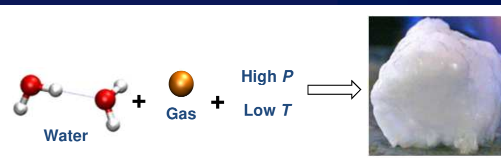
(**Petrobras**) Andreotti, T. et al, Wax Removal Procedure Used in Pre-Salt Oil Well, **2017**, OTC 28120

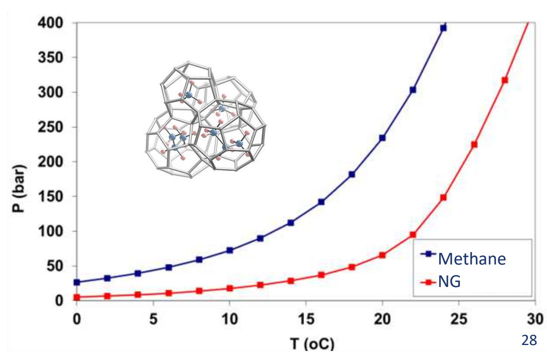
4. Hydrates

4. Hydrates



Hydrates are crystalline solids, formed when water and small molecules are in adequate PT conditions.





Flow Assurance Challenges in Deepwater Brazil Pre-salt

4. Hydrates

Water production in pre-salt Oil Fields

- Some fields have now low % water production
- High salinity (> 100.000 ppm)

System characteristics

- °API ~30
- Form stable emulsions
- CO_2 / H_2S
- High GOR
- High P (~ 200 bar)

Oil systems:

Steady state condition

- No hydrate risks

Shut-in / start-up conditions

- High P / low T – hydrate blockage risks
- Prevention procedures
- LDHI ?

Gas systems:

- Gas dehydration units
- THI

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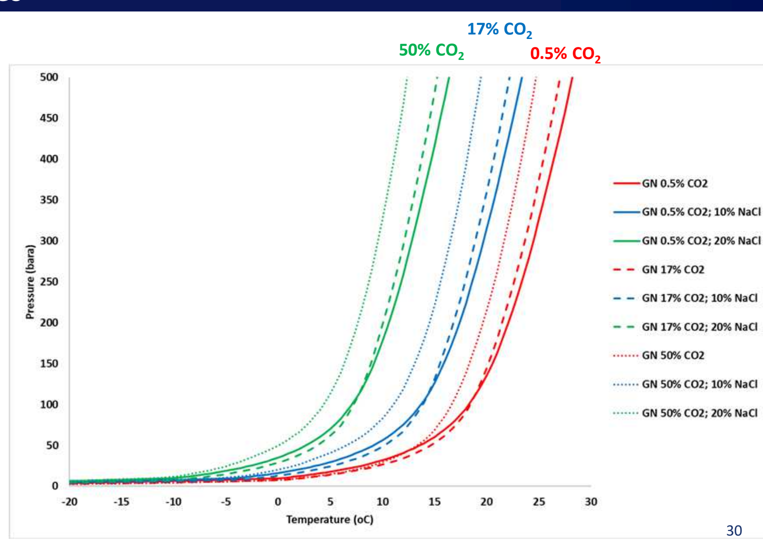
Flow Assurance Challenges in Deepwater Brazil Pre-salt

4. Hydrates

a) Hydrate formation in gas lines

CO_2 and NaCl effect on hydrate equilibrium conditions

- Excess of water: good correlation with experimental data.
- NaCl – THI
- CO_2 may act as "THI"



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4. Hydrates

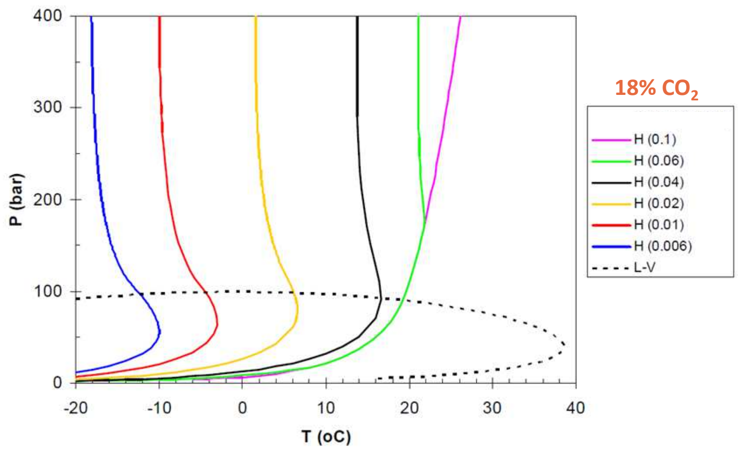
a) Hydrate formation in gas lines

Gas Dehydration Units

- Molecular sieves: 1 ppmv
- TEG: 20-40 ppmv

Low water content gases

- Few experimental data to validate simulators



Pseudo-retrograde dissociation

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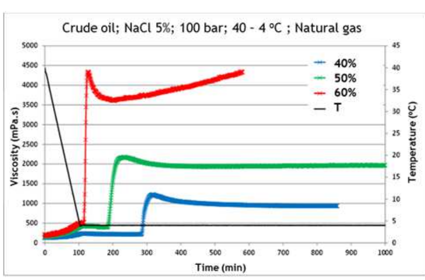
4. Hydrates

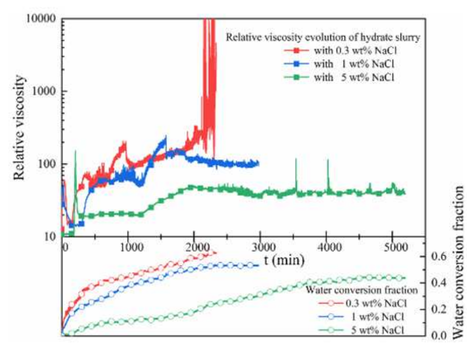
b) Hydrate formation in oil production lines

WC and NaCl effect on hydrate agglomeration

- Hydrate formation in w/o emulsions
- Slurries viscosity increase with increasing WC



- Model oil / brines (50% WC)
- Increasing NaCl concentration, slurry viscosity decreased



(Dalian Univ. Tec.) Liu, Z. et al, Effect of brine salinity on the rheological properties of hydrate-in-oil slurries, in press.

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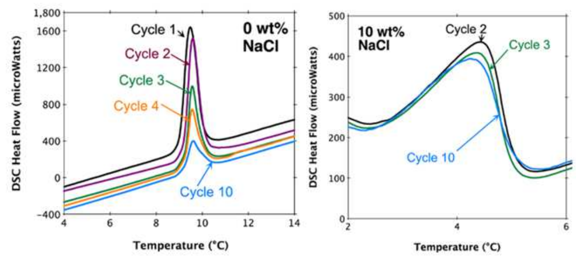
4. Hydrates

b) Hydrate formation in oil production lines

WC and NaCl effect on hydrate agglomeration

- Stability of hydrate slurries
- DSC methodology
  - Phase transitions peaks
  - Sucessive cooling / heating cycles
  - Stable slurry – no water droplets coalescence – dissociation peak will keep its area
  - Unstable slurry – water droplets will coalesce – dissociation peak will be lower at each cycle
- Same WC (30%), crude oil: more salt, more stable slurry



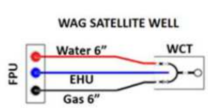
(UWA) Aman, Z. et al, Effect of Brine Salinity on the Stability of Hydrate-in-Oil Dispersions and Water-in-Oil Emulsions, Energy Fuels **2015**, 29, 12, 7948–7955

4. Hydrates

c) Hydrate formation during WAG operations

Water Alternating Gas (WAG)

- EOR method
- Alternate injection of gas and water in the same well.
- Prevention procedures to avoid fluids contact (valves, MEG or diesel)
- More than 30 operations without hydrate problems



First use of WAG method in ultra-deep water (2200 m)
https://presal.petrobras.com.br/tecnologias-pioneiras/#0

(Petrobras) Noville, I. et al, **Flow Assurance in Buzios Field: Key Challenges and Implemented Solutions,** 2021, OTC-31277-MS.

Webinars

5. CO_2 Separation and Injection

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5. CO_2 separation and injection

Webinars

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5. CO_2 separation and injection

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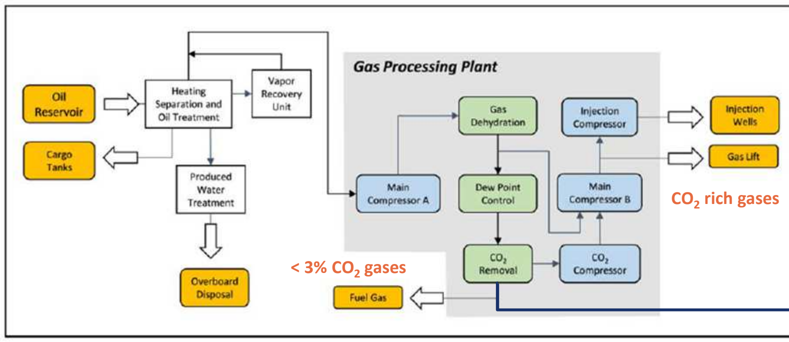
Gas treatment and CO_2 separation



Gas exporting line (if available)

GPP (Gas Processing Plant) example

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(Petrobras) Touma, S. L. et al (2019) Innovative Gas Treatment Solutions for Offshore Systems, OTC-29913

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5. CO_2 separation and injection

Webinars

CO_2 Injection

- EOR
- CCS technology
- 2020: 7 million tCO_2
- 2025: 40 million tCO_2

ENERGY, ATMOSPHERIC EMISSIONS AND CARBON MANAGEMENT

56

millions tCO_2e GHG emissions, a reduction of **5%** in relation to 2019

97%

of gas utilization (IUGA - associated gas utilization index) in the E&P area and reinjected

7 million tCO_2

separated from the gas produced in our pre-salt fields

811,912

terajoules consumed, which represents a

1.7%

reduction compared to 2019

Petrobras 2020 SUSTAINABILITY REPORT

https://sustentabilidade.petrobras.com.br/en/#strategy-and-results

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Flow Assurance Challenges in Deepwater Brazil Pre-salt

5. CO_2 separation and injection

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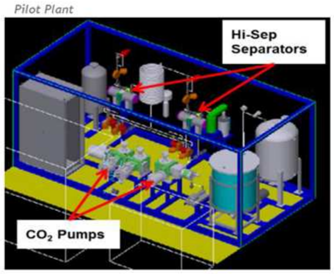
CO_2 separation

- Actual: polimeric membranes (Topside)
- Future: HISEP – Dense phase CO_2 separation (Subsea)

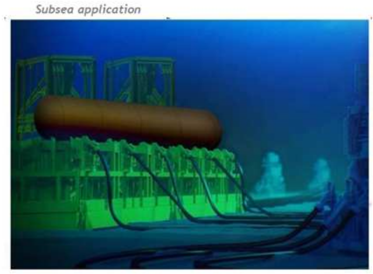
Pilot Plant



Subsea separation and injection:

- Lower CO_2 contents and lower GOR in production lines
- More space at topside

Subsea application



Conceptual studies for subsea application with: FMC Technologies, GE, OneSubsea, SAIPEM, AkerSolutions

(Petrobras) Ribeiro, O. (OTC 2017) in https://www.investidorpetrobras.com.br/en/presentations-reports-and-events/presentations/ 39

(Petrobras) Passarelli, F. M. et al (2019) HISEP: A game changer to boost the oil production of high GOR and high CO2 contente reservoirs , OTC-29762

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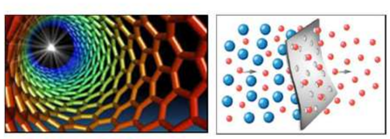
5. CO_2 separation and injection

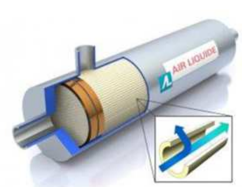
Webinars

CO_2 separation

- Future:
  - Carbon Molecular Sieve (CMC) Membranes: more efficient membranes for CO_2 separation from natural gas
  - All Membrane Technology: compact gas treatment system capable to remove H_2S, CO_2 and water; Reduction in topsides weight and FPSO cost or possible enabler to increase plant capacity.



Partnership with: Shell Global Solutions



Partnership with: Air Liquide

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(Petrobras) Ribeiro, O. (OTC 2017) in https://www.investidorpetrobras.com.br/en/presentations-reports-and-events/presentations/

Webinars

6. Final remarks

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CO_2

- CO_2 may destabilize water-in-oil emulsions and help fluids treatment. Presence of salts may decrease this effect.
- Asphaltene, scale deposition and corrosion issues must be carefully evaluated.

Hydrates

- Validation of thermodynamic equilibrium simulations for low water content gases (including CO_2 presence).
- Water high salinities may minimize hydrate agglomeration.
- Risks of hydrate formation during WAG operations may be minimized with prevention procedures.

Flow Assurance Challenges in Deepwater Brazil Pre-salt

6. Final remarks

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Wax

- CO_2 seems to have some influence on WDT, WAT and deposition, and problems in the field may be lower.
- Water may play a role on wax deposition thickness.
- Better understanding on deposition phenomena to improve flow simulators.

Fluid modelling

- Important in all flow assurance issues. Importance of good experimental data.

Hydrates, wax, emulsions, asphaltenes, scales...

- Few studies considering more than one issue.
- Improve lab data to help the development of flow simulators that merge different FA issues.

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Flow Assurance Challenges in Deepwater Brazil Pre-salt

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CO_2 injection / capture

- Important for the development of oil fields.
- EOR: Improve oil production.
- Storage of GHG.
- Continue the development of more efficient technologies.

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Thank you

Adriana Teixeira
adriteix@petrobras.com.br

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