FLOTATION OF PRODUCED WATER - EOR CONTEXT

DYNAMICS OF EVOLVING FLUID INTERFACES OCTOBER, 12TH 2016

H. CHAKIBI, I. HENAUT, J.-F. ARGILLIER
Table of contents

- CONTEXT
  - Waste water treatment in oil production
  - Flotation

- EXPERIMENTAL STUDIES
  - Water flooding context
  - Enhanced Oil Recovery context

- CONCLUSION

Combination of Hydrodynamic and interfacial processes

Multi-scales experimental approaches
Context: Water in oil production

- Hydrocarbons - Gas
- Salts
- Bacteria
- Minerals
- Radionuclides
- EOR chemicals

- Huge amounts: 240 millions water barils per day
- Environmental regulations
- Complex composition
Context: Main units for water treatment

- Decantation (>150µm)
- Hydrocyclones (20-150µm)
- Flotation (5-20µm)
- Filtration - Organic treatment
  Very small particles

\[ v_s = \frac{2}{9} \frac{\rho_p - \rho_f}{\mu} g R^2 \]
Context: Flotation process

- **4 steps**
  - Bubbles injection
  - Bubble and oil droplet approach
  - Bubble and oil droplet attachment
  - Rise of the bubble/drop aggregate

- **Cell design parameters**
  - Gas flow rate,
  - Oil flow rate
  - Geometrical dimensions,
  - Temperature etc.

- **Feed parameters**
  - Oil concentration and type,
  - Gas nature,
  - Water salinity,
  - Interfacial tensions,
  - Surface rheology etc.

Experimental studies: multi-scale approach

Macroscopic scale
Flotation column
- Synthetic produced water (300ml)
- Crude oil (200ppm) in salted water
- Air injection Q=40ml/h
- Fintered glass disk

Microscopic scale
Captive drop experiment

Induction time (= time of rupture-time of the first collision)
INFLUENCE OF SALINITY
ON FLOTATION EFFICIENCY
Experimental studies: multi-scale approach

- Water flooding context: influence of salinity on flotation efficiency
  - Lab results: macroscopic scale

For [NaCl] > 1 g/ water is clean
Experimental studies: multi-scale approach

- Water flooding context: influence of salinity on bubbles size
  - Lab results: macroscopic scale
Experimental studies: multi-scale approach

- Water flooding context: influence of salinity on flotation efficiency
  - Lab results: macroscopic scale
Experimental studies: multi-scale approach

- Water flooding context: influence of salinity on flotation efficiency
  - Lab results: microscopic scale: bubble/drop attachment
Experimental studies: multi-scale approach

- Water flooding context: influence of salinity on flotation efficiency
  - Lab results: microscopic scale: induction time

![First Collision, t=0s](image1)

![Film rupture t=t_{ind}](image2)

Graph: Max Induction time vs Ionic Strength (mM)

- Y-axis: Max Induction time (s)
- X-axis: Ionic Strength (mM)

- Data points for different salinity levels, showing decrease in induction time with increasing ionic strength.
Experimental studies: multi-scale approach

- Water flooding context: influence of salinity on flotation efficiency
  - Lab results: microscopic scale: zeta potentials of droplets

- Charged droplets: ionisation of the asphaltens and napthenic acids
  ZP depends on $I$: equilibrium at the interface depends on salinity

- Bubbles are significantly negatively charged
Experimental studies: multi-scale approach

- Water flooding context: influence of salinity on flotation efficiency
  - Lab results: microscopic scale: zeta potentials of droplets
Experimental studies: multi-scale approach

- Water flooding context: influence of salinity on flotation efficiency
  - Lab results: microscopic scale: zeta potentials of droplets

Hollow symbols = CaCl2
Full symbols = NaCl
INFLUENCE OF EOR POLYMER ON FLOTATION EFFICIENCY
Experimental studies: multi-scale approach

- **EOR context: influence of polymer on flotation efficiency**
  - Lab results: macroscopic scale
    - 200ppm crude oil
    - Water with 7.5g/L NaCl
  - **Polymer**
    - HPAM ($M_w=8.5\times10^6$ g/mol; $C^*=600$ppm)
    - 200, 400, 600, 1000, 1200, 1500ppm

Water remains dirty and a foam is stabilized.
Experimental studies: multi-scale approach

EOR context: influence of polymer on flotation efficiency
- Lab results: macroscopic scale

Dilute regime
- Newtonian fluid
- Small bubbles, well dispersed

Semi-dilute regime
- Shear-thining (viscoelastic) fluid
- Inhomogenous bubble dispersion
- Preferential ways
Experimental studies: multi-scale approach

**EOR context: influence of polymer on flotation efficiency**

- Lab results: macroscopic scale: additional experimental set-up

1) Compressed air inlet
2) Buffer zone, P=0.180-0.200b
3) Bubbles injection: $\delta t_{\text{inj}} = 40 ms$
4) High speed camera
Experimental studies: multi-scale approach

EOR context: influence of polymer on flotation efficiency
- Lab results: macroscopic scale: additional experimental set-up
- Bubble trajectory and speed
  - Position: \((X(t), Y(t))\)
  - Rising velocity \(U(t) = \sqrt{(v_x^2(t) + v_y^2(t))}\)
  - \(v_x(t) \ll v_y(t)\)

<table>
<thead>
<tr>
<th>Newtonian fluid</th>
<th>Glyc-water(15%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HPAM-1000ppm</td>
<td></td>
</tr>
</tbody>
</table>
Experimental studies: multi-scale approach

- EOR context: influence of polymer on flotation efficiency
  - Lab results: macroscopic scale: additional experimental set-up

Rising single bubble (medium not sheared) vs Rising swarn bubble (medium sheared by previous bubble)

Effect of shear-thinning properties of the polymer: bubbles accelerate
Experimental studies: multi-scale approach

- EOR context: influence of polymer on flotation efficiency
  - Lab results: macroscopic scale: additional experimental set-up

![Bubbles trajectories: 3330-500ppm](image1)

![Bubbles trajectories: 3330-3000ppm](image2)

Effect of elastic properties of the polymer: central gathering of bubbles
Experimental studies: multi-scale approach

- EOR context: influence of polymer on flotation efficiency
  - Lab results: microscopic scale (film scale)

The attachment between bubble and drop is slow down by the polymer.
Conclusion and perspectives

**Influence of salinity**
- Flotation efficiency is related to electrostatic repulsions between droplets and bubbles.
- The higher ionic strength, the lower the electrostatic repulsions between air bubble and oil droplet (rupture of pseudoemulsion film).

**Influence of polymer**
- Increase in viscosity which slows down the rising of bubbles.
- Influence of the dispersion of bubbles.
- Increase in induction times.

**Interfacial rheology**
- Discriminate between elastic and shear thinning effects.
- Study of several parallel lines of bubbles.
acknowledgements to

D. Langevin and A. Solonnen (LPS, Orsay)
E. Rio
J. Vermant and H. Vandamme
Observation of adhesion mechanisms

- Droplet rise
- First Collision, \( t=0s \)
- Surfaces deformation
- Film rupture \( t=t_{\text{ind}} \)
- Oil spreading
- Film drainage
- Complete oil spreading on air/water