Wettability Alteration and Increasing Recovery in the Permian Basin: Application to Conventional and Unconventional Reservoirs*

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Abstract

Wettability has a significant effect on hydrocarbon recovery from all types of reservoirs. Each reservoir has a wettability state that leads to maximum recovery, but the initial wettability of a reservoir is usually not optimal. Traditionally, we have used surfactants and chemical agents to try to optimize wettability and recovery, but this process is expensive and does not always produce the desired results. This talk will outline the state of the science in wettability, as well as a methodology to realize the goal of maximum recovery.

This methodology changes wettability by changing water chemistry. This technique can be employed during normal waterflood operations in conventional fields, or during hydraulic fracturing and completions in unconventional targets. This technique has several advantages including substantially lower costs, ease of application and lower probability of negative outcomes. The successful approach to wettability alteration requires several key steps: screening the fields to identify good candidates, simple laboratory techniques to evaluate the increased recovery potential, economic evaluations to estimate costs and benefits, and finally, well-constrained predictive models to help design the wettability-modifying fluids.

Examples from the Permian basin using the methodology described are presented. These include formations such as the Spraberry, Avalon and Bone Springs. In conventional reservoirs that have favorable conditions incremental recoveries between 5 to 15% OOIP are possible and given the relatively low CAPEX and OPEX many cases will be profitable. The application of this technique to unconventional resources is still being explored, but offers the opportunity to increase initial flow rates and extend decline curves. While some current assumptions will be refined as we become more knowledgeable, the basic idea, that we can alter wettability with water chemistry to optimize recovery seems well justified.

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Field Assistants

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Conclusions

- Hydrocarbons wet rock surfaces through the water film.
- We have a new experimental technique that rapidly investigates wettability at the grain scale.
- Surface chemistry models will predict wettability.

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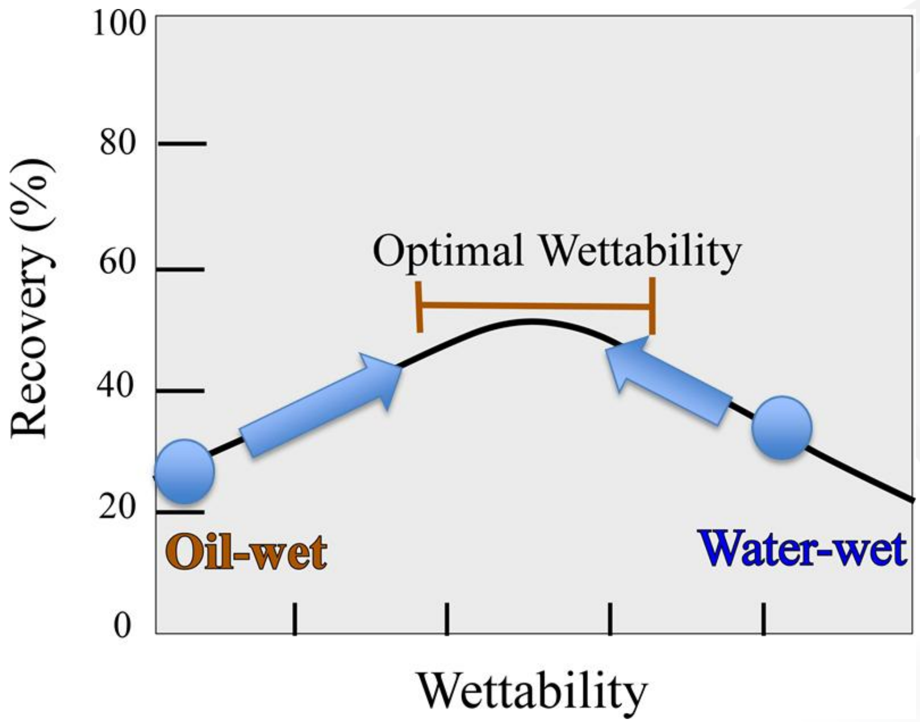
Applied Science

- Reservoir wettability is the equilibrium between rock, water and oil.
- Wettability is a function of salinity (total and composition).
- We can optimize reservoir wettability by changing salinity.



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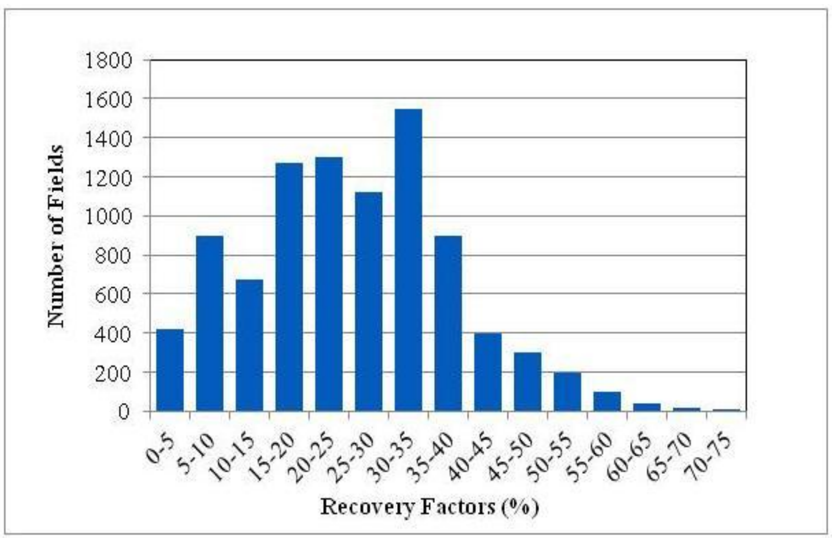
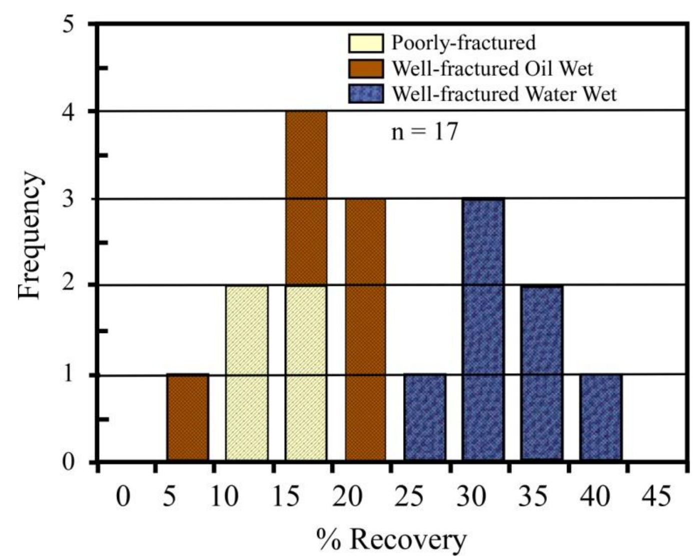
Applied Aspect

- Current world average recovery is 32% of OOIP.
- Wettability is major control on oil mobility during waterflood.
- Initial wettability is result of equilibrium between rock, water and oil.
- We can change water chemistry on the reservoir scale (lab and field data).



Modified from Harper, 2004, BP Energy Institute
data from IHS Energy, approximately 9000 fields worldwide



Modified from SPE 84459

Wettability Alteration

- Chemical Flooding
- Surfactants
  - Natural (pH alteration and production of natural surfactants from oil)
  - Artificial (manufactured) limited by salinity, temperature, hardness and expensive $6-12/bbl.
  - Salinity – laboratory observation?

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Water Chemistry?

- Usually we think about
  - compatibility and formation damage
  - effect on additives
- But wettability is directly related to water chemistry.
- So any changes in water chemistry, change reservoir wettability.
  - e.g. - scale formation before re-injection during WF

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Who is using this technique?

Successes (conventional, non-systematic)

BP - North Slope –flooding shallow SS field (15% OOIP).

Conoco-Phillips - North Sea –flooding deep chalk field (30% OOIP).

Shell - Syria –flooded SS field (10-15% OOIP).

Pioneer - Spraberry SS (lab) – 10% OOIP

Failures (conventional, non-systematic)

Independents - Wyoming –Minnelusa SS – no increase in recovery.

Stat Oil - North Sea –Stratfjord SS - minimal response (<2% OOIP).

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Wettability

- the quality or state of being wettable : the degree to which something can be wet
  - Merriam-Webster Dictionary
- Wettability or wetting is the actual process when a liquid spreads on a solid substrate or material.
  - Biolin Scentific
- Wettability describes the preference of a solid to be in contact with one fluid rather than another based on the balance of surface and interfacial forces.
  - Aldallah et al. 2007
- A type of damage in which the formation wettability is modified, generating a change in relative permeability that eventually affects well productivity.
  - Schlumberger Oilfield Glossary

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Wettability

"If your car is waxed, water runs off"

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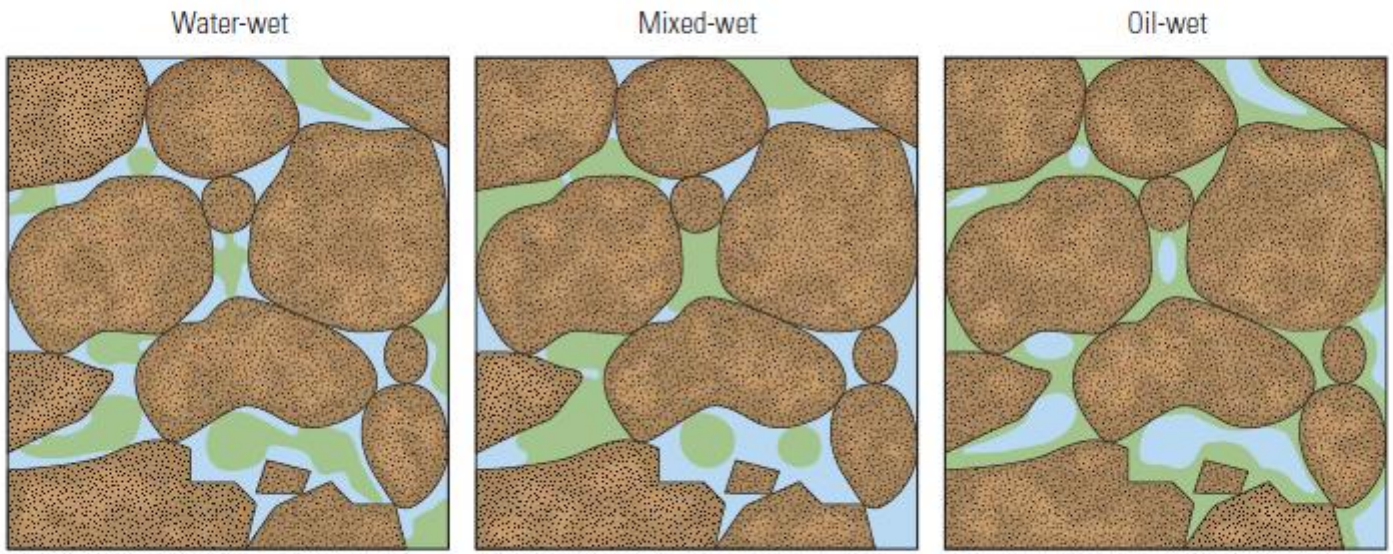
Standard Wettability Formulation

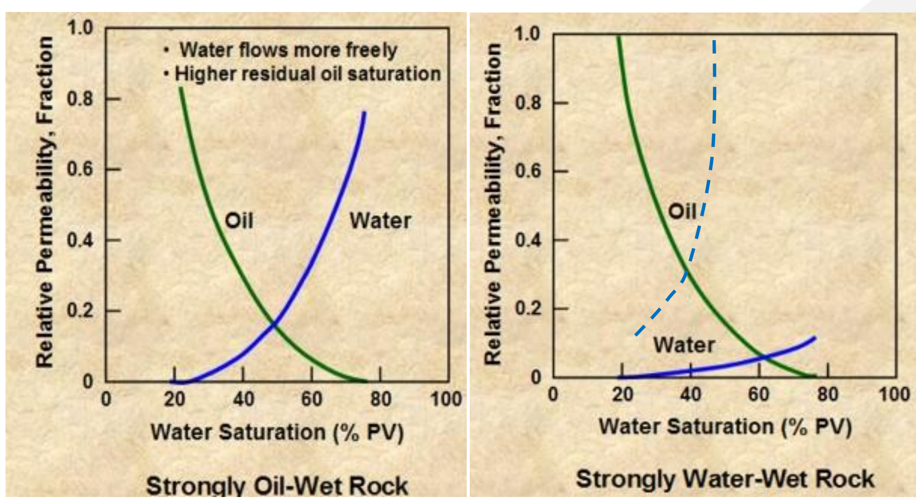
Oil displaces water from the mineral surface and then wets the mineral (surface binding) – leads to calculation of disjointing pressure, capillary force measurements, IFT, etc.

Classic View of the Reservoir

Conceptual



Aldallah et al. 2007



Computational

http://www.spec2000.net/09-relperm.htm

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What scale are we talking about?

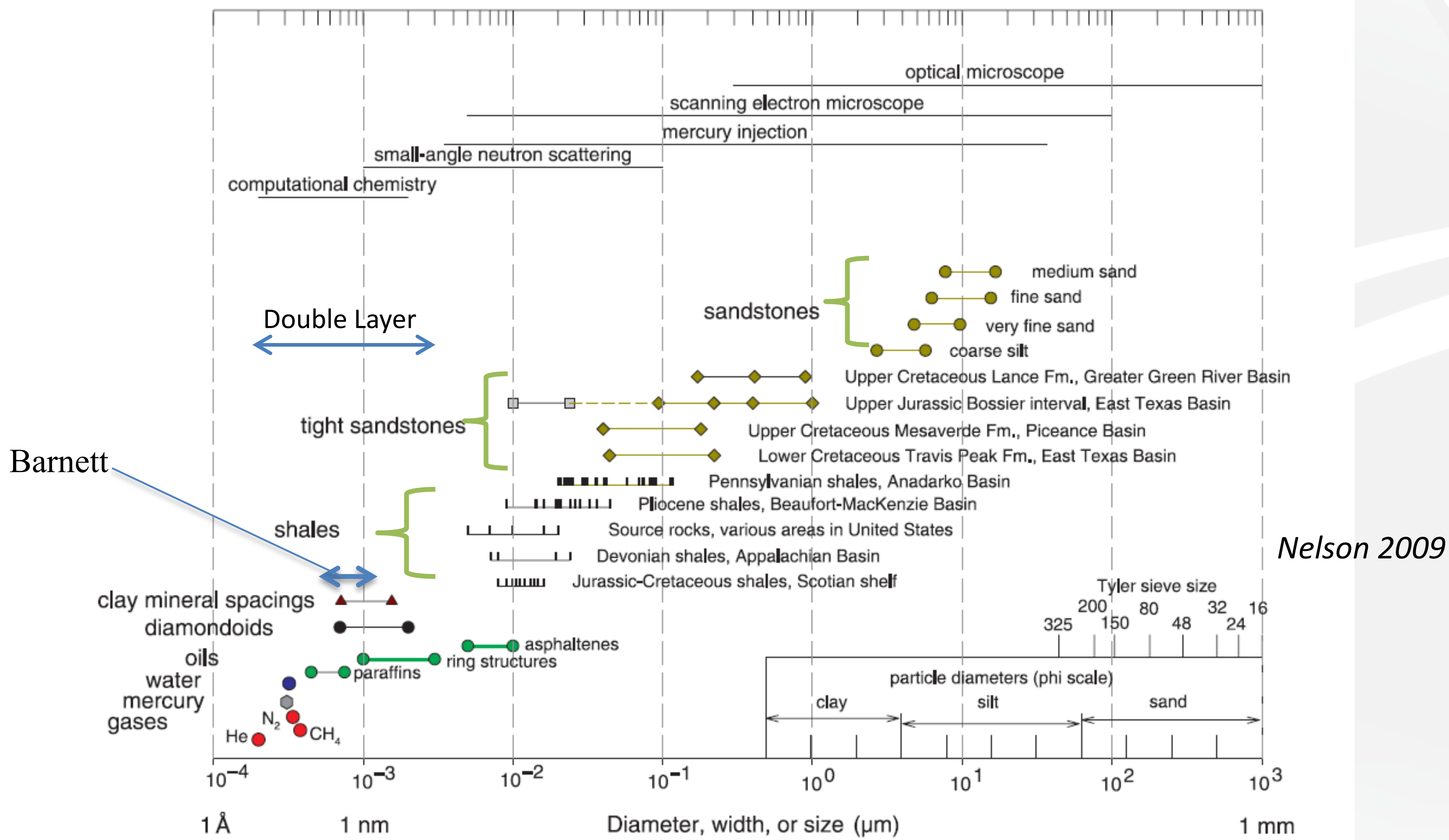

Figure 2. Sizes of molecules and pore throats in siliciclastic rocks on a logarithmic scale covering seven orders of magnitude. Measurement methods are shown at the top of the graph, and scales used for solid particles are shown at the lower right. The symbols show pore-throat sizes for four sandstones, four tight sandstones, and five shales. Ranges of clay mineral spacings, diamondoids, and three oils, and molecular diameters of water, mercury, and three gases are also shown. The sources of data and measurement methods for each sample set are discussed in the text.

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Measurements of Wettability

- Contact angle measurements

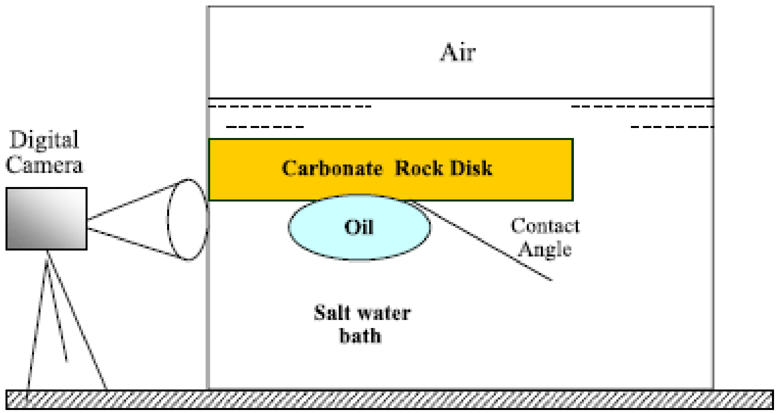
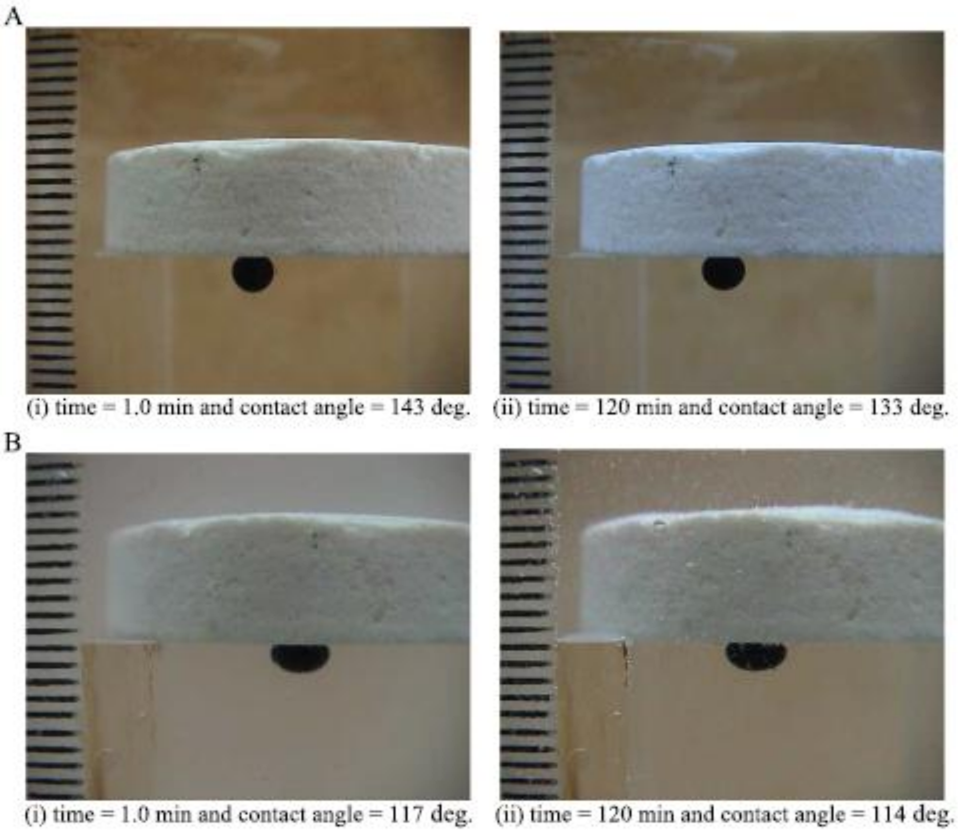


Fig. 1. Schematic diagram of apparatus used to measure the contact angle.

Shedid and Ghannam 2004



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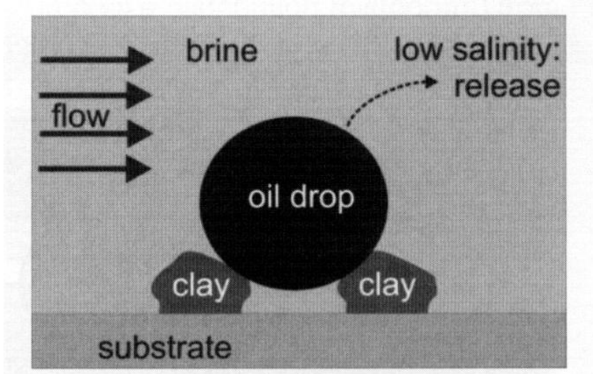
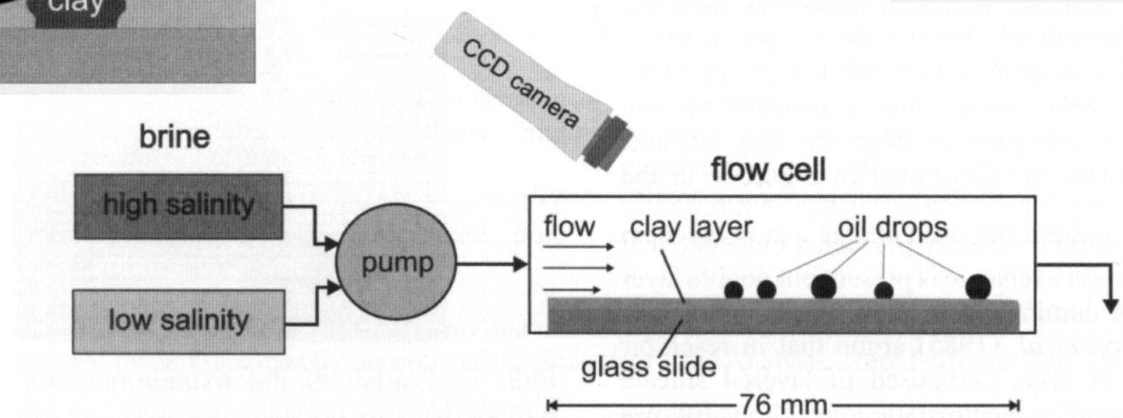
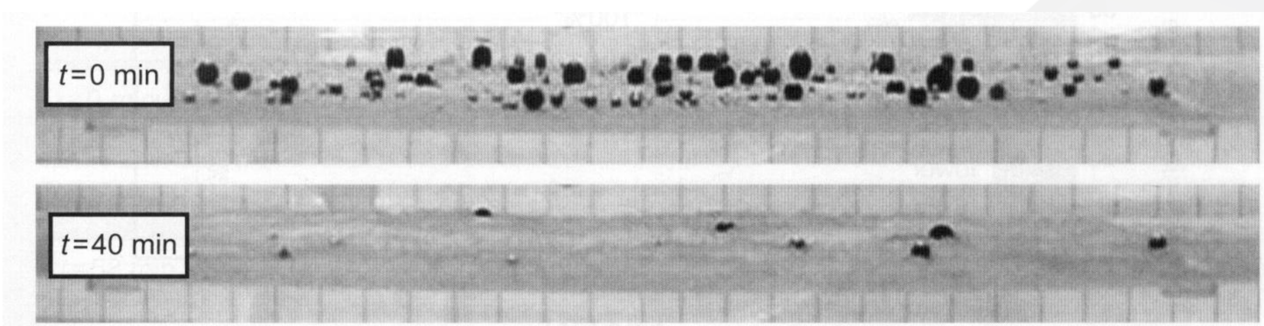
Experiments to represent reservoir







Berg et al.
2010

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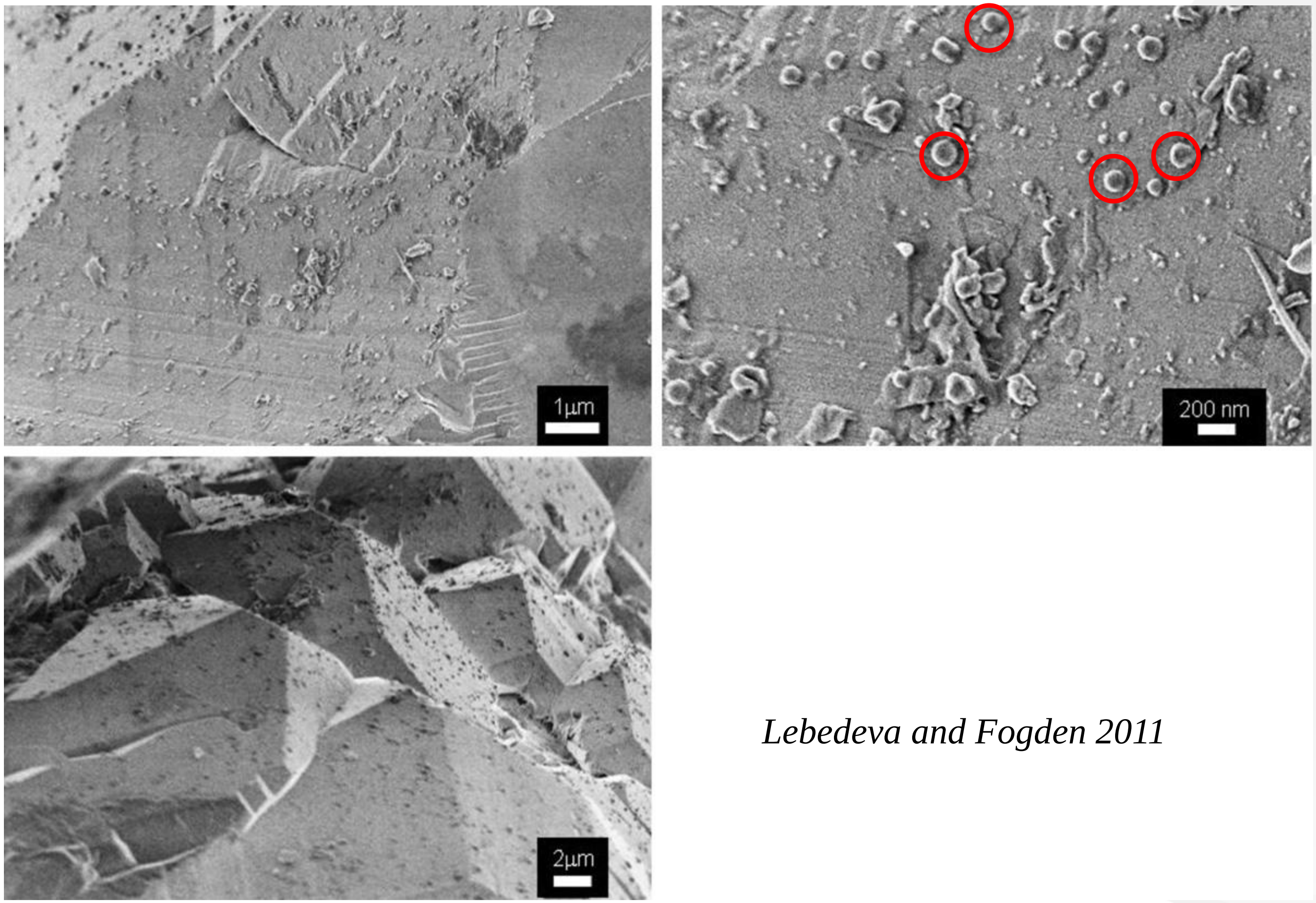
Observations of Wettability

FESEM images - Sandstone surface coated with oil, at pH of 4 in 0.01 M NaCl



Lebedeva and Fogden 2011

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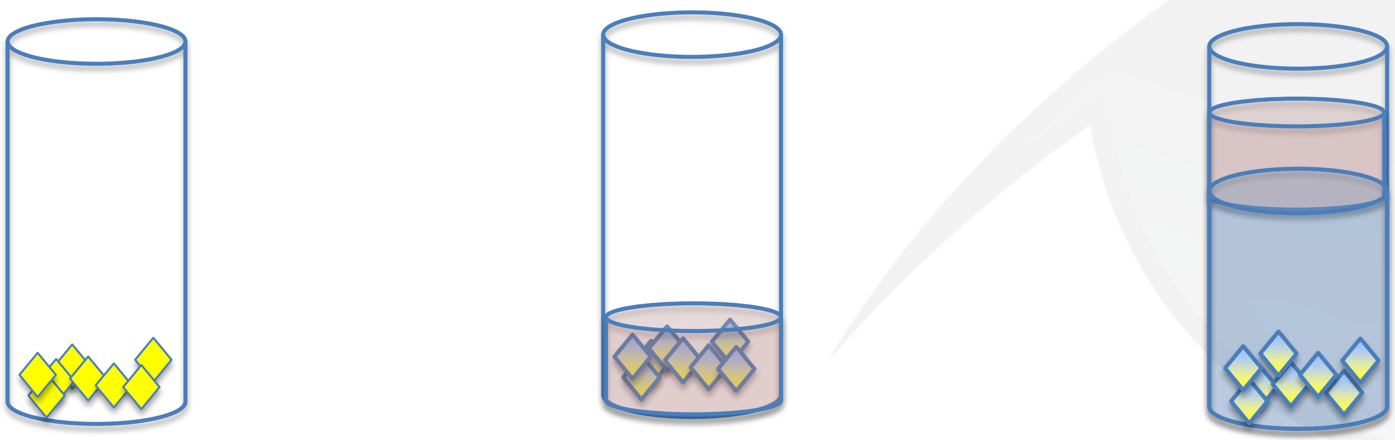
Modified Floatation Test

- Modified Flotation Test
  - Age rock in 3ml of oil (decane) for 48 hours, stir every 12 hours.
  - Add brine to oil-rock mixture.
  - Stir and allow 24 hours.
  - Decant, dry, and weight fractions.

Gravity Separation

Age rock in oil

Add brine



From Mwangi and others, 2013

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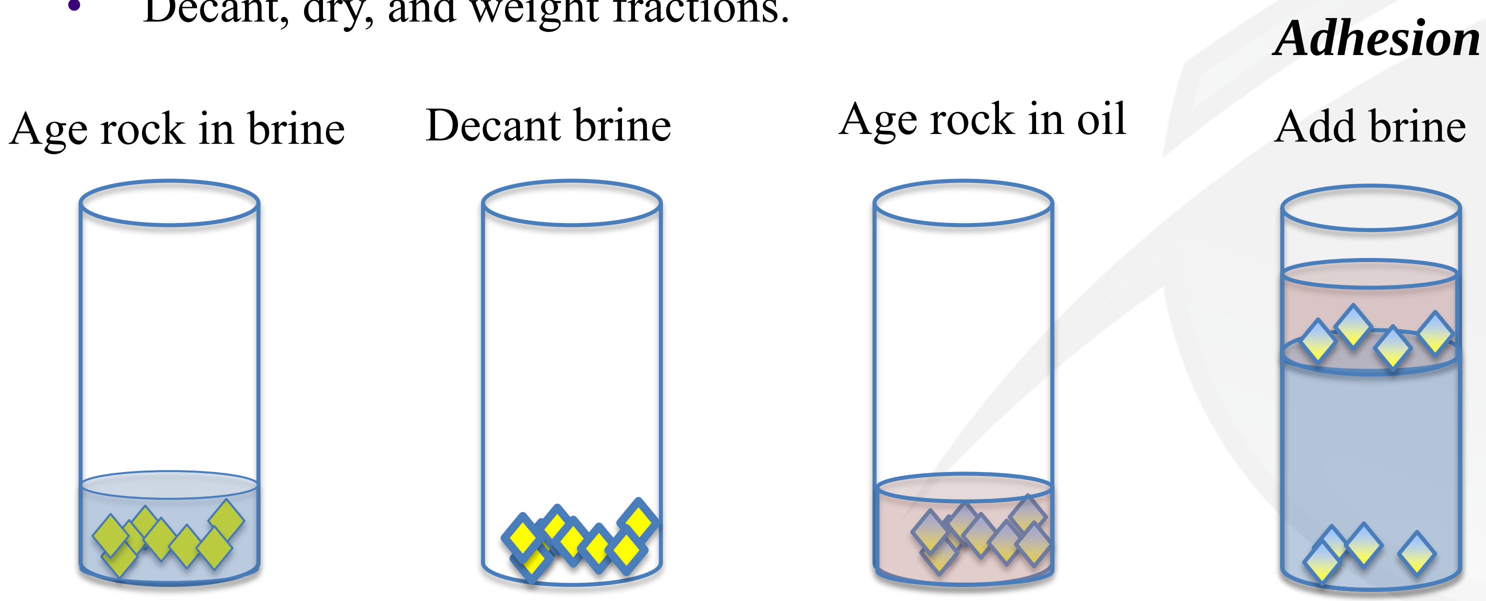
Modified Floatation Test

- Modified Flotation Test
  - Age 0.2 grams of rock in brine for 48 hours.
  - Decant brine.
  - Age rock in 3ml of oil (decane) for 48 hours, stir every 12 hours.
  - Add brine to oil-rock mixture.
  - Stir and allow 24 hours.
  - Decant, dry, and weight fractions.



From Mwangi and others, 2013

Observations

- Grains are carried up in the hydrocarbon phase by adhesion between oil phase and rock surfaces (wettability).
- When rock is mixed with oil only, no grains “float”.
- When rock is mixed with water first, grains “float”.

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Alternative Wettability Formulation

The electrostatic attraction between surfaces and oil cause the surface to become "oil-wet", however there is still a very thin water film. The scale of interaction is that of the double layer, 1 to 10 nm.

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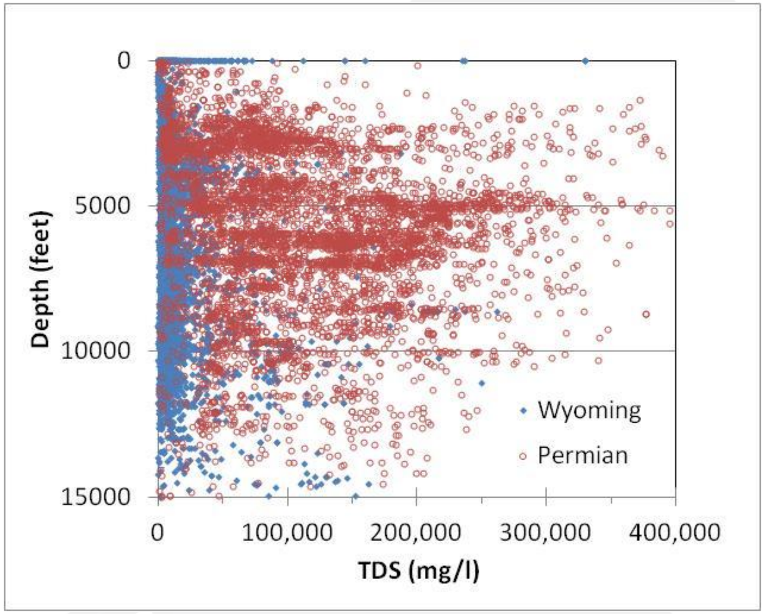
Esal Workflow

- Screening
  - empirical basis
  - water source assessments
- Scoping
  - modified Kinder-Morgan model
  - multiple economic evaluations
- Experiments
  - rapid scan to find optimum chemistry
- Modeling
  - assess fluid-fluid-rock interactions
  - design optimum fluid and avoid formation damage
  - water treatment requirements



Engineered Salinity - Advantages

- Incremental Production (5-15% OOIP) is similar to other techniques (Thermal, Chemical, CO_2, Microbial).
- Response is rapid (3-9 months).
- Cost of field test is low.
- Works in both clastic and carbonate reservoirs.
- CAPEX is low compared to typical EOR.
  - No steam plant or recycling plant.
  - No replacement of tubing and pipe.
- OPEX is low
  - No expensive chemicals.
  - No change in operations.
  - Water treatment can be designed to remove scale and improve injectivity in addition to changing wettability.

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Why the Permian Basin?

- Good resource information.
- Multiple targets, both conventional and unconventional.
- Producers are smaller, more agile, more prone to adopt and try something new (not the majors).

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Screening the Permian Sandstones

Bone Spring and Spraberry = good targets.

Targets for Consortium Research (Screening and Design)

- Delaware Basin - Delaware group, Bone Spring
- Midland Basin – Spraberry (Jo Mill)

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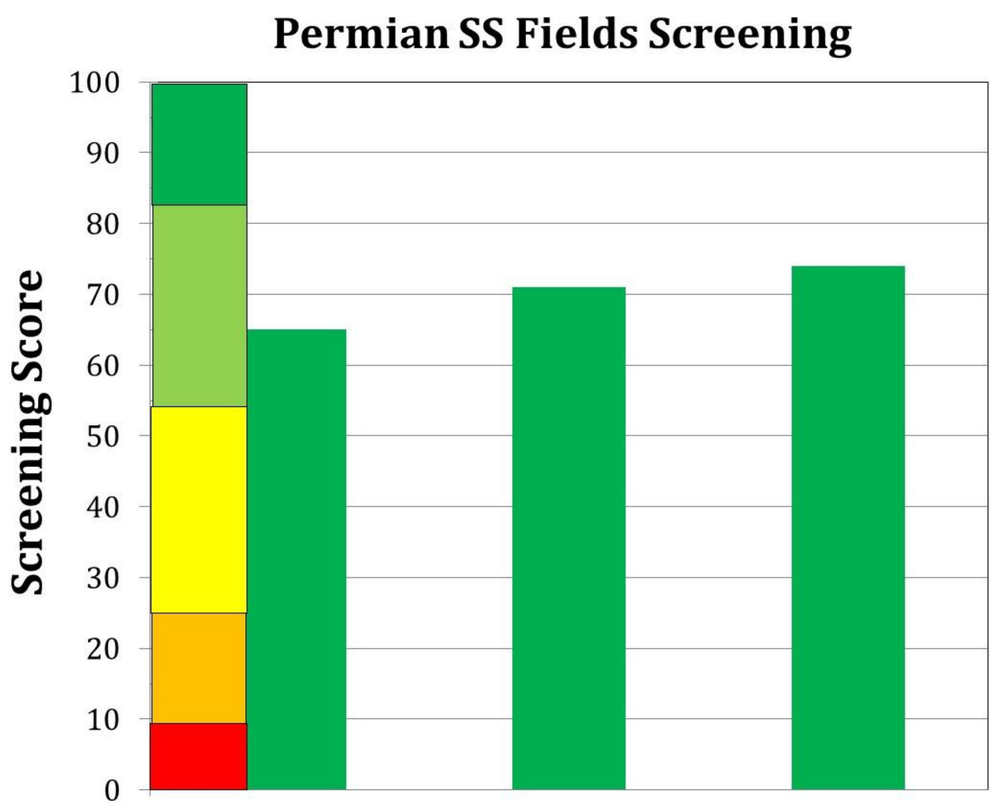
Screening the Permian Sandstones

Avalon, Bone Spring and Spraberry Sandstones.



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Scoping

- Estimate the cost and benefit.
  - Potential Costs -
    - Water Treatment
    - Installation
    - Equipment Operation and Maintenance
  - Benefits - production estimated with empirically-based equations using:
    - Reservoir geology
    - Production water chemistry
    - Oil chemistry
    - Oil Price

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Wettability Modification – Economic Examples

Field	Size (BBLS)	Wells (#)	Recovery (% OOIP)	Project (Y)	CumPreTax ($M)
Nugget 3	127,744,810	19	5 10 15	25	250.3 668.8 1100.6
Nugget 2	46,115,627	18	5 10 15	30	86.5 238.5 398.0
Almond	40,486,587	125	5 10 15	9	82.0 216.1 356.3
Mesaverde 2	16,025,030	59	5 10 15	25	33.9 86.9 142.3
Nugget 1	9,617,523	10	5 10 15	10	18.5 50.2 83.7
Mesaverde 1	584,783	4	5 10 15	30	1.2 3.1 5.1

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What about Unconventionals?

- Optimize wettability to conserve reservoir energy for hydrocarbon movement.
- Water control – minimize water movement (flowback and produced water).
- Prevent formation damage.

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Engineered Salinity – Unconventional Advantages

- Typical slickwater frac – fresh water containing a friction reducer, biocide, surfactant, breaker or clay control additive – commonly used in gas wells.
- Currently use fresh water that does not produce optimal wettability, better choice is treated brackish water.
- Blending base fluid from multiple source waters.
  - Existing wells in other zones
  - Adding water source wells to field
- Other Practical Considerations.
  - Produced water source reuse
  - Water Treatment options
  - Disposal of reject streams
  - Regulatory issues.

Questions?

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