PVT pour les fluides non-conventionnels de type pre-salt

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BRAZILIAN PRE-SALT FLUIDS

Pr: 600-700 bar

Tr: 80 - 100°C

GOR 200 - 600 m³/m³

CO₂ up to 55 mol% LO

Asphaltene 0.1-0.3 mass% DO

Wax 5-7 mass% DO
PHASE BEHAVIOR OF RESERVOIR FLUIDS

P.S. oil

P.S. oil With CO²
Conventional PVT techniques: Synthetic method

\[ Y_{ext} = -\frac{V_{ext}}{P} \left( \frac{P - P_{ext}}{V - V_{ext}} \right) \]
Challenges

✓ Multi-scale observation for both fluid and solid phases

- $L \rightarrow L + V$ : mm
- $L \rightarrow L + L$ : mm to $\mu$m
- $L \rightarrow L + Wax$ : 0.5 $\mu$m
- $L \rightarrow L + Asphaltenes$: 50 nm

✓ High opacity

- Indirect detection of phase transitions : Sensor in full immersion

✓ Complex phase behavior

- Direct observation : Fluids : full sample (stirring) HP full visibility cell

Solids : focalization on a small sample (static) HP microscopy

Combined Investigation
Indirect detection method: QCR sensor (QCM)

- Measurements of the resonance properties
- Calculation of the physical properties of the surrounding media

\[
\Delta f_{n,oil} = -\sqrt{n} \frac{C_m}{\sqrt{\pi f_0}} \sqrt{\rho_{oil}\eta_{oil}} - n2C_m\rho h_D
\]

\[
\Delta \Gamma_{n,oil} = \sqrt{n} \frac{C_m}{\sqrt{\pi f_0}} \sqrt{\rho_{oil}\eta_{oil}}(1 + R)
\]
QCR sensor in full oil immersion

Viscous friction leads to a huge attenuation

Steady state method

Oil with unstable Asphaltenes

Dead oil

Toluene

Vacuum

Fluid (P,T)
High pressure cell

- $P: 0.1 - 100 \text{ Mpa}$
- $T: 0 - 100 \text{ C}$
- $V: 20 - 50 \text{ cm}^3$
Fluid phase transitions using QCR

\[ \Delta f_{n,oil} = -\sqrt{n} \frac{C_m}{\sqrt{\pi f_0}} \sqrt{\rho_{oil} \eta_{oil}} - n^2 C_m \rho_D \]

\[ \Delta \Gamma_{n,oil} = \sqrt{n} \frac{C_m}{\sqrt{\pi f_0}} \sqrt{\rho_{oil} \eta_{oil}} (1 + R) \]
Fluid phase transitions using QCR

- The minimum is in good agreement with the observed break in the PV curve.
- QCR is more sensitive than PV method.
- QCR cannot detect LL phase separation

Constant Mass Expansion (gas + oil)
Asphaltene instability threshold measurement using QCR

Unstable Asphaltenes lead to:

- an increase of viscosity

\[ \sqrt{\rho \eta_{\text{fluid}}} \rightarrow \Delta f_{\text{fluid}} \rightarrow \Delta \Gamma_{\text{fluid}} \]

- mass deposition

\[ h_D \rightarrow \Delta f_{\text{fluid}} \]

- Electrical response to AI is Huge. It allows to sense the UAI Threshold

\[ \Delta f_{n,oil} = -\sqrt{n} \frac{C_m}{\sqrt{\pi f_0}} \sqrt{\rho_{oil} \eta_{oil}} - n2C_m \rho h_D \]

\[ \Delta \Gamma_{n,oil} = n \frac{C_m}{\sqrt{\pi f_0}} \sqrt{\rho_{oil} \eta_{oil}(1 + R)} \]
Wax Appearance Temperature measurement using QCR

- Wax precipitation leads to an increase of viscosity
- No mass deposition on quartz surface

\[
\Delta f_{\text{fluid}} \quad \Delta \Gamma_{\text{fluid}} \quad \sqrt{\rho \eta_{\text{fluid}}} 
\]

\[
\Delta f_{n,oil} = -\sqrt{n} \frac{C_m}{\sqrt{\pi f_0}} \sqrt{\rho_{oil} \eta_{oil}} - n2C_m \rho h_D
\]

\[
\Delta \Gamma_{n,oil} = \sqrt{n} \frac{C_m}{\sqrt{\pi f_0}} \sqrt{\rho_{oil} \eta_{oil}} (1 + R)
\]
Direct observation

Under visible light, crude oils absorb most of the radiation and appear as dark fluids. In situ observation of phase transitions is limited.

Transmittance of a material is a function of the:

- thickness of the sample
- wavelength of the incident light

Fluid sample thickness ↘ 1 to 1/10 mm

Optical density

Visual → Infra Red : 1 - 2 μm, SWIR
PVT CELL with SWIR CAMERA

- Fixed focal 12.5 mm length lens
- long working distance objective lens
  - x4
  - x8

InGaAs detector: 0.9 - 1.7 µm, (indium gallium arsenide)
PVT CELL with SWIR CAMERA

Recombined gas + PS oil $P_x$ phase diagram

LV / LL / LLV
Asphalt / Bitumen

$P, x$ phase diagram of Recombined gas + PS oil
HP Microscopy

Device

Gap: 1 mm

Magnification: 5; 20; 50

Visual camera

SWIR camera
Conclusion

Combined Investigation using 3 devices

Full characterization of PS oil in reservoir conditions
Conclusion

Characterization of gas injection

40 % mol gas

60 % mol gas

70 % mol gas

78 % mol gas

80 % mol gas

84 % mol gas

pressure, MPa

temperature, K

300 400 500 600 700 800 900 1000

0 20 40 60 80 100

40 % mol gas

60 % mol gas

70 % mol gas

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300 400 500 600 700 800 900 1000

0 20 40 60 80 100

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Conclusion

Characterization of gas injection

![Graph showing pressure vs. temperature with data points for different gas compositions.]

- Gas 60
- Gas 70
- Gas 78
- Gas 80
- Gas 84

- System gas content, mol%
- C1
- CO2
- C3C4
- C5C10
- C10C20
- C20P
- CNA

- Pressure, MPa vs. Temperature, K

Lump mol fraction

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Merci de votre attention