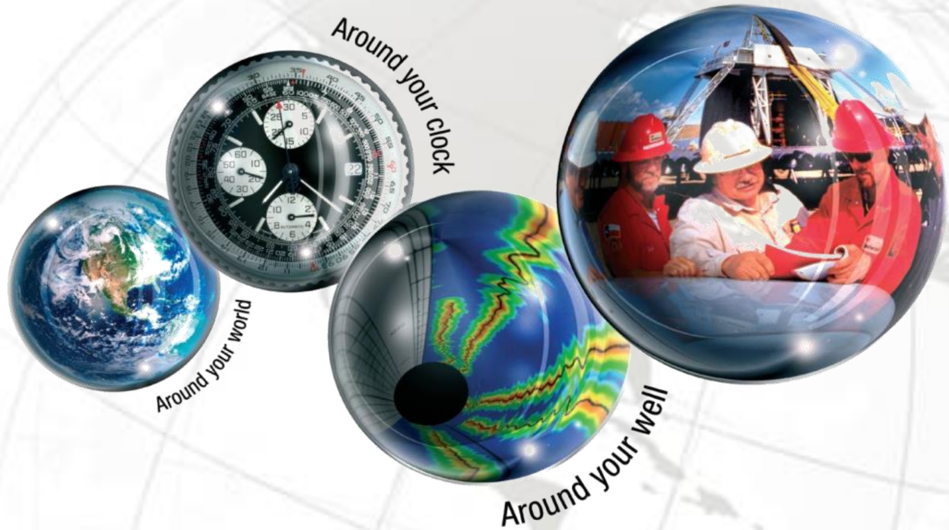
Weatherford®

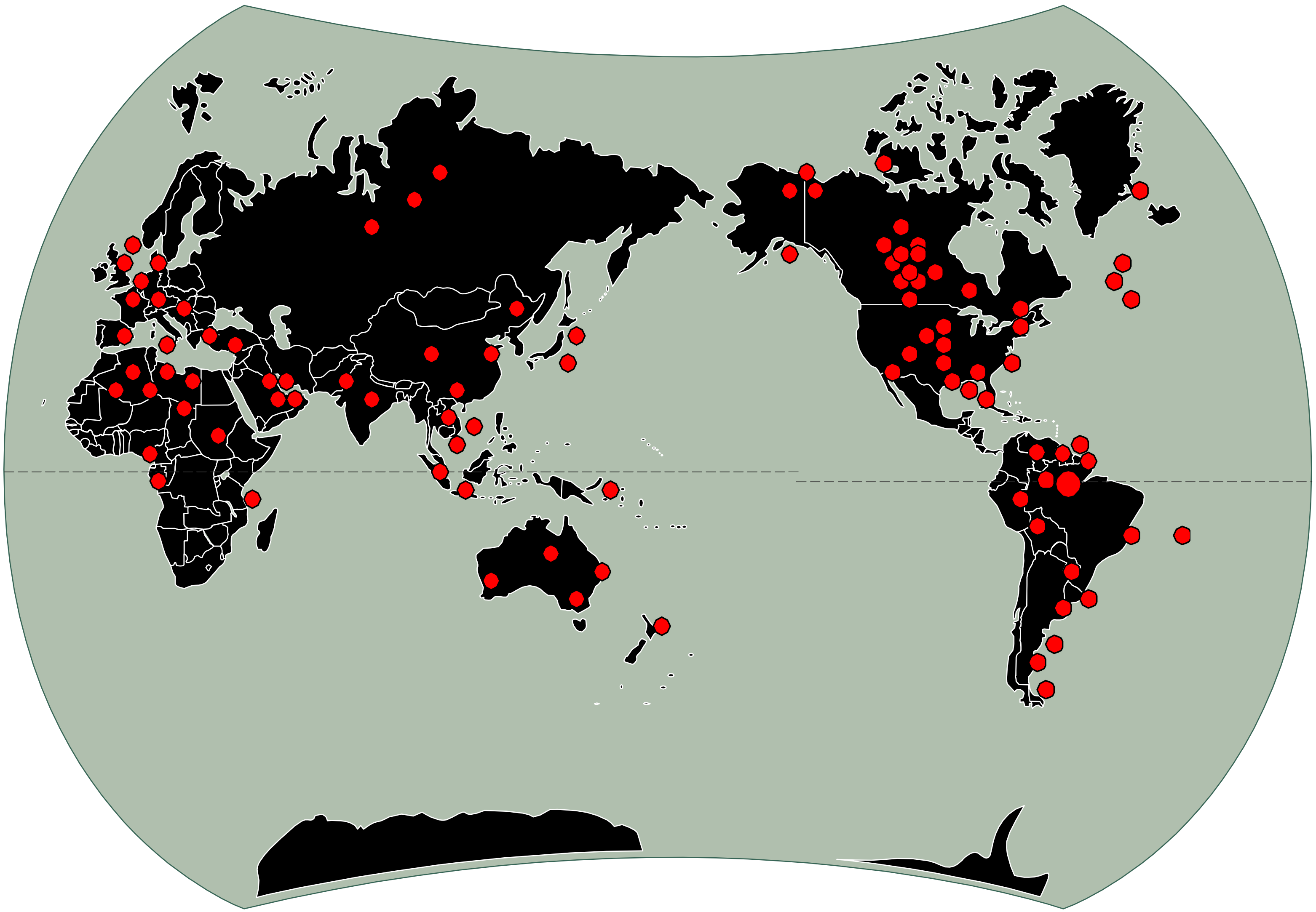
LABORATORIES



All Around You

Weatherford's Integrated Laboratory Services (ILS) effectively combines the experience and expertise of leaders in the oil and gas service industry by integrating their considerable abilities under one roof.

Global Experience in 50+ Countries



Weatherford® LABORATORIES

Agenda For The Session

- EOR and Services Overview
- Cost Effective data collection
- Gas Injection
- Chemical Flood
- Thermal EOR
- Discussion

Cost effective data collection

- Phase data acquisition through the life of the field
- Objectives of data acquisitions should go through a detailed justification exercise
- Investigate EOR at early stages of production (EOR floods can take place at the end of Water -Oil Relative permeability tests)
- Preserve Material for future analysis
- Proper geological description can optimize the samples analyzed
- It is sometimes more effective to perform EOR when water cuts are low

EOR Techniques

Properties	N2 & Flue Gas	Hydrocarbon	CO2	Immiscible Gas	Miscellar/polymer ASP, & Alkaline Flooding	Polymer Flooding	Combustion	Steam
Oil API Gravity	> 35 Average 48	> 23 Average 41	> 22 Average 36	>12	> 20 Average 35	> 15, < 40	> 10 Average 16	> 8 – 13.5 Average 13.5
Oil Viscosity (cp)	< 0.4 Average 0.2	< 3 Average 0.5	< 10 Average 1.5	< 600	< 35 Average 48	> 10, < 150	< 5000 Average 1200	< 200000 Average 4700
Composition	High % C1–C7	High % C2–C7	High % C5–C12	Not Critical	Light intermediate. Some organic acids for alkaline floods	Not Critical	Some asphaltic components	Not Critical
Oil Saturation (%PV)	> 40 Average 75	> 30 Average 80	> 20 Average 55	> 35 Average 70	> 35 Average 53	> 70 Average 80	> 50 Average 72	> 40 Average 66
Formation Type	Sandstone or Carbonate	Sandstone or Carbonate	Sandstone or Carbonate	Not Critical	Sandstone preferred	Sandstone preferred	High porosity sandstone	High porosity sandstone
Net Thickness	Thin unless dipping	Thin unless dipping	Wide range	Not critical if dipping	Not critical	Not critical	> 3 meters	> 6 meters
Average Perm. (mD)	Not critical	Not critical	Not critical	Not critical	> 10 mD Average 450 mD	> 10 mD Average 800 mD	> 50 mD	> 200 mD
Depth (m)	> 2000	> 1200	> 800	> 600	< 3000 Average 1000	< 3000	< 3800 Average 1200	< 1500
Temperature (°C)	Not critical	Not critical	Not critical	Not critical	< 100	< 100	> 50	Not critical

Table based on the 1996 Society of Petroleum Engineers Paper entitled "EOR Screening Criteria Revisited" by Taber, Martin, and Seright.

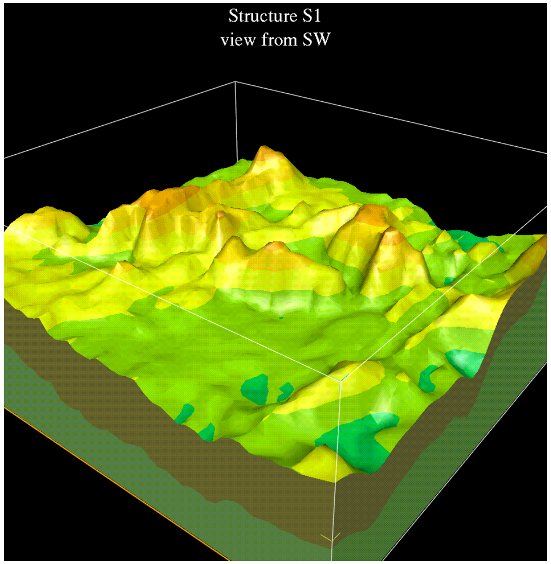
Weatherford® LABORATORIES

EOR Services in demand today

- Gas Injection
  - Sor recovery & CO_2 sequestration,
  - Incremental oil recovery by gas
- Thermal
  - Heavy oil recovery, cap rock integrity
- Chemical Flood A,S&P
  - Heavy oil to light oil plays,

Service Overview

- Laboratory
  - Reservoir Rock Properties
    - OOIP, OGIP, Productivity, Damage
  - Reservoir Fluid Properties
    - P, Bo, Rs, Viscosity, Solids
  - EOR, fluids & core floods
    - Gas, Steam, Chemical
  - Physical
    - Screens, Packers, Scaling,
    - Formation damage (tight rock)



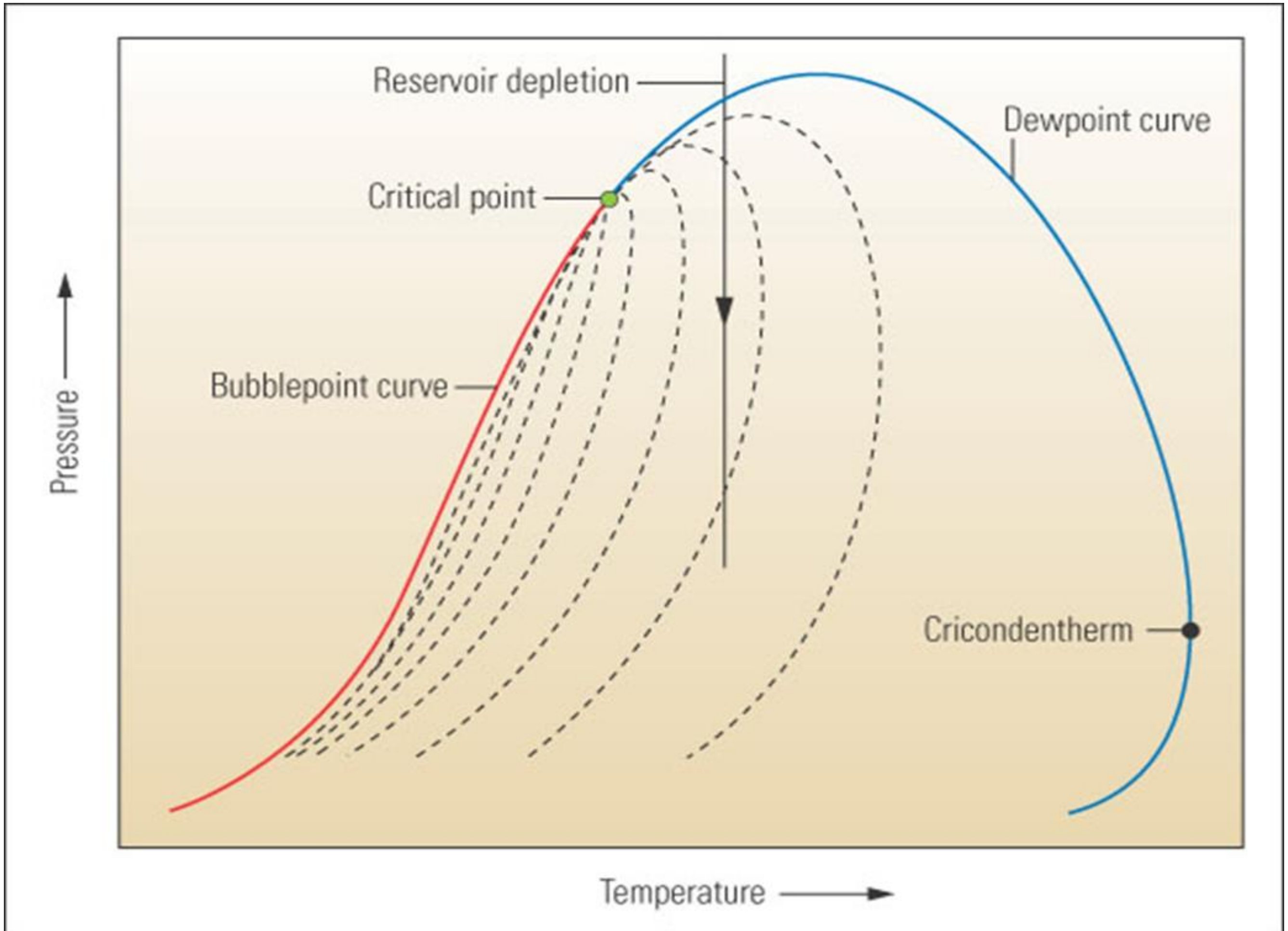
- Consulting
  - planning the study,
  - managing the study while it is in the lab and
  - applying the lab results to operator operations

Weatherford®
LABORATORIES

Six Parameters That Control EOR

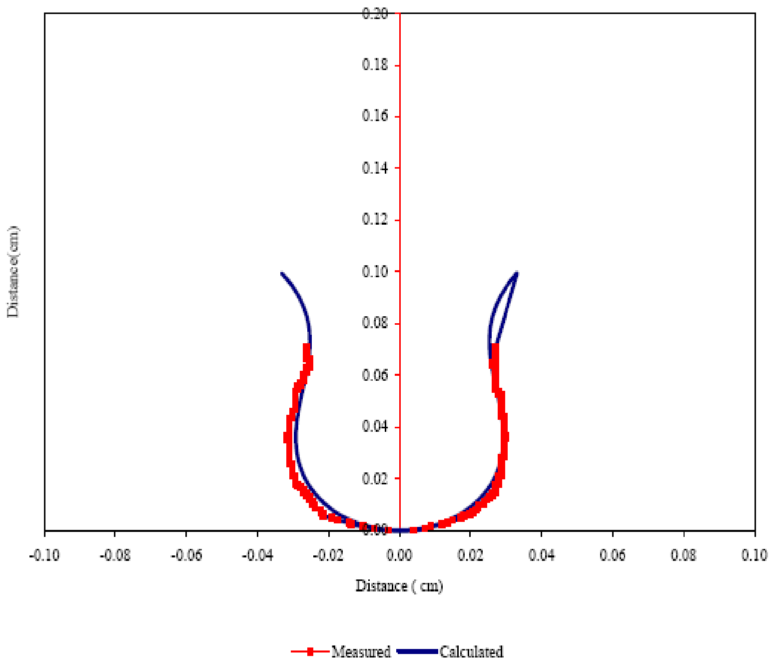
- Phase Behavior
- Interfacial tension (IFT)
- Viscosity ratio’s
- Pore throat size distribution
- Wettability
- Gravity

Fluid Phase Behavior



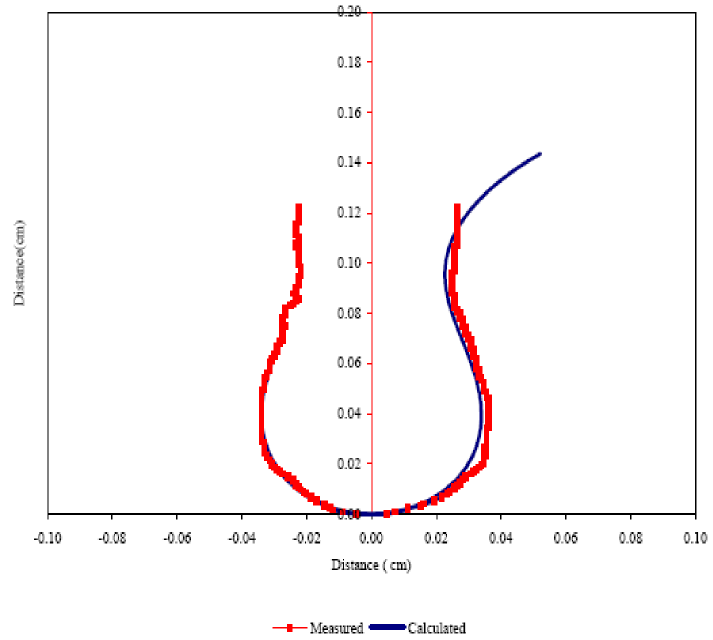
Interfacial Tension IFT

MISCIBILITY STUDY
3RD CONTACT REVERSE @ 5700 psia (39.30 MPa) & 178 F (354.2 K) WITH SOUR GAS (13 % H2S)



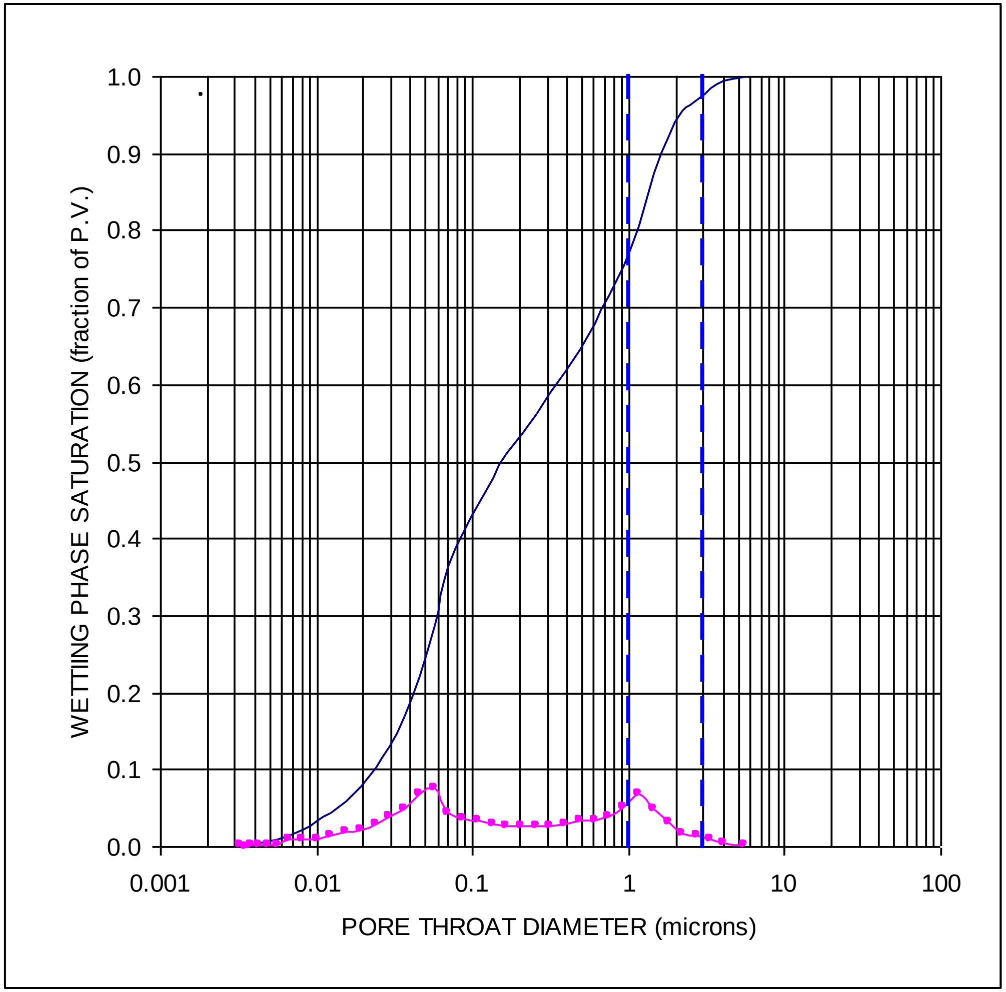
IFT = 1.065 dyne/cm

MISCIBILITY STUDY
3RD CONTACT FORWARD @ 5700 psia (39.30 MPa) & 178 F (354.2 K) WITH SOUR GAS (13 % H2S)



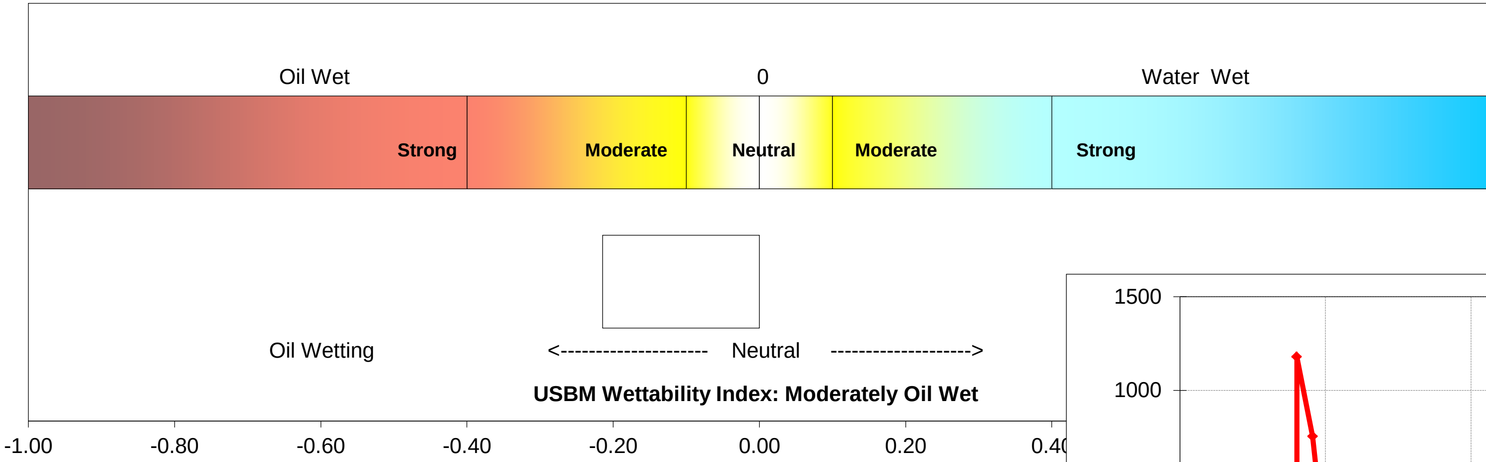
IFT = 0.442 dyne/cm

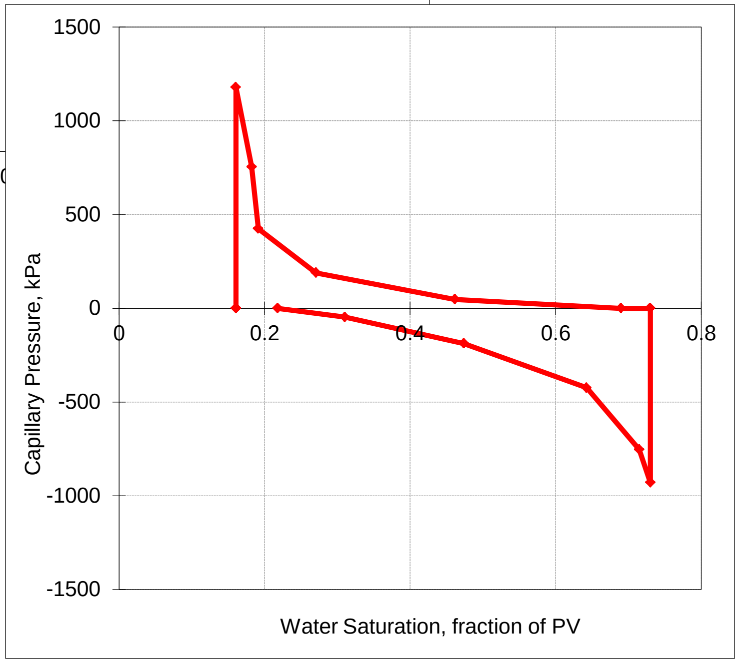
Pore Throat Size Distribution



Weatherford®
LABORATORIES

Wettability



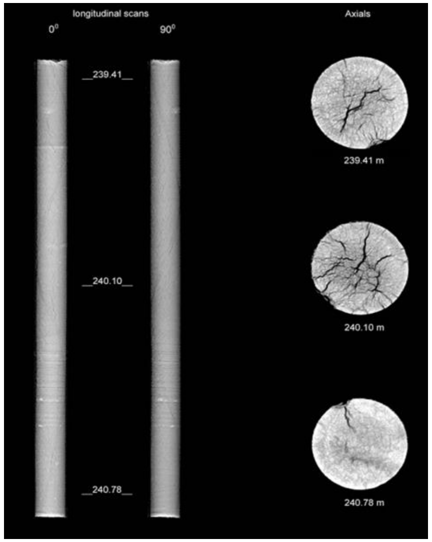


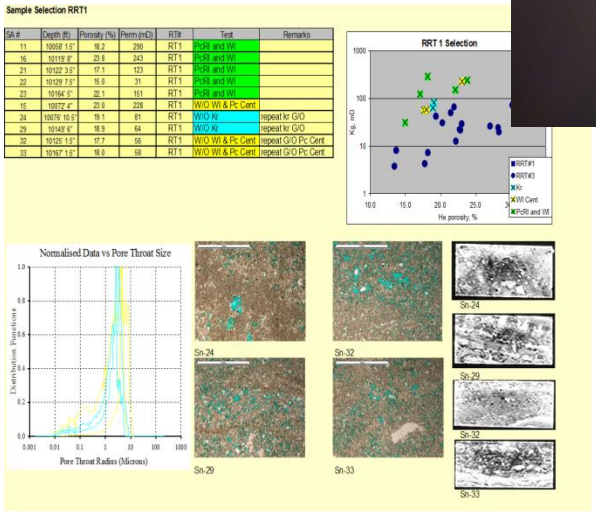
Weatherford®
LABORATORIES

H_2S Capability – Yes We Can!

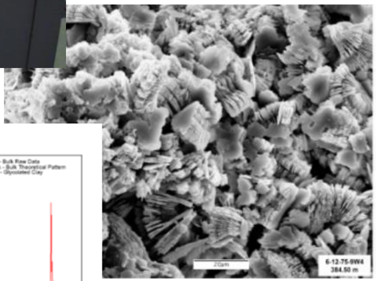
Weatherford
LABORATORIES

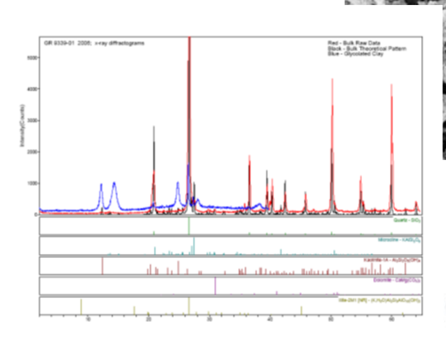
Fluid & Rock Characterization





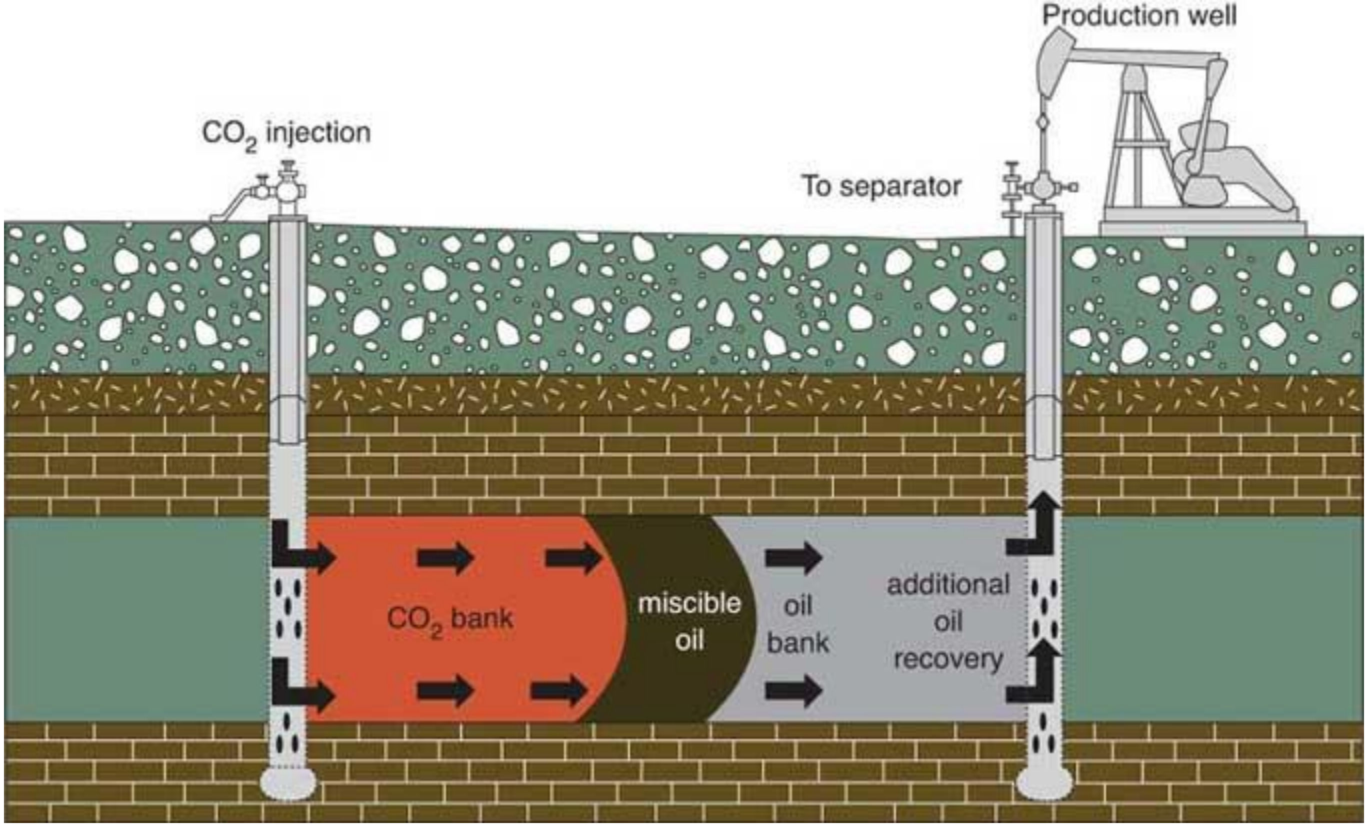
SA #	Depth (ft)	Porosity (%)	Perm (mD)	RT#	Test	Remarks
11	10058' 1.5"	18.2	290	RT1	PcRI and WI	
16	10119' 8"	23.8	243	RT1	PcRI and WI	
21	10122' 3.5"	17.1	123	RT1	PcRI and WI	
22	10129' 7.5"	15.0	31	RT1	PcRI and WI	
23	10164' 5"	22.1	151	RT1	PcRI and WI	
15	10072' 4"	23.0	228	RT1	W/O WI & Pc Cent	
24	10076' 10.5"	19.1	81	RT1	W/O Kr	repeat kr G/O
29	10149' 6"	18.9	64	RT1	W/O Kr	repeat kr G/O
32	10125' 1.5"	17.7	56	RT1	W/O WI & Pc Cent	repeat G/O Pc Cent
33	10167' 1.5"	18.0	58	RT1	W/O WI & Pc Cent	repeat G/O Pc Cent





Weatherford® LABORATORIES

Gas Injection



Weatherford LABORATORIES

Enhanced Oil Recovery - Fluids

- Rising Bubble (RBA)
- Slim Tubes – for MMP, MME
  - 60 foot X ¼ " sand packed tube
  - Gas displacing oil -> idea of miscibility
- Swelling Study – for MMP, MMW
  - Mixes (5) of oil + solvent
  - See effect on Ps & physical properties
- Multi – contact Experiment, >>MMP, MME
  - Sequential mixing of oil & solvent
  - Equilibrium phases re-contacted
  - IFT, K values, Comps, and more

PVT Lab – Large capability

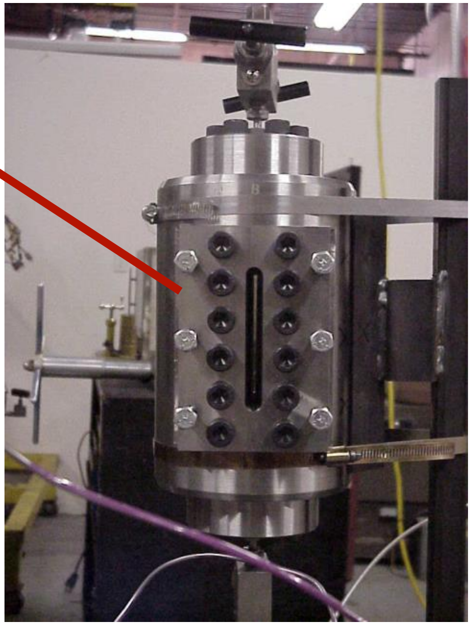
7 PVT stations in this lab
And 3 more in the isolation lab

Slim tube being run in the Isolation lab (H2S/CO2 Injection gas mix)

Weatherford
LABORATORIES

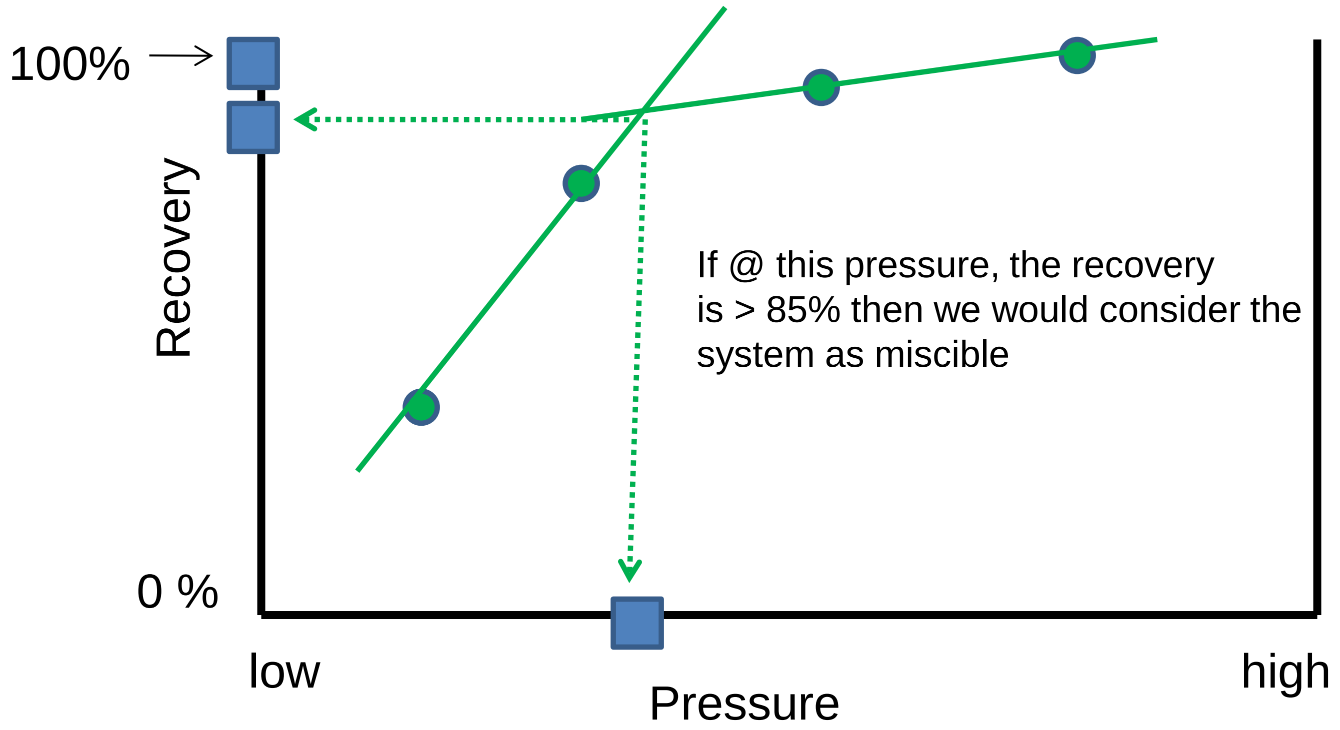
EOR Rigs

Slim Tube



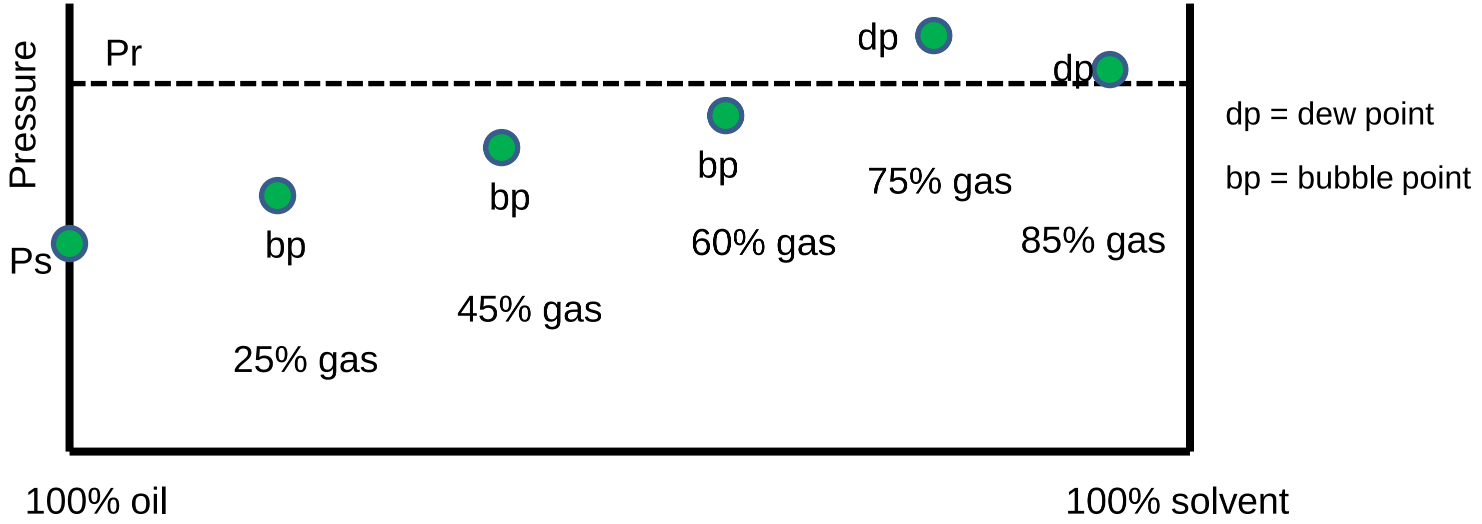
PVT Cell
Swelling
Or
Multi contact

Slim Tube Plot - MMP

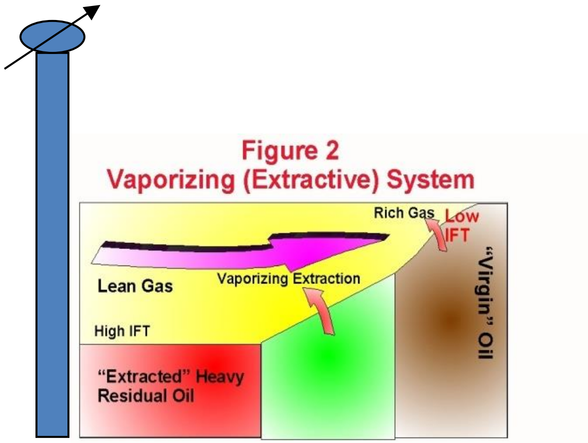


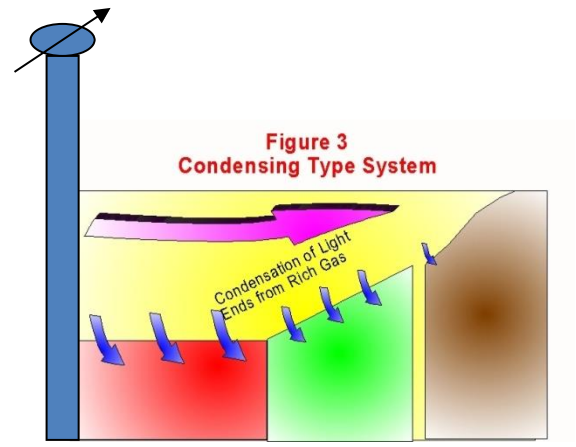
Swelling Test – P-X

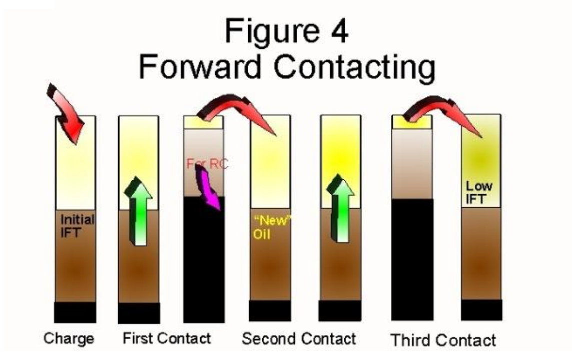
- Incrementally (5 steps) add solvent to live oil & measure bubble point / dew point, swelling & composition of the upper & lower phases.
- Graph shows a "pass" ie bubble points of all mixes are < Pr; all oil – gas mixes are single phase at P < Pr.

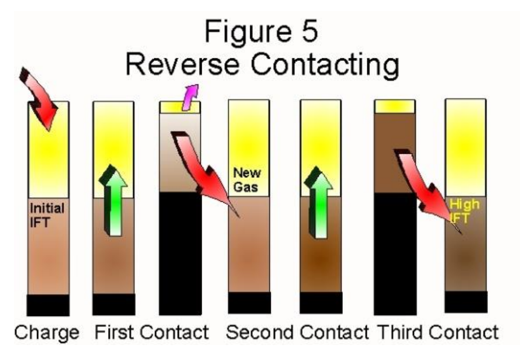


Multi - Contact





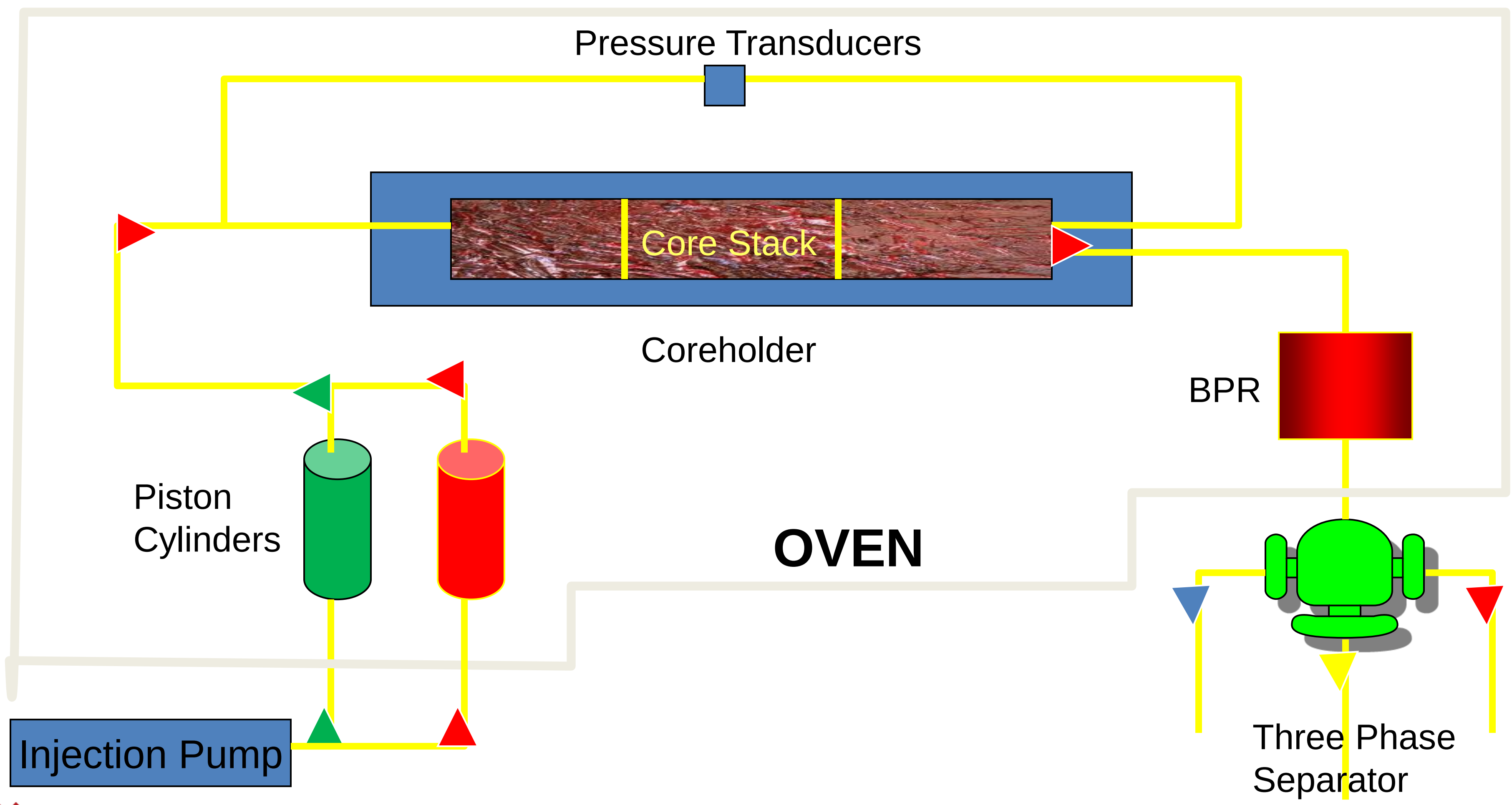




Multi – Contact test

- 6 equilibrium points
  - 3 forward contacts & 3 reverse
- Viscosity of lower phase at highest and lowest IFT contact
- K values at each contact
- IFT at the highest & lowest stages
- GOR, Density and Bo of the contacted stages
- Closely models the near well bore region (reverse contact) and deep in the reservoir (forward contact)

EOR Core Floods



Using multi-contracted phases in core floods = unique service

Figure 9
Oil Saturation Trapped in Micropores

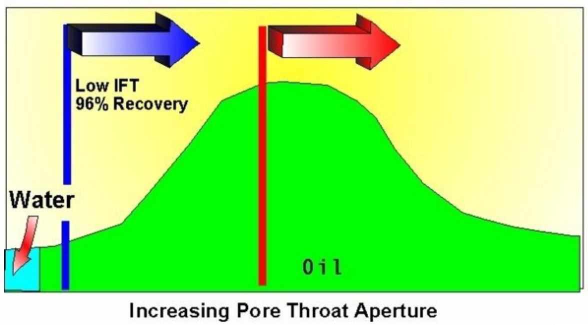


Figure 10
Micropores Water Saturated Oil Saturation Trapped in Macropores

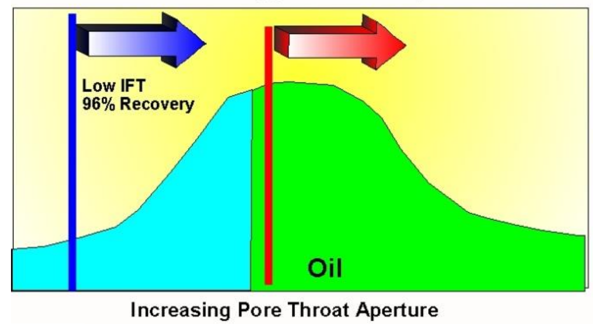
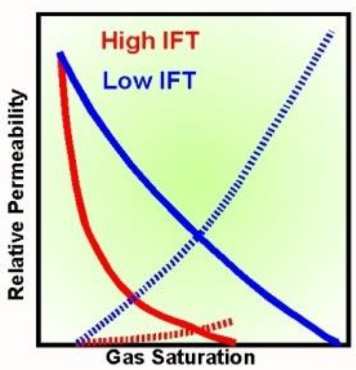
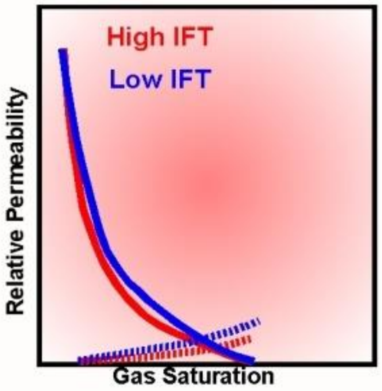


Figure 7
IFT Dominated Reservoir



Overlay the high
And low IFT curves
To indicate reservoir
Sensitivity to miscibility

Figure 8
Mobility Dominated Reservoir



Weatherford® LABORATORIES

Results from fluids EOR tests

- Basic live oil properties
- Determine Minimum Miscibility Pressure
- Determine Minimum Miscibility Composition
- Fine tune injection solvent to get leanest composition that fits into given pressure or least cost

Gas Injection - Conclusions

- Understanding fluid phase behavior is critical to predicting the success of the EOR plan
  - MMC & MMP
  - Vaporizing vs Condensing drives
- The solvent composition may be tuned to optimize the flood
- Can run the RBA as a predictor of miscibility, run 1 slims rather than 4, run the swelling test & run the MC for saving time and $
- After the fluid properties have been defined, run core floods. Though fluids properties may indicate miscibility, Sor may still not be recovered – think heavy oil core + toluene -> takes forever to clean it though 100% miscible
- Gravity effects, pore micro & macro features, wettability & saturation will significantly control the Sor recovery.

Weatherford® LABORATORIES

Calgary EOR Capability

Non thermal core studies

Steam floods, 7 stations

Weatherford LABORATORIES

Core Testing Rig – Steam Floods

Weatherford®
LABORATORIES

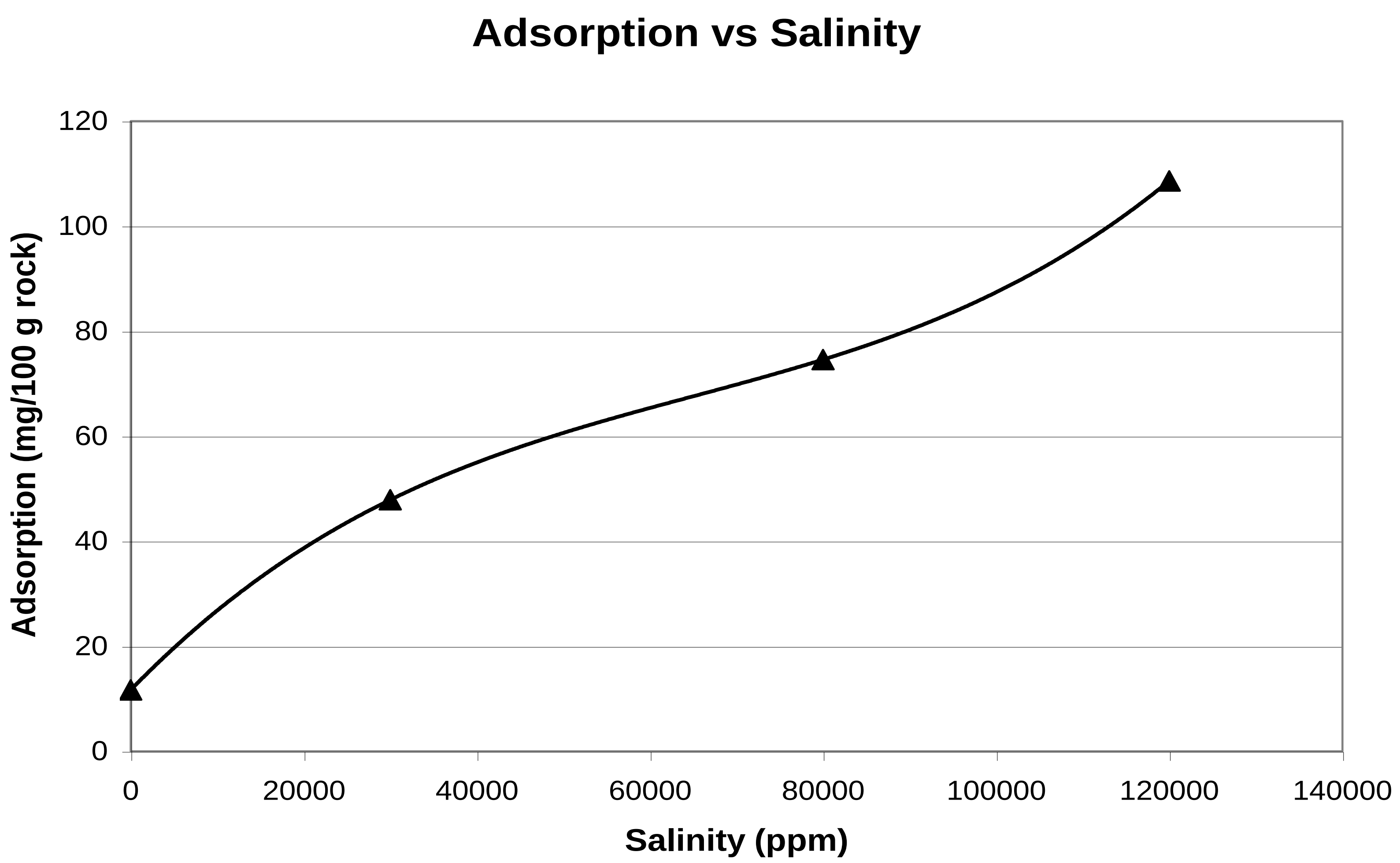
Miscibility?

- Is miscibility always necessary for successful oil recovery
- Why are some reservoirs not sensitive to (low) interfacial tension & residual oil recovery?
- Why do some reservoirs allow high residual oil recovery with high interfacial tension injectants?
- How can you tell?

Chemical Flooding - ASP

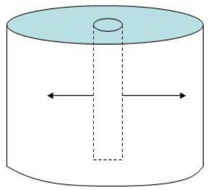
1. Selection of potential reagents including A,S &P
2. Screen on basis of rock, clays, salinity, phase behavior
3. Confirm IFT, adsorption, viscosity
4. Run core floods, axial and radial
5. Simulate for optimal slug size

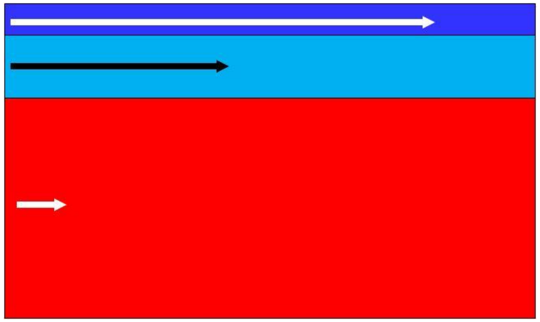
Higher adsorption with increasing salinity

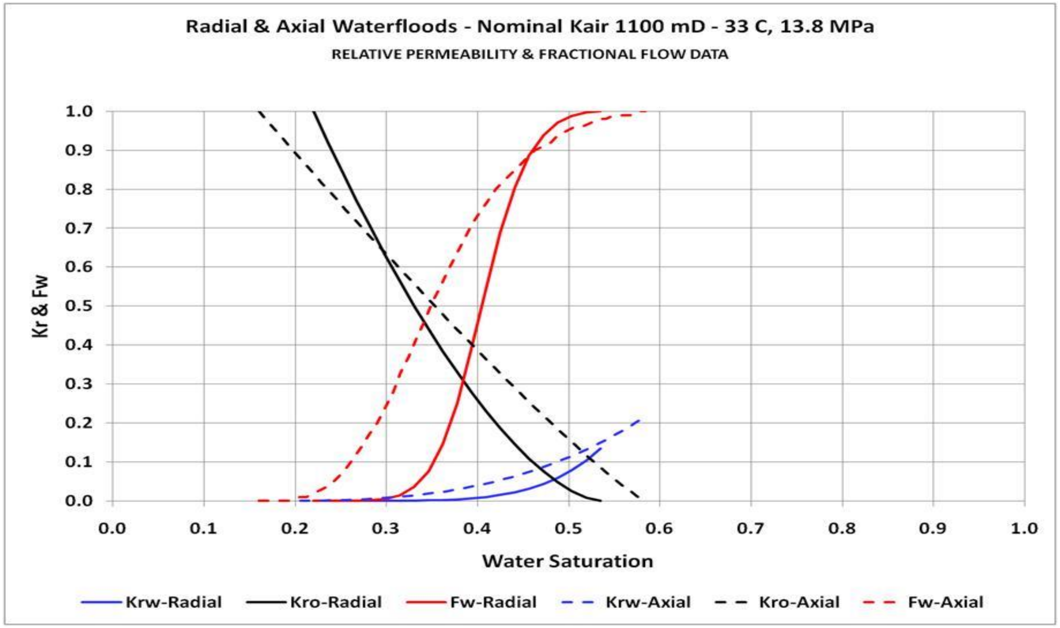


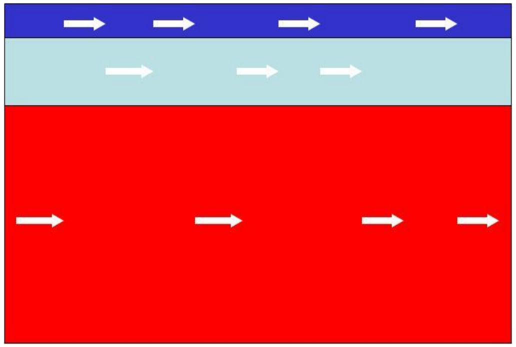
Weatherford®
LABORATORIES

Radial and Axial Core Floods

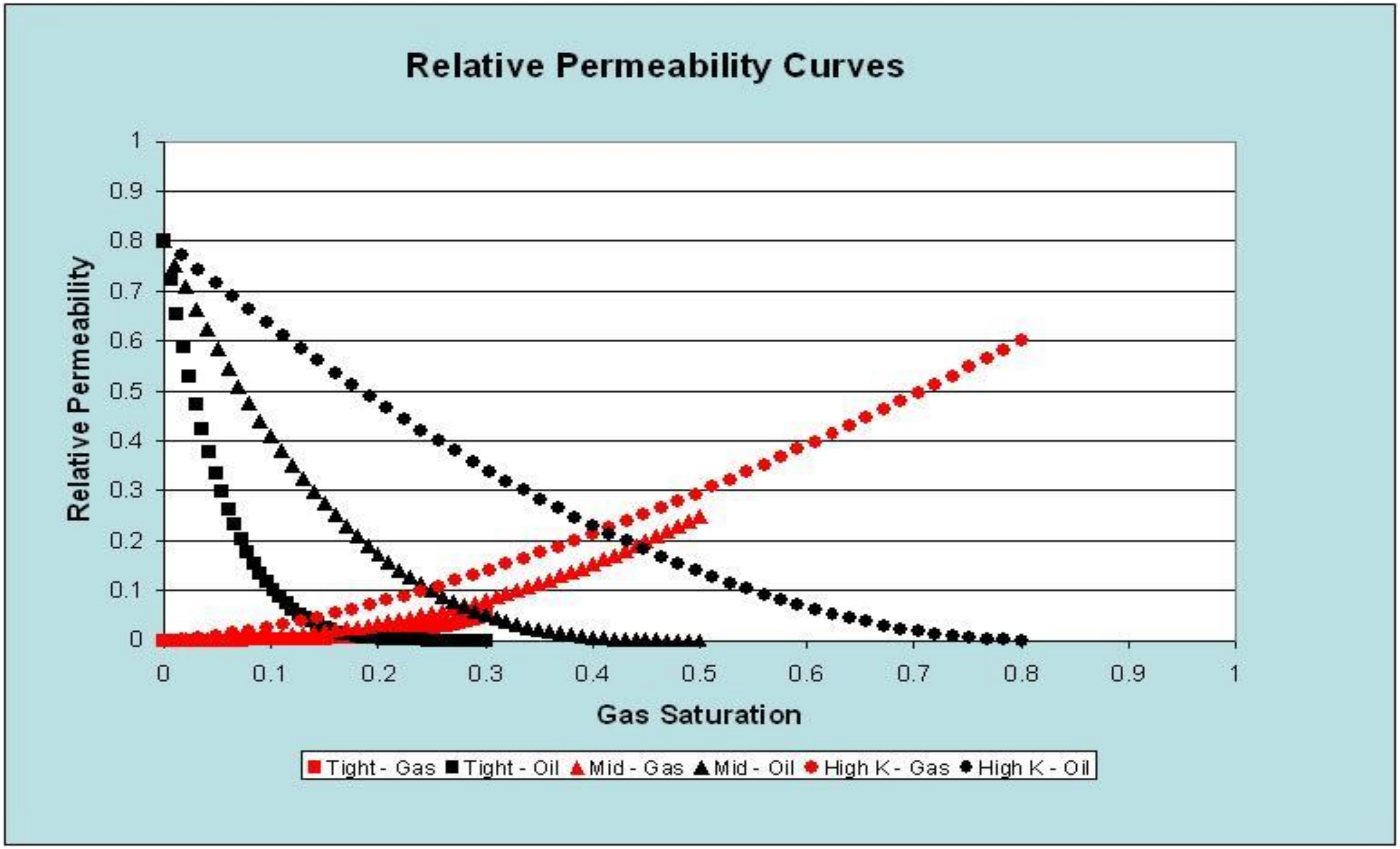






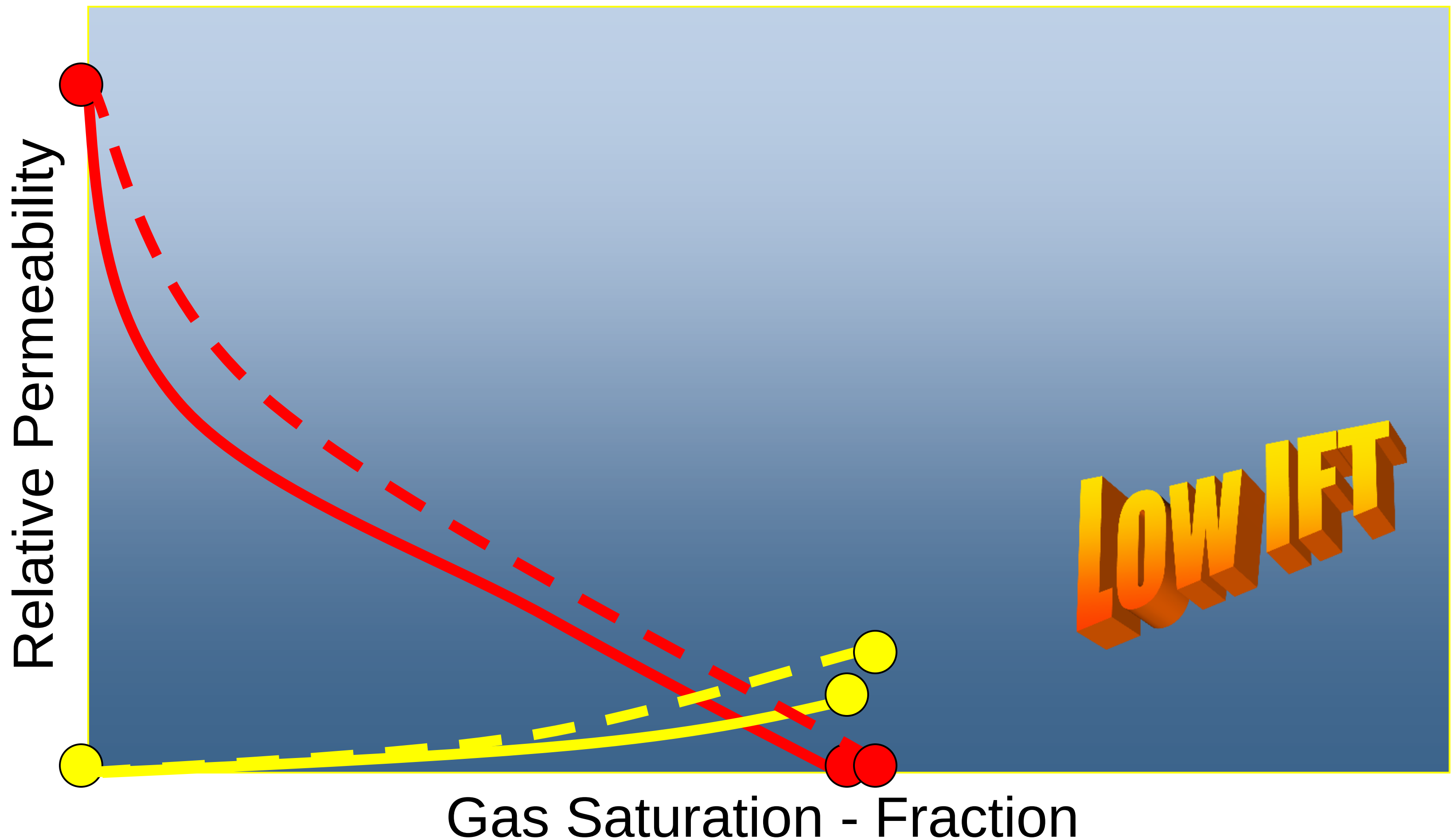


Chemical Flooding



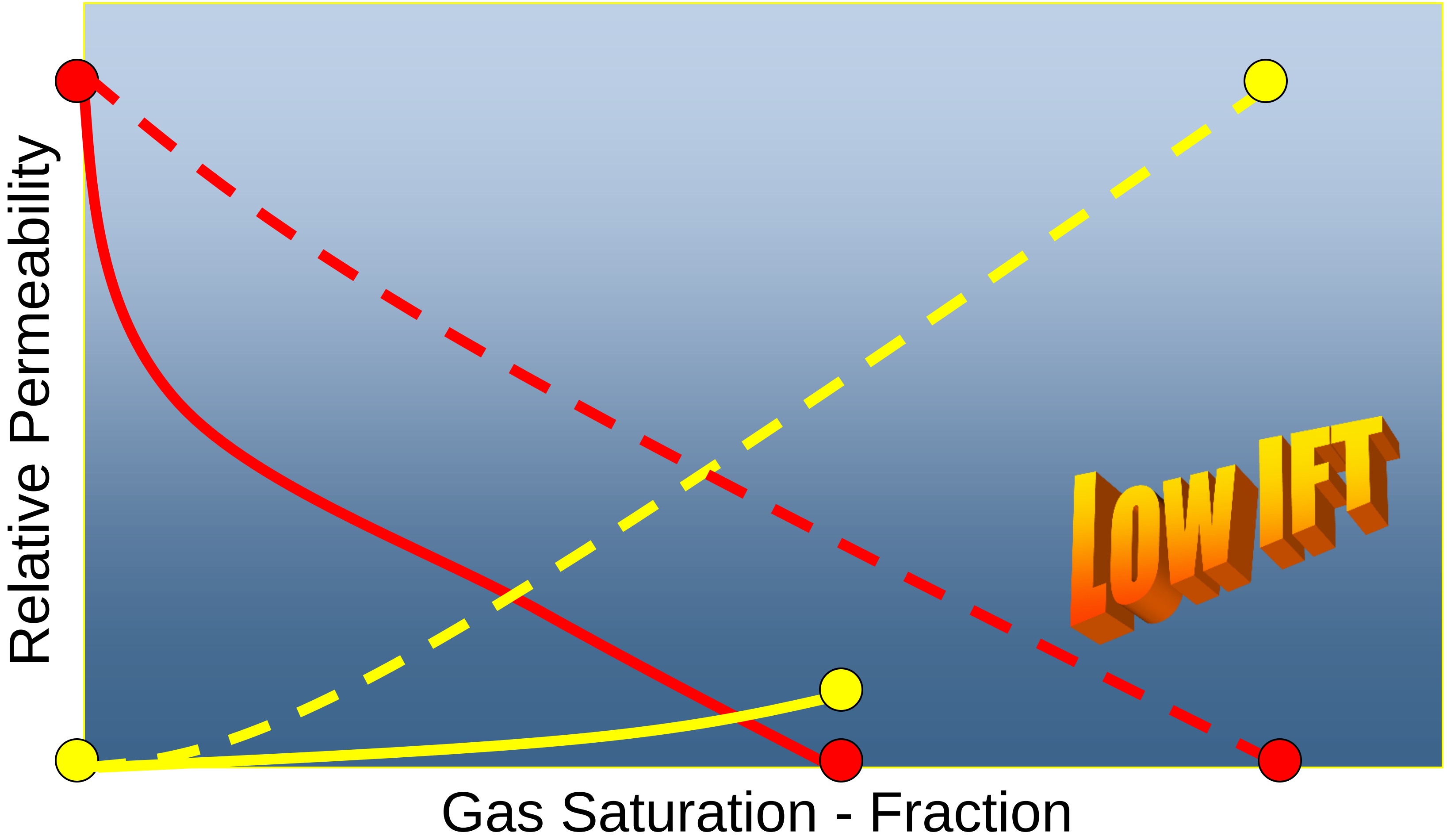
Weatherford®
LABORATORIES

For a Reservoir Dominated by Mobility



Weatherford LABORATORIES

For a Reservoir Dominated by IFT

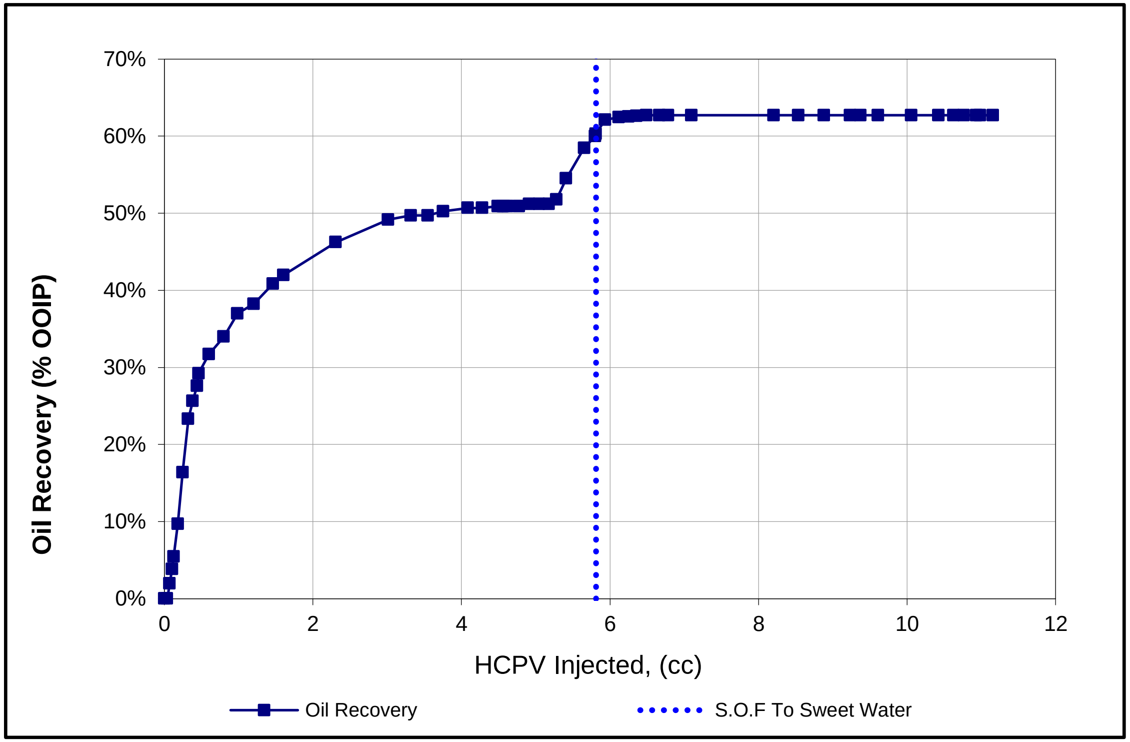


Sweet/Smart (Low Salinity) Water Flooding

Mechanisms of Low Salinity Water Flood

1. Ionic Exchange/adsorption of polar components from crude oil
2. IFT Reduction results from pH change
3. Wettability alteration
4. Alteration of Zeta potential

Sweet/Smart (Low Salinity) Water Flooding

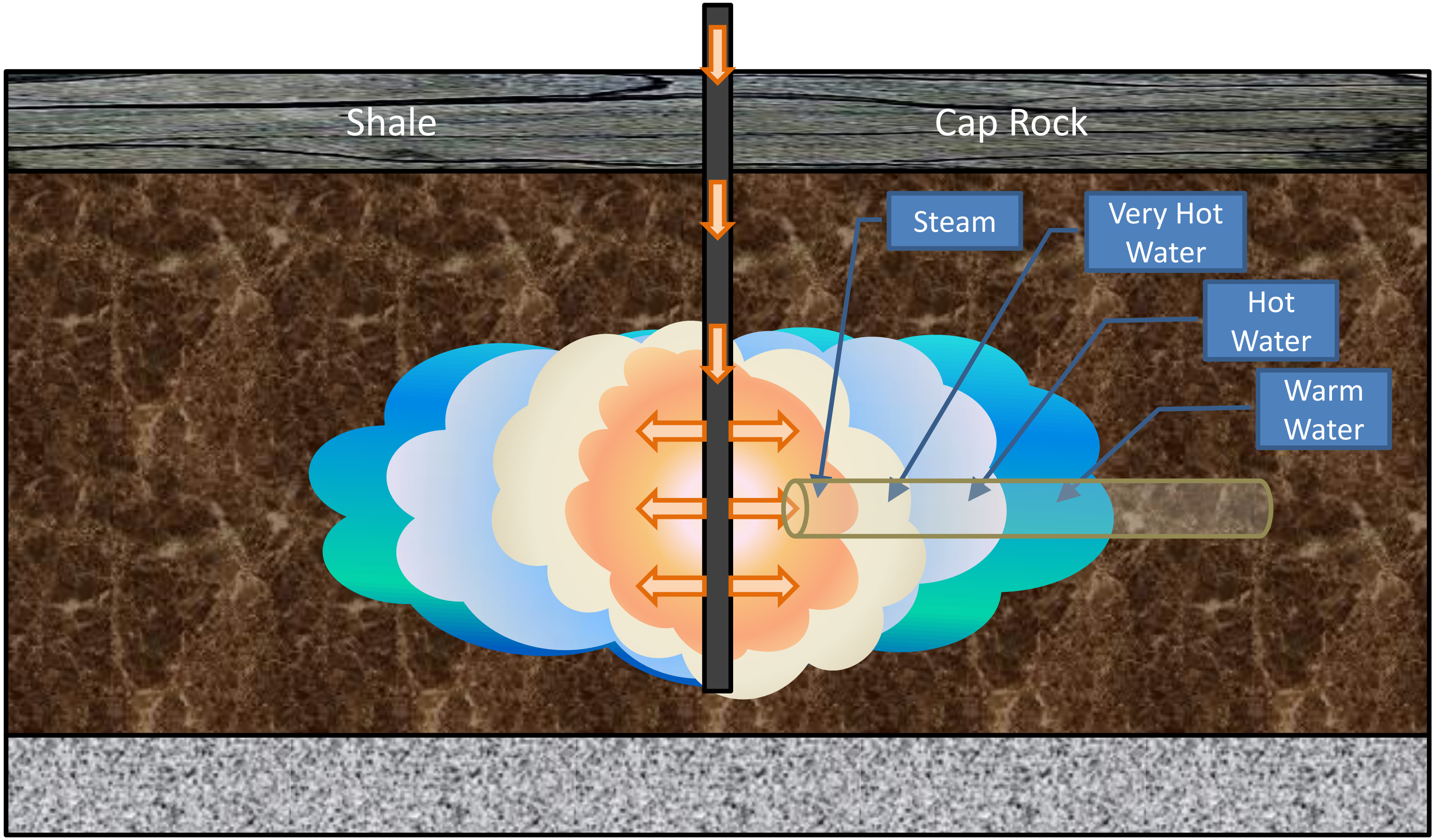


Weatherford® LABORATORIES

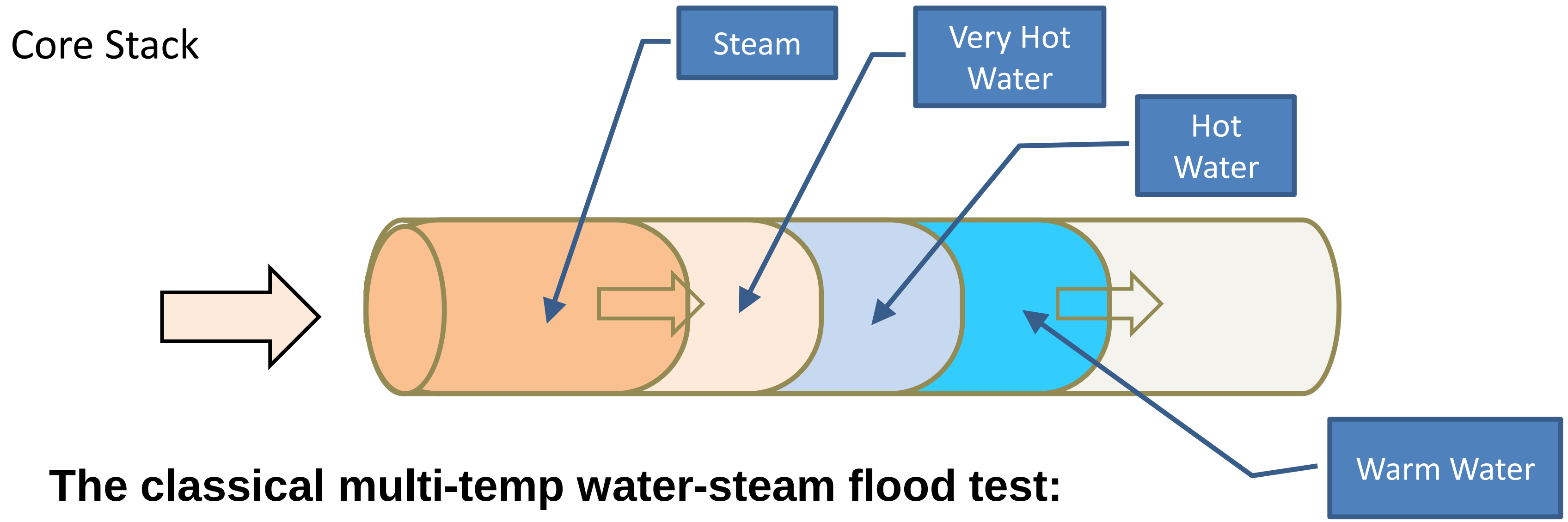
Thermal Recovery Schemes

- Steam flood design including shale barriers
- Cyclic Steam (CCS)
- Steam Assisted Gravity Drainage (SAGD)
- Solvent Assisted SAGD
- Chemically Assisted SAGD
- Design of slot parameters (straight cut, key hole, rolled top, aperture) can not easily be predicted
- Fire Flood

Steam Injection into the Formation



Laboratory Core Flood Scenario



The classical multi-temp water-steam flood test:

1. Flood core at minimum mobilization temperature (~80 °C).
2. Flood core at several increasing temperatures up to 240 °C.
3. Flood core with saturated steam at 240 °C.
4. Optional floods at the end with fresh water to evaluate potential clay sensitivity to the injection process.

Thermal/Steam Effects

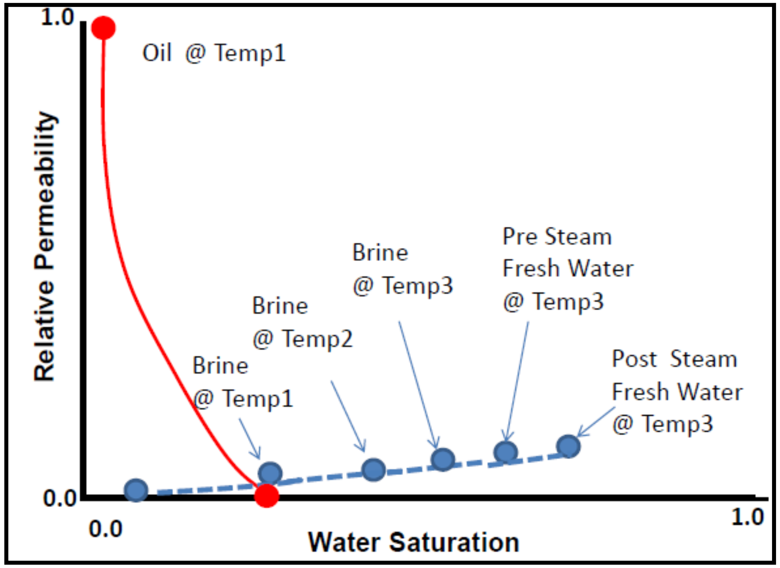


Figure 1 – Typical Steamflood Test Profile, No Damage effects

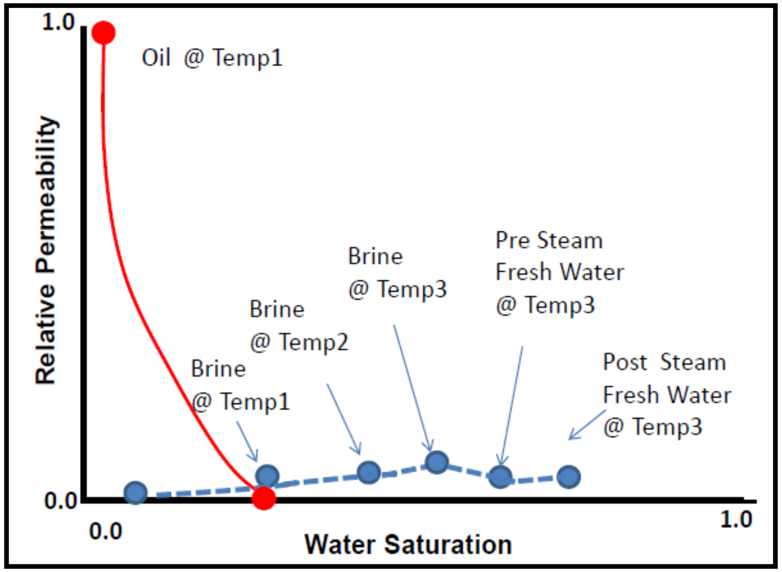
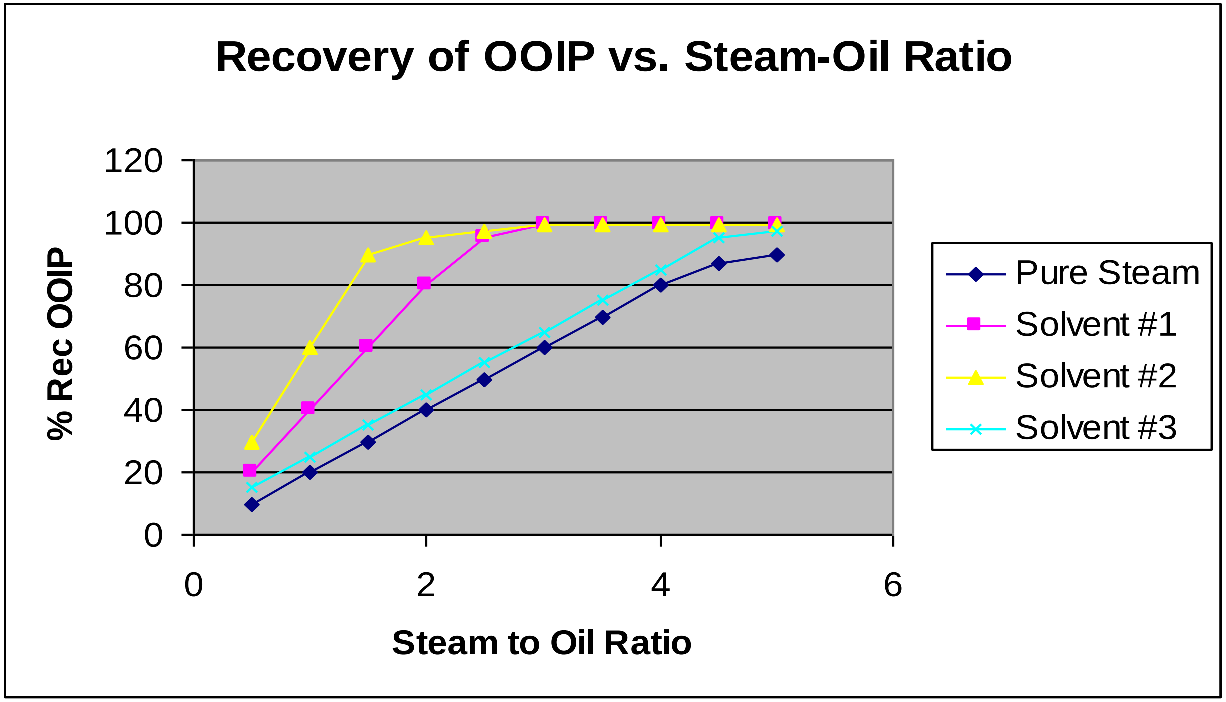


Figure 2 – Typical Steamflood Test Profile, Damage Effects

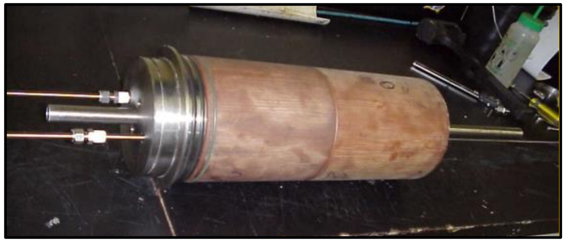
Weatherford® LABORATORIES

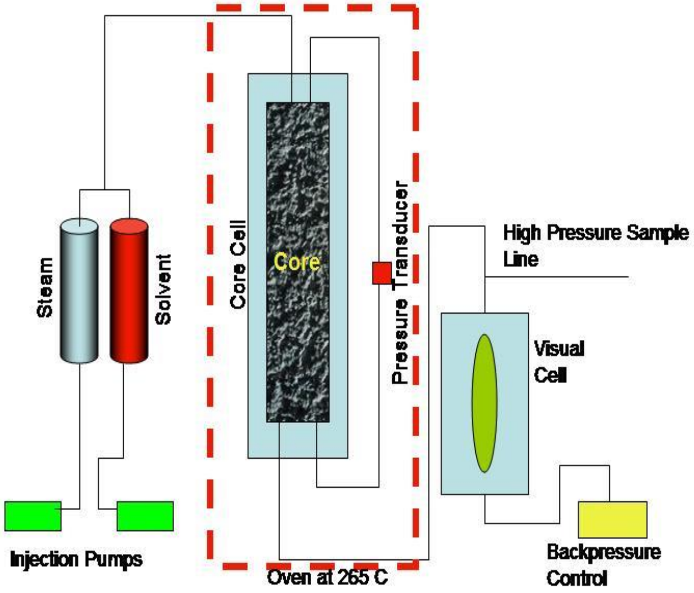
Solvent in Steam



Steamflood Testing Lab

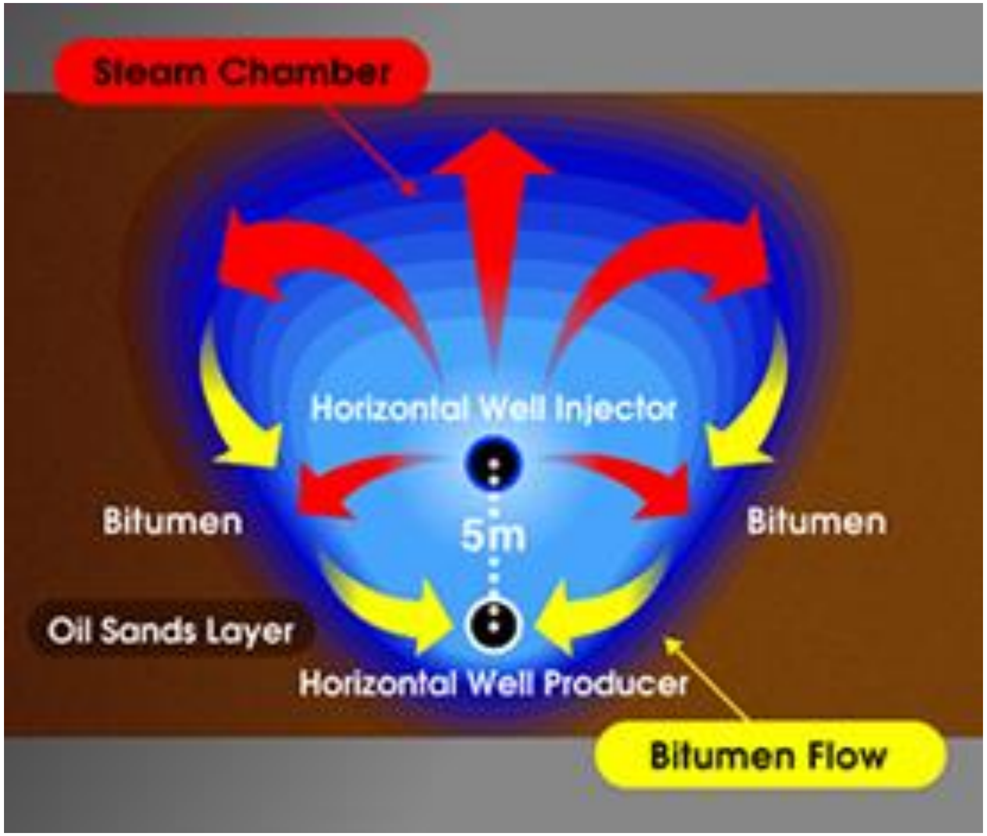
- Dynamic (relative permeability) test – fresh, frozen core
- Reactor test – not a sand pack





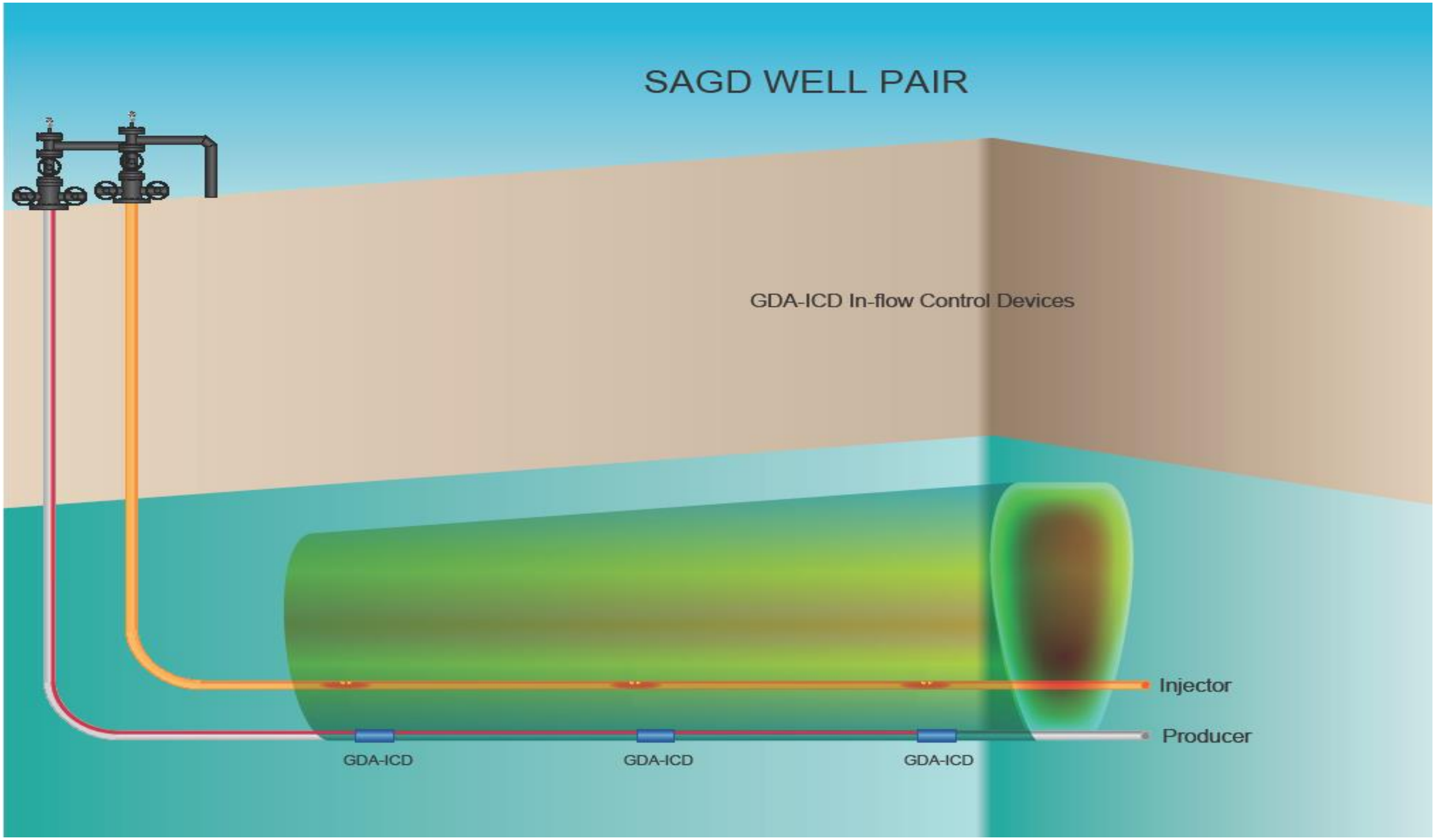
Weatherford®
LABORATORIES

Steam Chamber

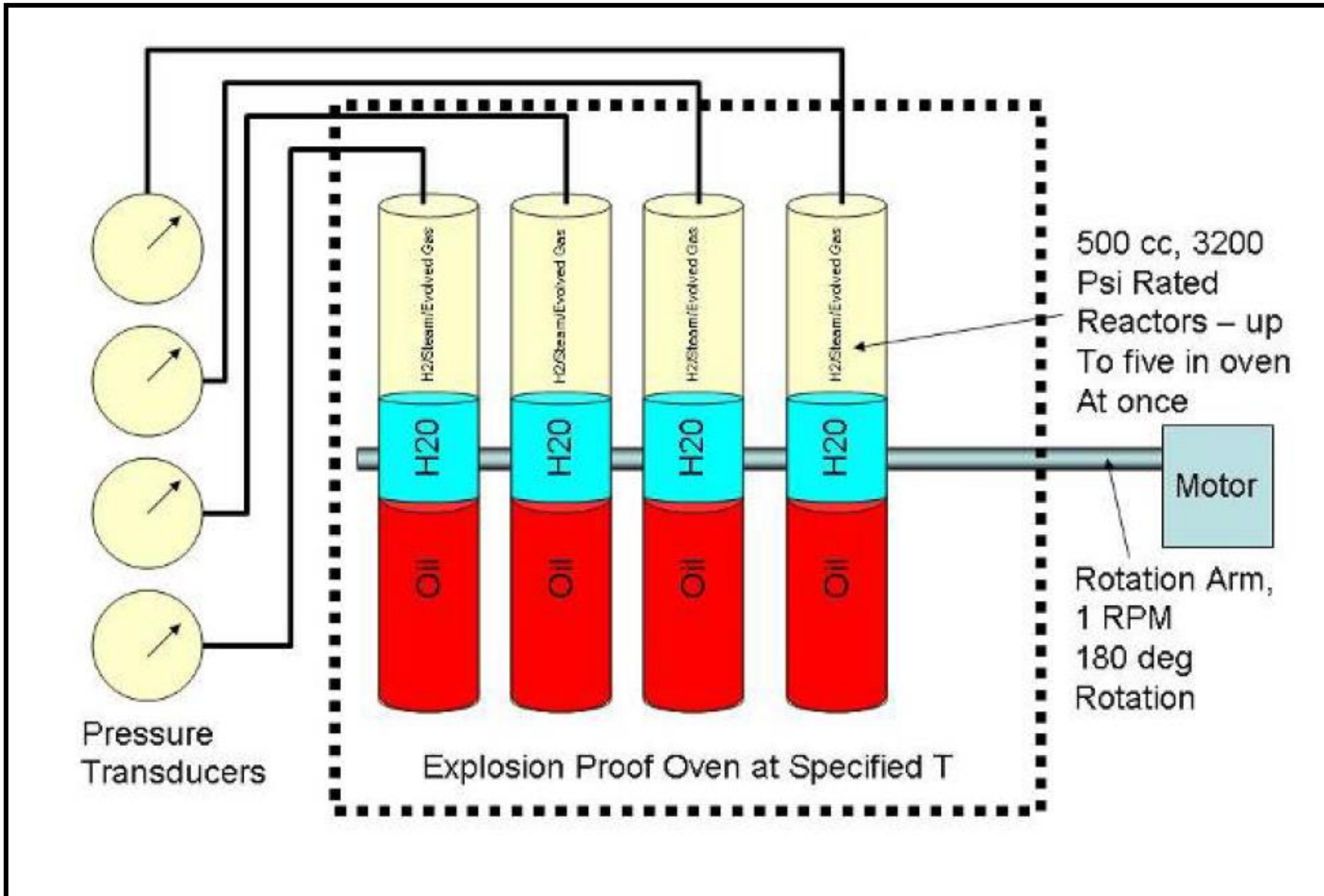


Laboratory Simulation of
Steam Chamber

Steam Chamber – Well Pair



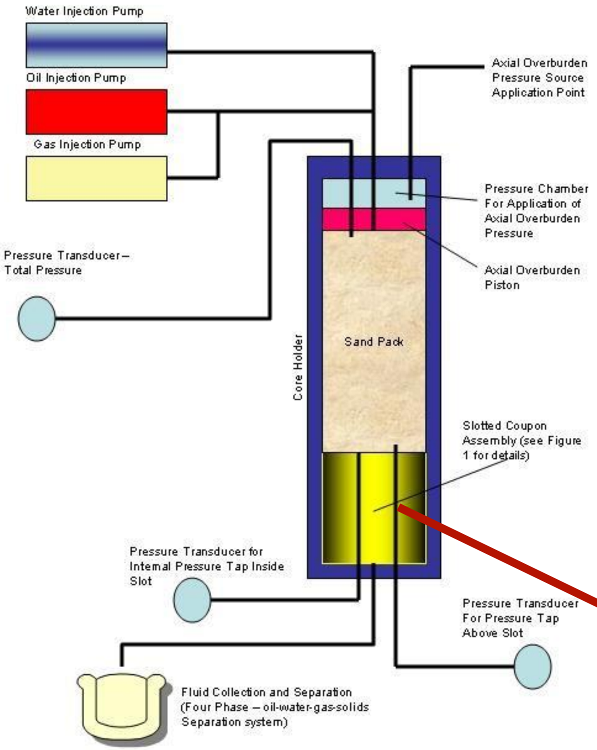
Aquathermolysis Test Apparatus

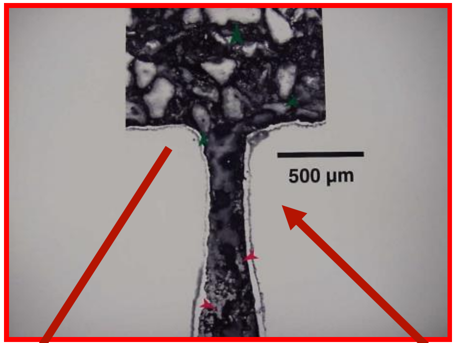


SAGD Pilot

Screens & Slotted Liners

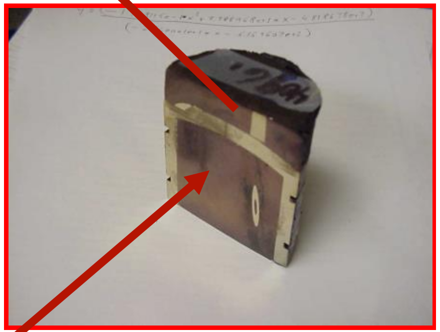
Figure 2 – Experimental Apparatus   Sand Control Study





OXY OMAN MUKHAIZNA SAND CONTROL STUDY
PARAMETRIC SAND CONTROL STUDIES - 'FINE' GRAINED SAND
0.020" x 0.028" SC BASE SLOT

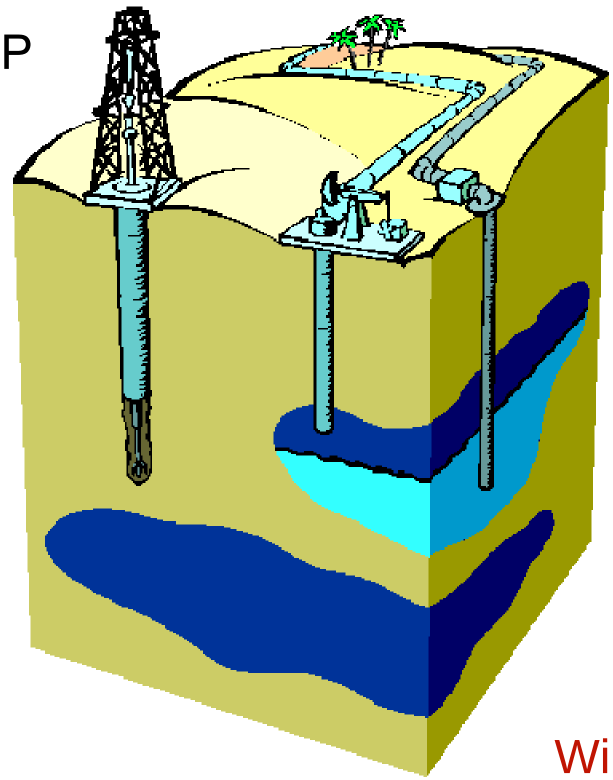
RATE O.W.G. CC/HR	AVG PACK DELTA P PSI	AVG TOP SLOT DP PSI	AVG BOT SLOT DP PSI	PRODUCED SAND GRAMS
40, 0, 0	0.38	0.05	0.03	0.00
80, 0, 0	0.75	0.32	0.13	0.00
120, 0, 0	0.99	0.38	0.18	0.00
160, 0, 0	1.39	0.37	0.18	0.01
160, 80, 0	3.65	0.49	0.18	0.01
160, 160, 0	4.97	0.68	0.19	0.01
160, 240, 0	6.72	0.83	0.17	0
160, 320, 0	7.62	0.97	0.18	0.02
160, 320, 10000	14.67	1.61	0.33	0.02
160, 320, 20000	20.64	2.00	0.20	0.01
160, 320, 30000	29.46	2.30	0.20	0.01
160, 0, 0	1.98	0.39	0.09	0



Recap

What kind of gas to inject

What's the OOIP / OGIP



When will water break through

Damage & prevention

What's left behind

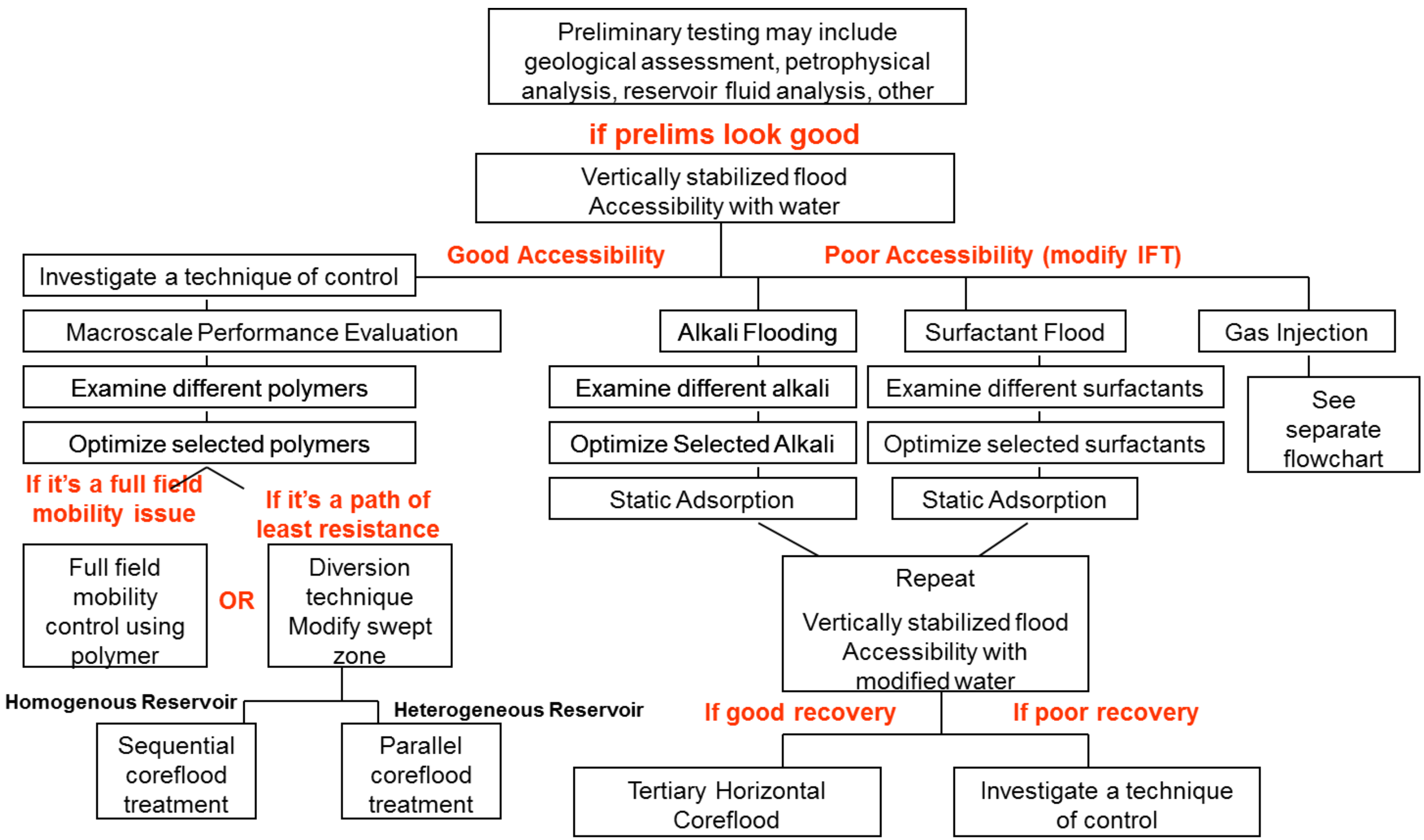
Will Steam work

What's the water cut

Will chemical flooding work

How fast can we produce it

Enhanced Oil Recovery Flowchart



Weatherford®
LABORATORIES

What this means for You …

Opportunity

- What to do with existing pools
- CO_2 sequestration
- Heavy oil being considered
- Tight formations

Weatherford Labs fit

- Increase efficiency & effectiveness of recovery of current pools
- EOR potential
- Steam flood potential
- Damage / optimization

Understand & Apply Results

Any questions or comments?

Weatherford® LABORATORIES