Field Case Study #3

Implementation of Low Salinity Waterflooding

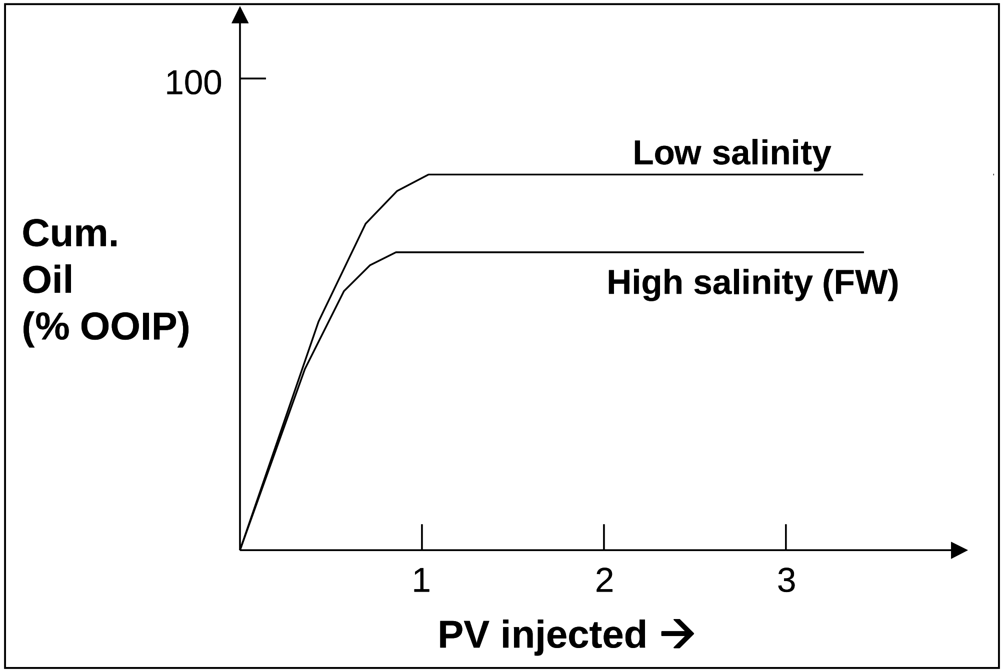
Mike Singleton

Flow Assurance & Scale Team: Scale Workshop
Treetops Hotel, Aberdeen, 29 January 2019

LEADERS IN IDEAS AND SOLUTIONS

Background

- **Low Salinity Waterflooding has been shown in some cases to increase recovery by ~16% compared to "High Salinity" case**



Effect of low salinity on cumulative oil recovery profiles; brine injection in a clay-bearing core conditioned with crude oil (after Tang and Morrow, 1996).

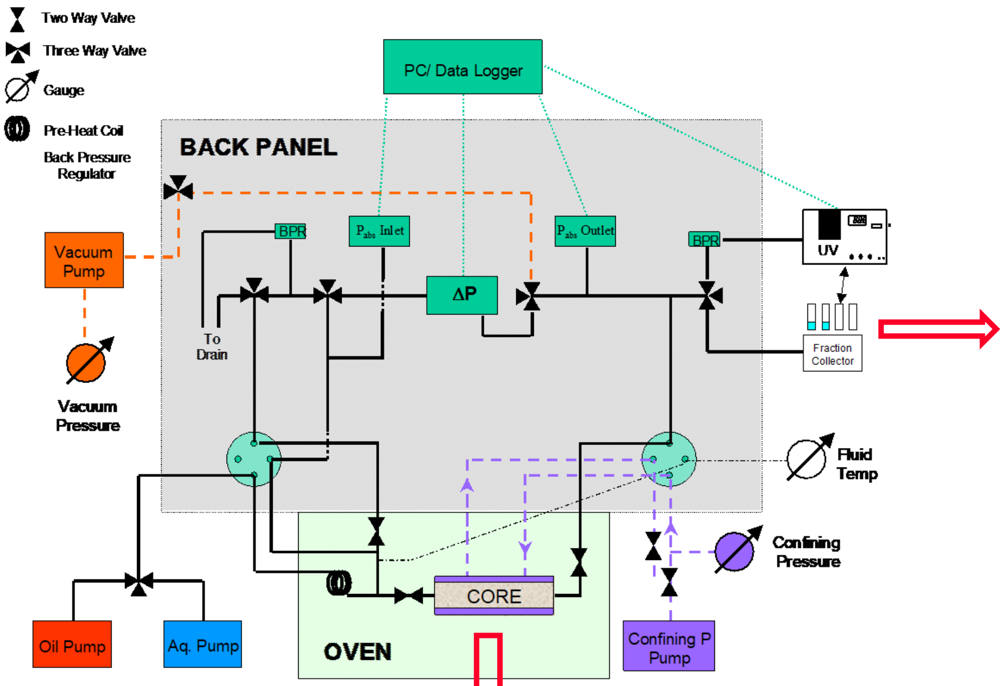
Background

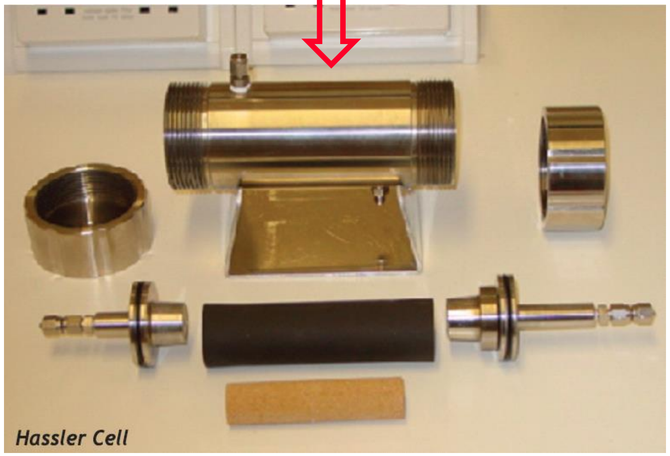
- **Work undertaken for BP under FASTrac – Commercial activity of FAST**
- **Series of detailed Core Flood experiments performed**
- **Supplemented by pore scale network modelling**
- **Results from which contributed to full field implementation of Low Salinity Waterflooding in Clair Ridge**

Study at HWU - Laboratory

- **Series of detailed Core Flood experiments performed**
- **Focus on factors controlling increased recovery**
  - Brine – Rock – Oil interactions
- **Reservoir conditioned core floods**
  - Oil recovery
  - Full effluent analysis
    - – brine composition by ICP analysis
    - - pH

Core Flooding



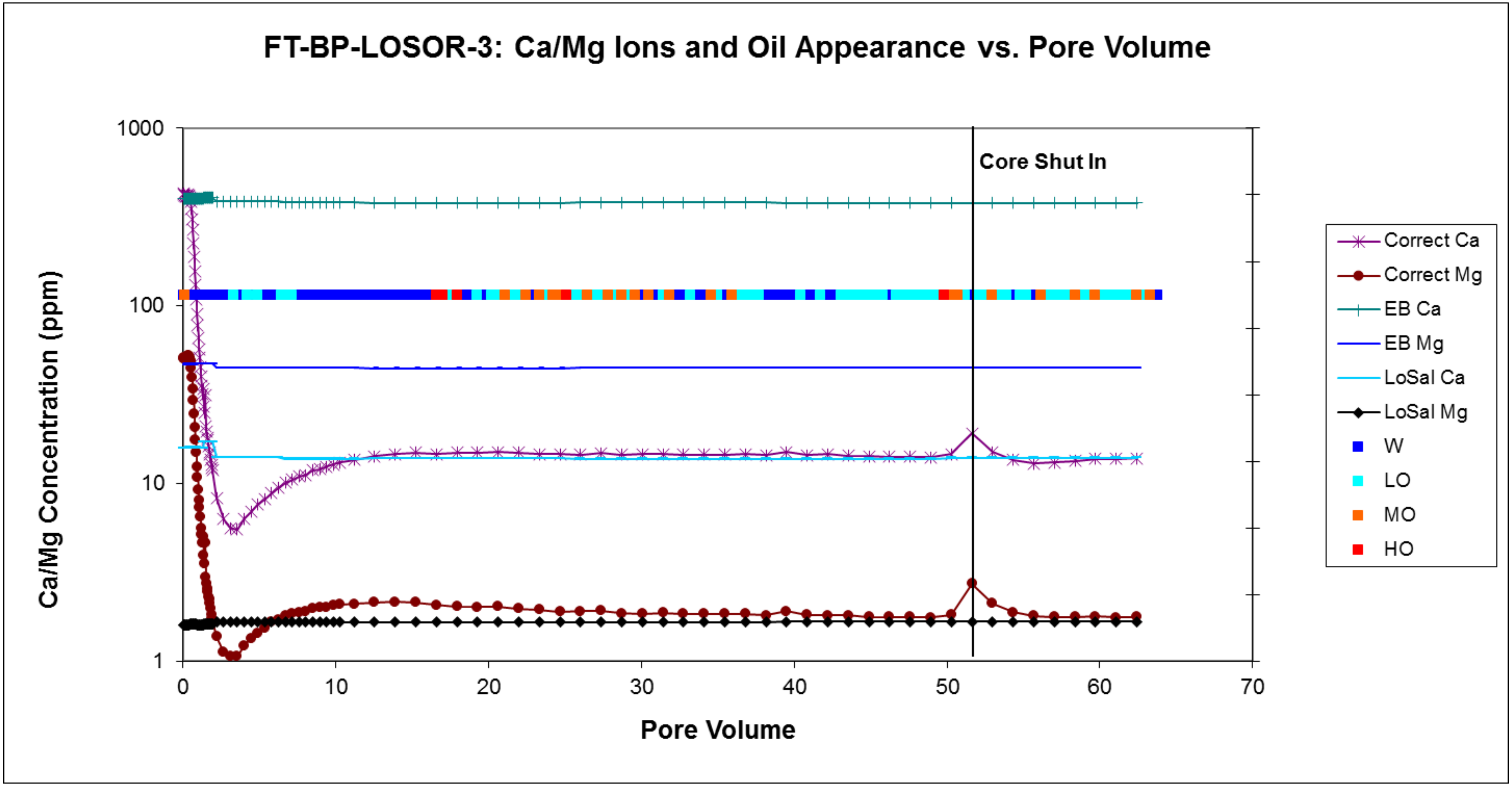


Salinity transition from 35,000mg/l (High) to 1,000mg/l (Low)

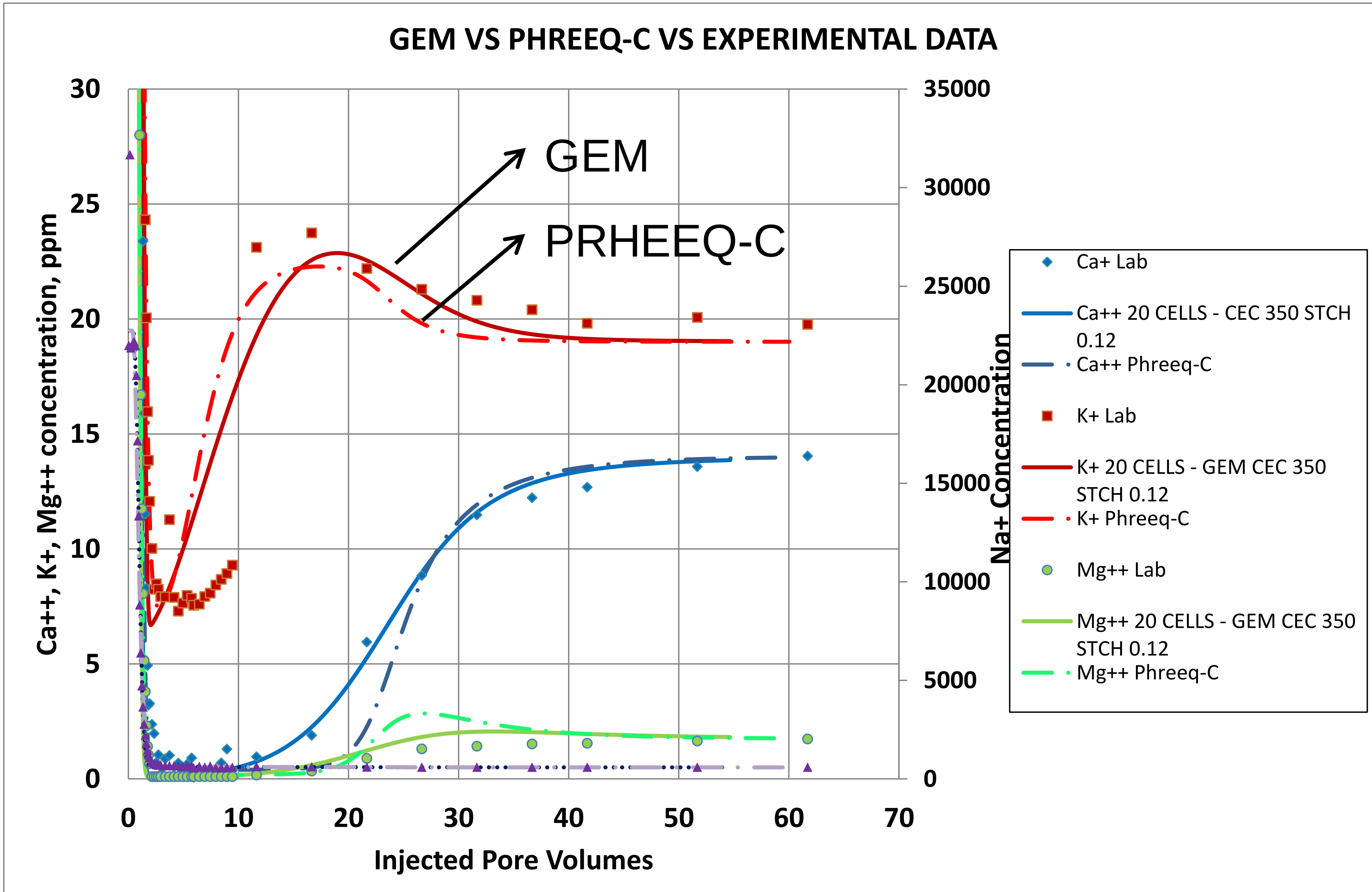
Full effluent analysis – pH, [Ca^{2+}], [Mg^{2+}]

Oil Recovery

Results


FT-BP-LOSOR-3: Ca/Mg Ions and Oil Appearance vs. Pore Volume
Ca/Mg Concentration (ppm)
1000
100
10
1
0
10
20
30
40
50
60
70
Pore Volume
Core Shut In
Correct Ca
Correct Mg
EB Ca
EB Mg
LoSal Ca
LoSal Mg
W
LO
MO
HO

Matching Experimental Data by Ion Exchange



Results

Multi-component ion exchange (MIE)

Where …

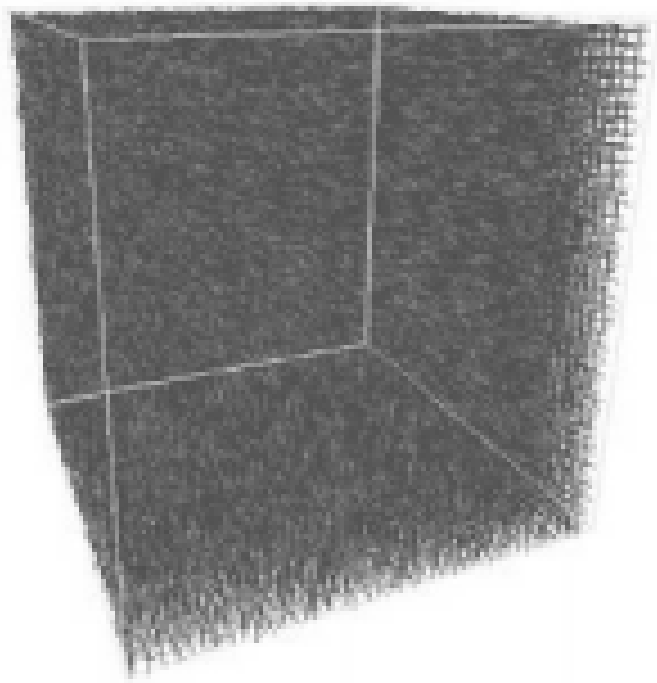
1. MIE => leads to a “self freshening” zone (low Ca, Mg)

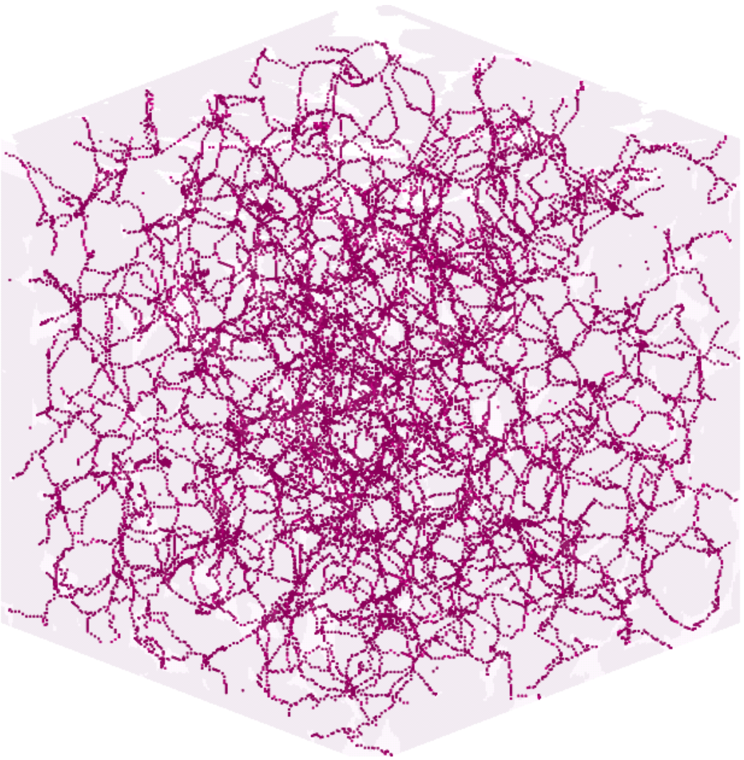
2. Within this zone double layer expansion occurs (DLVO)

3. Mixed –wet system becomes ***SLIGHTLY*** more water-wet

Pore Scale Modelling

Pore Network Model Representations of Porous Media





Quasi-static (capillary dominated) displacement physics described by Y-L equation

$$P_c = \frac{2\sigma . \cos\theta_{ow}}{r}$$

Pore Scale Modelling

$$\frac{2.\sigma_{ow1}.\cos\theta_{ow1}}{R_1} = \frac{2.\sigma_{ow2}.\cos\theta_{ow2}}{R_2}$$

$$R_2 = R_1\left(\frac{\sigma_{ow2}}{\sigma_{ow1}}\right)\cdot\left(\frac{\cos\theta_{ow2}}{\cos\theta_{ow1}}\right)$$

THUS …

$$\left(\frac{\sigma_{ow2}}{\sigma_{ow1}}\right) > 1 \qquad \left(\frac{\cos\theta_{ow2}}{\cos\theta_{ow1}}\right) > 1$$

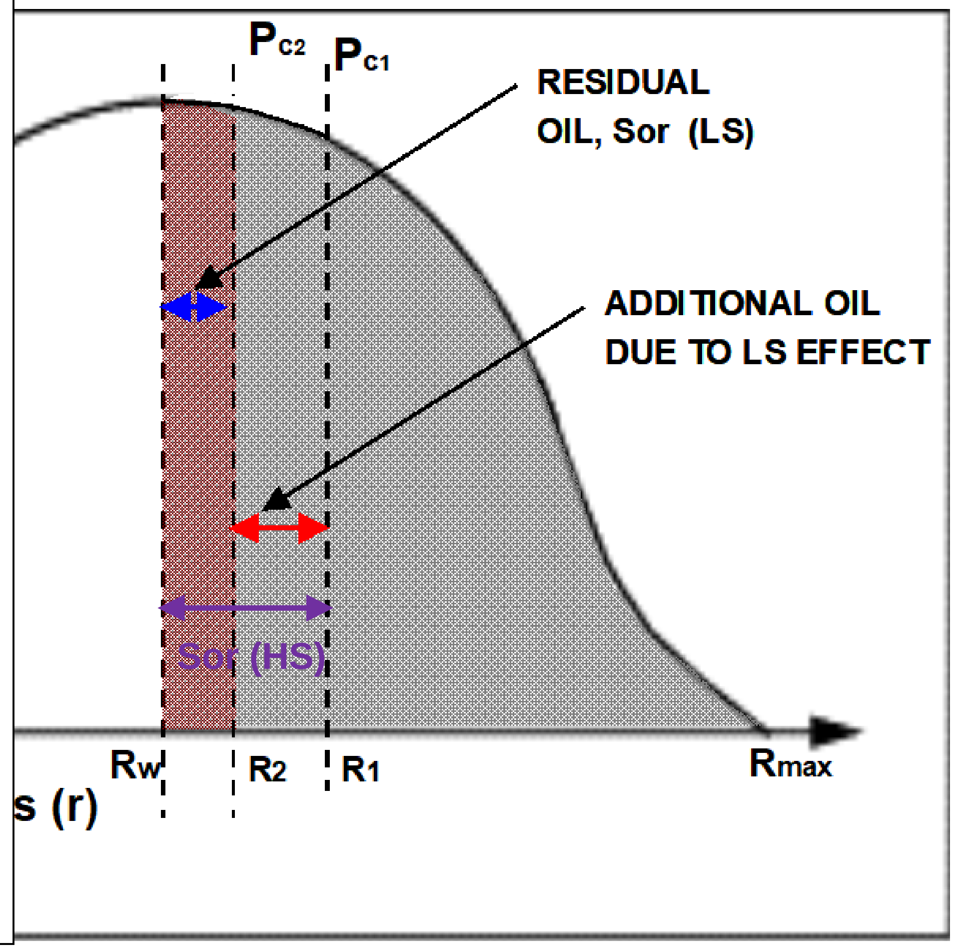


Figure 16: Phase occupancy of the remaining oil for the low salinity (LS) water flood in a “mixed wet large” (MWL) system.

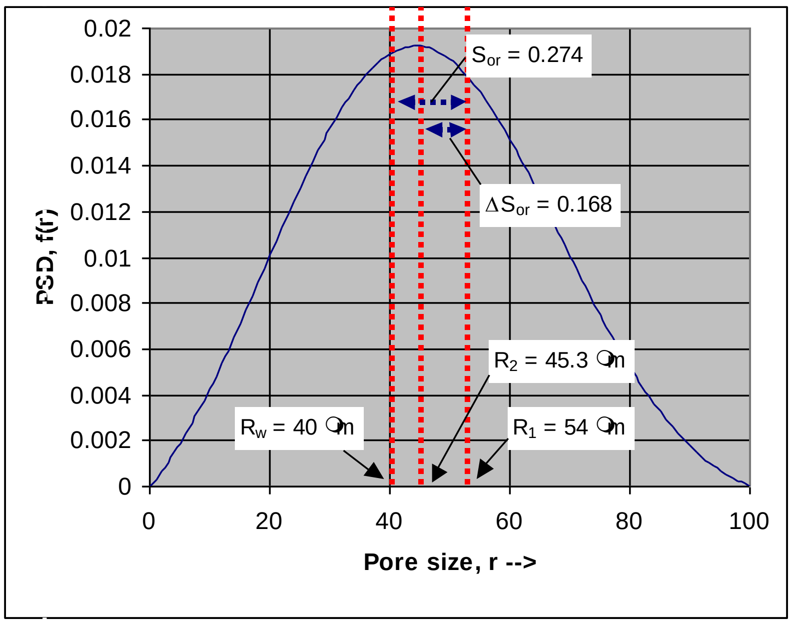
Pore Scale Modelling

Assume in oil wet pores:

θ_{ow} **HS = 140º ➔** θ_{ow} **LS = 130º**

HS : cos 140º = -0.766

LS : cos 130º = -0.6436



Rw	Calc. R1 (μm)	Calc. Sor	Calc. R2 (μm)	ΔSor	%inc. oil
40	54	0.274	45.3	0.169	61.7
50	65	0.338	54.5	0.239	70.7
60	100	0.492	83.9	0.079	16.1

Results

Building on Multi-component ion exchange (MIE)

Where …

1. MIE => leads to a “self freshening” zone (low Ca, Mg)

2. Within this zone double layer expansion occurs (DLVO)

3. Mixed –wet system becomes ***SLIGHTLY*** more water-wet

4. Consequence of changes of θ_{ow} are ***LARGE*** in ΔS_{or} according to simple pore-scale model ($P_{c,HS} = P_{c,LS}$)

Outcome

"[This work] has made a significant contribution to the fundamental understanding of the mechanism by which Low Salinity Water Flooding increases oil recovery. Without such understanding and contribution, BP would not be in a position to change their Water Flood strategy to a default base case position of Low Salinity Water Flooding."

BP's Chief Adviser on Low Salinity