The Importance of Using Live Crude for ASP Formulations

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Outline of Discussion

- Chemical Flooding – How does it work?
- Relative Permeability transition – waterflood to chemical flood.
- Optimal Salinity Concept –
  - Determination for Dead Crude Oil
  - Live Crude Oil Determination
- Importance of the difference – does it matter?
- Predictions based on oil chemistry

Formulations for Chemical Flooding

- Typically surfactant formulations are developed with dead crude (stock tank oil).
- However, dead crude is chemically different from reservoir live crude which contains dissolved gases.
- Does this difference negatively impact the performance of the surfactant formulation?
- How significant is this variable?

Prior Work

- Nelson (1983) – little change in mid-point salinity with equilibrated methane at 2050 psi.
- Puerto and Reed (1983) – midpoint salinity is lower for live crude.
- Roshanfekr et al (2009) – live crude with 17% methane shows a decrease in mid-point salinity of 0.35% compared to dead crude.
- No clear conclusion whether this is an academic curiosity or whether it will affect field recoveries. Floods formulated with dead crude could be overoptimum for live crude.

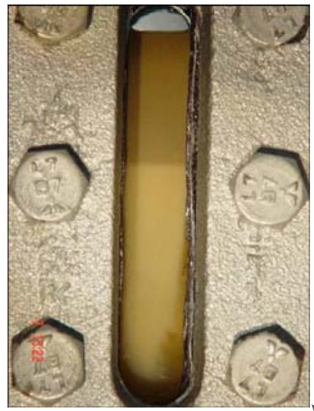
Lower Midpoint Salinity for Live Crude

Higher Solubilization Ratio for Live Crude

NaCl 0.5% 0.75% 1.0%

Vo/s=59

Live



Vo/s=20

Dead

- Chemical Slugs contain 1.5% Na_2CO_3 – + 0.5% NaCl is recommendation for field test.

Alternate Strategy for Live Crude Adjustment

Adjusting Ratio of a Surfactant Blend

0.5% surfactant + 1.0% Na_2CO_3 + 0.25% NaCl + 0.5% IBA

Higher Vo/s for live crude

Live Crude

70% IOS 2024 + 30% Petrostep A1

Dead Crude

100% IOS 2024

Adding 30% of a more hydrophilic surfactant achieves midpoint salinity with live crude.

Effects of Overoptimum Flood Conditions

Mitigation of Risk with Salinity Gradient

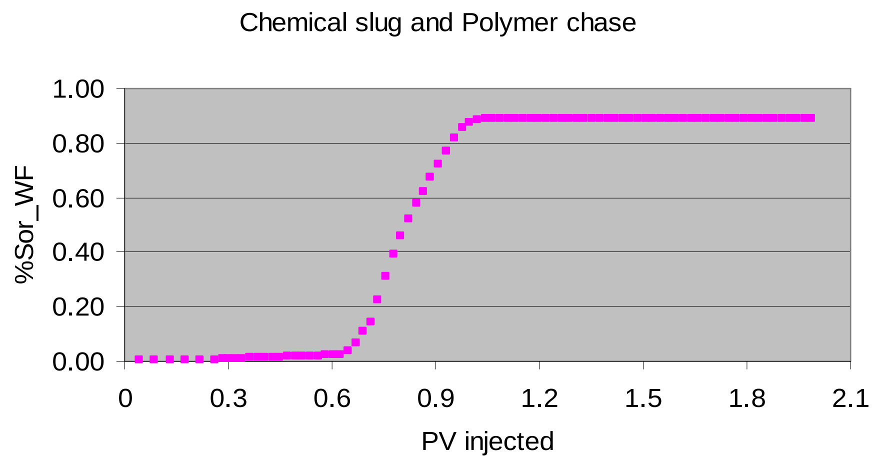
Slug Salinity	Type	Waterflood	Drive	Surfactant	Permeability	Oil Recovery
1%	constant	1%	1%	0.8% 2024	4250 md	95%
1.25%	constant	1.25%	1.25%	0.8% 2024	8400 md	93%
1.5%	constant	1.5%	1.5%	0.8% 2024	4900 md	48%
1.5%	gradient	1.5%	1%	0.8% 2024	4300 md	77%

- Midpoint salinity is 1.25% for this surfactant system.
- Flood that is 0.25% overoptimum performs poorly. This would be the case if a live crude field test were formulated with the dead crude used in this study.
- Flood that is 0.25% below midpoint salinity performs well.
- Poor recovery of overoptimum flood is partially mitigated by salinity gradient.

Live Crude Flood confirms Phase Behavior Prediction

Oil	IOS 2024	PS-A1	IBA	Na2CO3	FP-3430	NaCl	Oil Recovery
Dead	0.5%	0%	0.5%	1.25%	0.1%	1%	91%
Live	0.35%	0.15%	0.5%	1.25%	0.1%	1%	89%

Adjustment of Surfactant Ratio to account for live crude gives excellent result.



Theoretical Considerations

- Experimental work indicates midpoint salinity is lower with live crude.
- Is this always to be expected?

Thermodynamics – How is the free energy of mixing of surfactant tails in crude oil affected by dissolved methane?

$$\Delta G_m = \Delta H_m - T\Delta S_m$$

Assumption – changes in ΔG_m (surf solubility in oil with increasing methane) is dominated by the change in Enthalpy (ΔH_m).

Regular Solution theory ---- "Enthalpy Parameter" defined as $V_O(\delta_S - \delta_O)^2$

where V_o = molar volume of neat oil
δ_S = solubility parameter of surfactant tails
δ_O = solubility parameter of neat oil

V_o and δ_O can be calculated from physical properties of the oil

δ_S is approximated from chemically similar structures

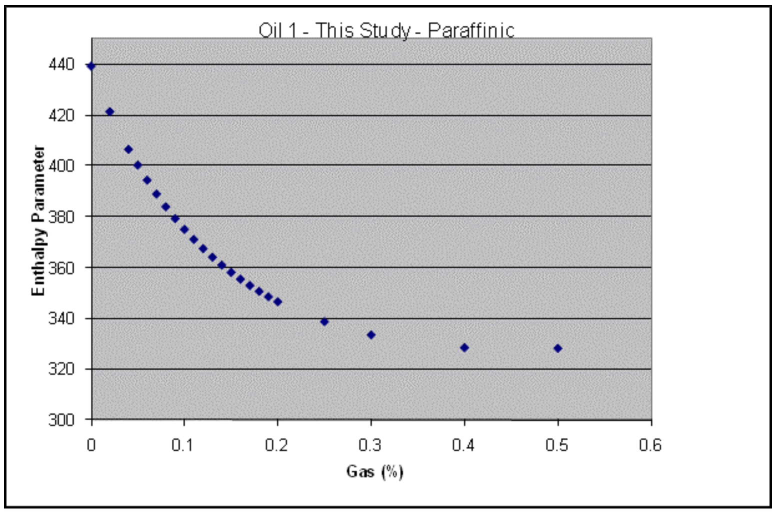
V_{meth} and δ_{meth} are known quantities for methane.

Predictions for Two Crude Oils

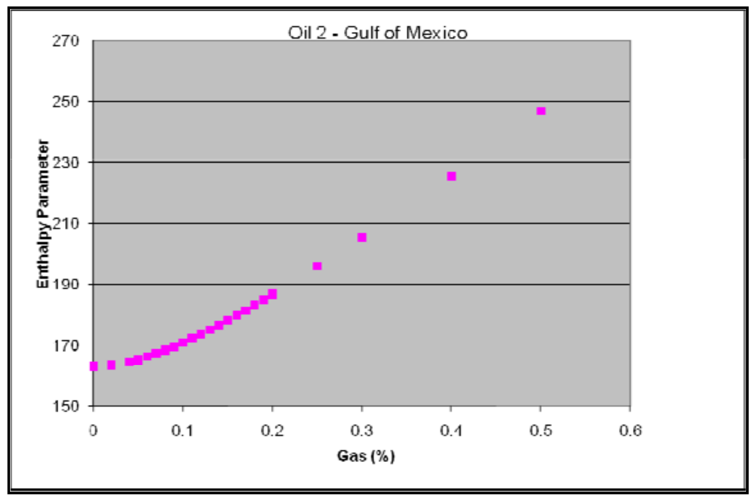
Enthalpy Parameter Change with increasing Methane

Calculated from volume fraction weighting equations of the pure components

Dead Crude Oil	Molar Volume	Solubility Parameter
This Study - Paraffinic	283 ml/mole	7.1 $(cal/cm^3)^{1/2}$
Gulf of Mexico Oil	353 ml/mole	7.62 $(cal/cm^3)^{1/2}$



Prediction – lower midpoint salinity with increasing methane. Confirmed by experiment



Prediction – higher midpoint salinity with increasing methane. Unconfirmed by experiment

Conclusions

- Chemical Flooding formulations should be optimized with live crude before field projects commence.

- Reasonable approach, screen surfactants with dead crude, final tuning of formulation with live crude.

- A chemical flood formulation optimized for a dead crude oil used in this study was overoptimum with respect to the live crude oil.

- The dead crude formulation can underperform if used in a field test for displacement of live crude.

- Experiments have shown that surfactants tend to become more soluble in oil with increasing methane content.

- Theory predicts this is not always the case. It is reasonable that highly aromatic oils will have the opposite behavior.