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Navigating the Future of Unconventional Resources

Innovative Laboratory Technologies for Tight Oil Formations

Petro Nakutnyy, Saskatchewan Research Council

June 15, 2017

NS17 - 163

Outline

- Tight Oil Challenge
- Overview of Possible EOR Solutions
- New Research Tools for Tight Oil
- Summary and Conclusions

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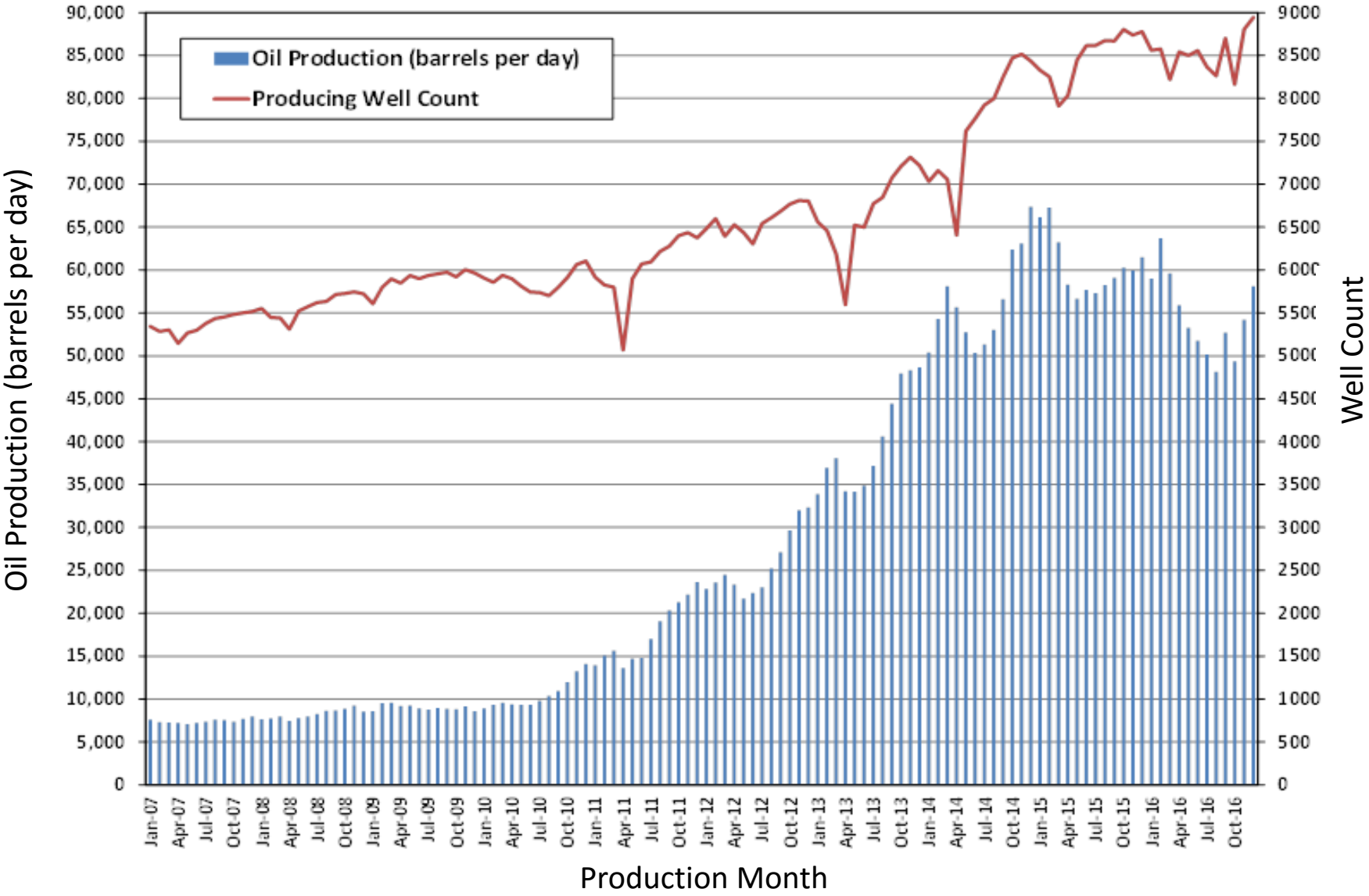
Saskatchewan Viking Total Oil Wells and Production

Data source:
GeoScout



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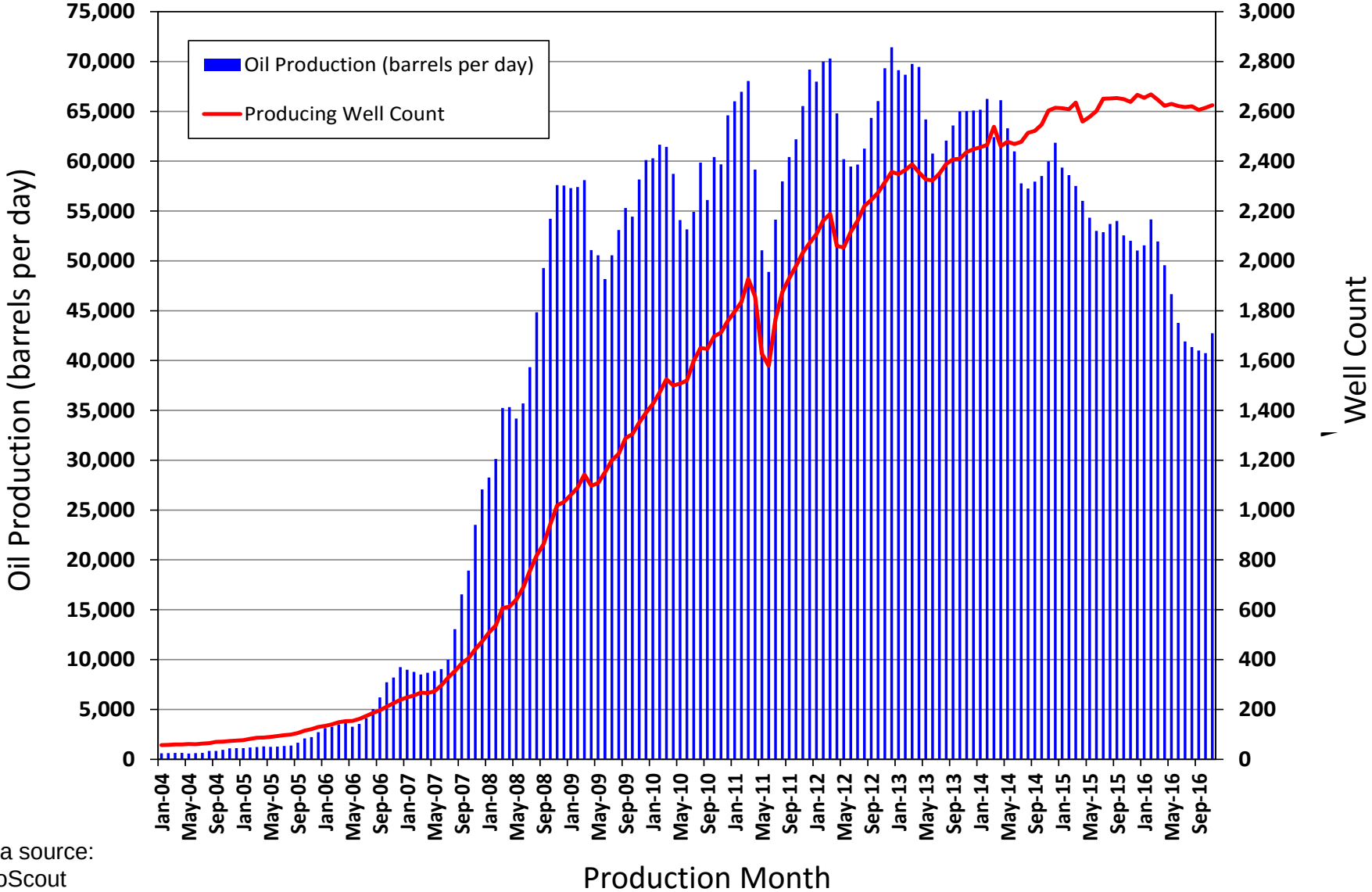
Saskatchewan Bakken Total Oil Wells and Production



Data source:
GeoScout

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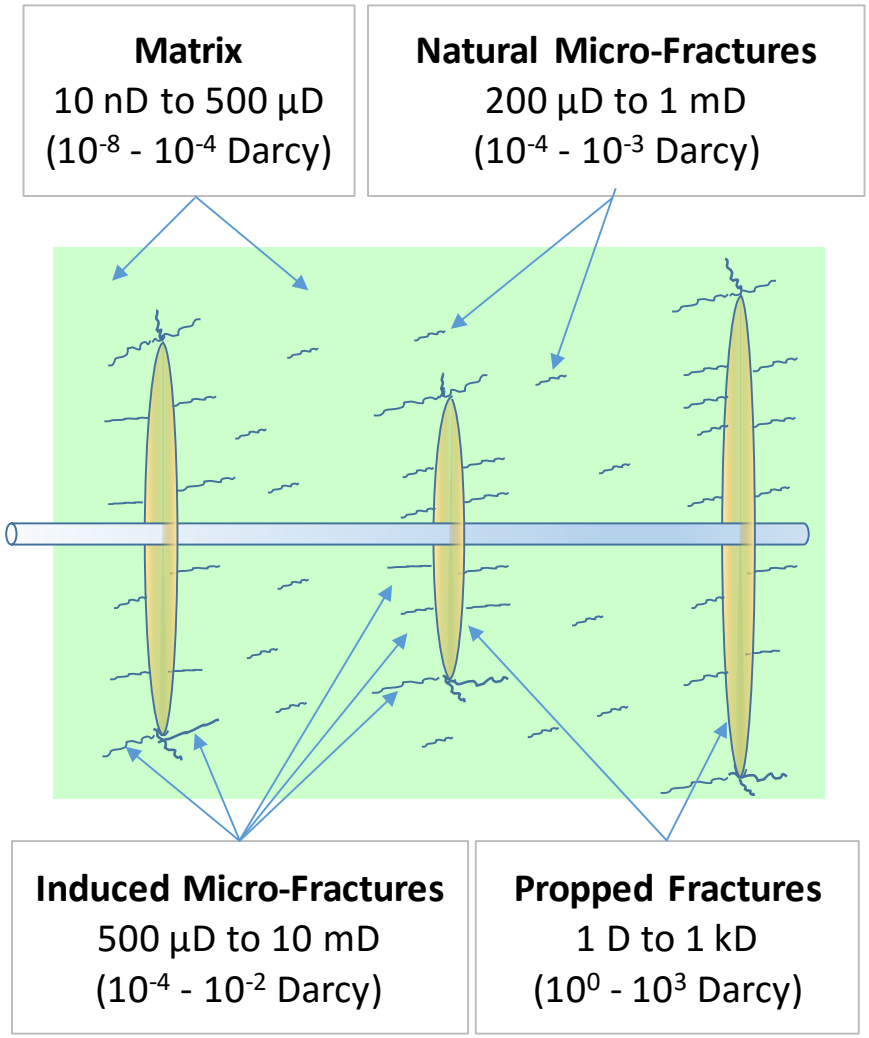
Tight Oil Reservoir Permeability Contrast

- Range of Permeabilities can span 7 - 11 orders of magnitude
- Makes laboratory and field modelling a challenge
- Provides many different surfaces for fluid/rock interaction



Note micro-fractures exaggerated for clarity

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PTAC TOGIN Roadmap Workshop – 2015/16

Most important challenges as voted by the participants

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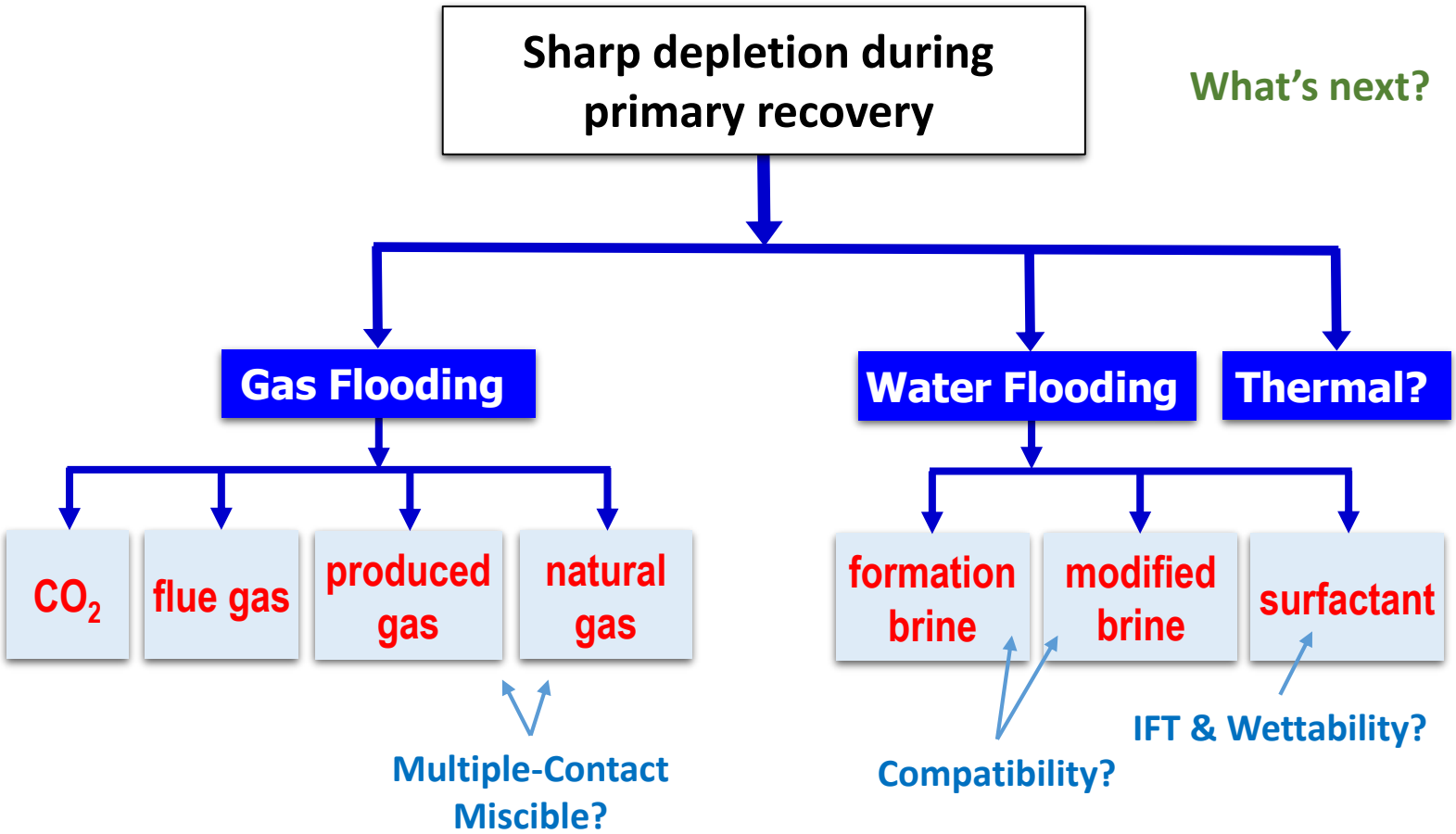
EOR Types - What is Being Considered?



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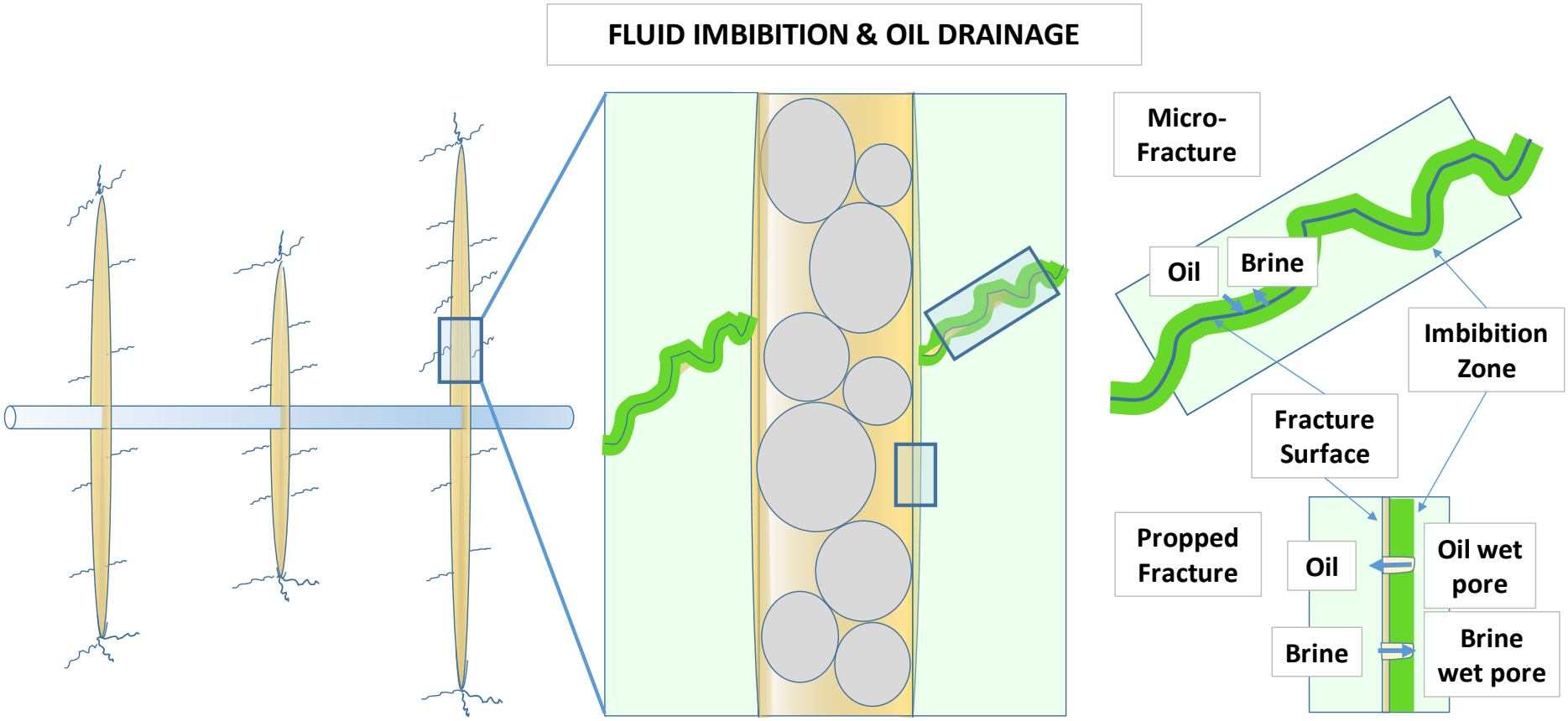
Challenges and Wishful Thinking for EOR



Note micro-fractures exaggerated for clarity

'Target specific minerals in pores to alter wettability'

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New Research Tools and Techniques

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New Tools and Techniques: Gas Flooding

Challenges and New Approaches in Laboratory Evaluation

- ✓ Better injectivity, particularly in <0.1 mD reservoirs
- ✓ Immiscible (dry produced gas, nitrogen) vs. Miscible (rich gas, CO_2)
- ✓ No capillary locking effects with miscible gas

- Continuous injection vs. cyclic → ➢ Dual-permeability modeling system
- Induced fractures, micro fractures → ➢ "Smart" frac design ➢ Dual-permeability modeling system
- Potential for dissolution, precipitation, acid fracking → ➢ "Smart" frac design ➢ Dual-permeability modeling system

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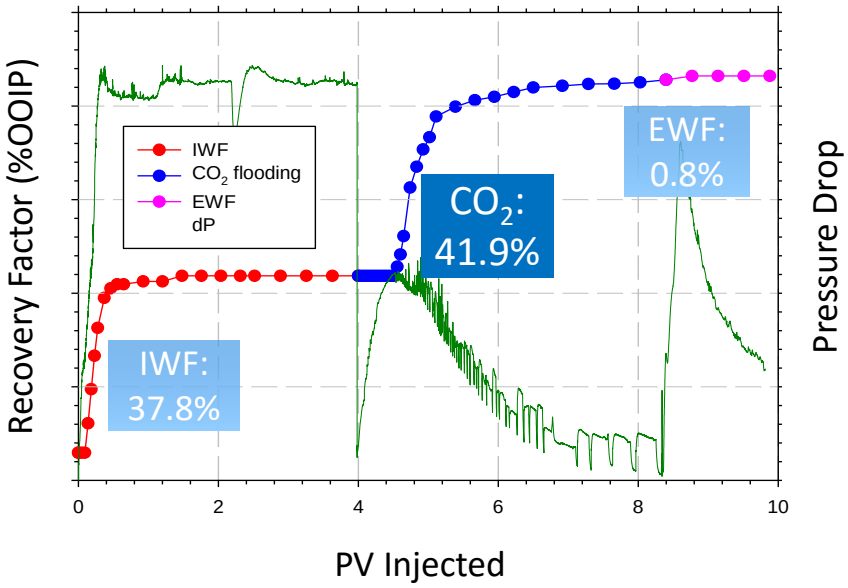
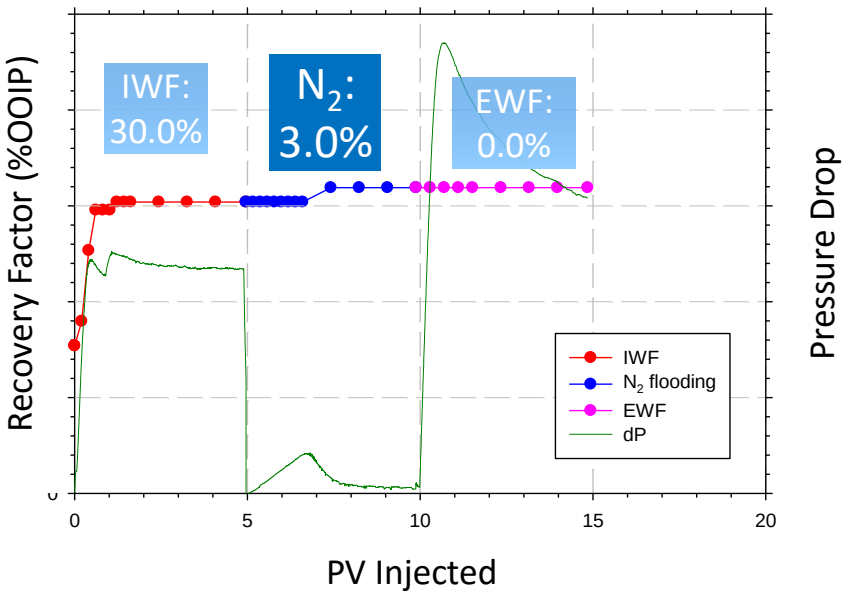
Gas Flooding

Laboratory coreflood study

Pressure depletion ➔ IWF ➔ gas flood ➔ EWF



Miscible CO_2 Flooding



Immiscible Nitrogen Flooding

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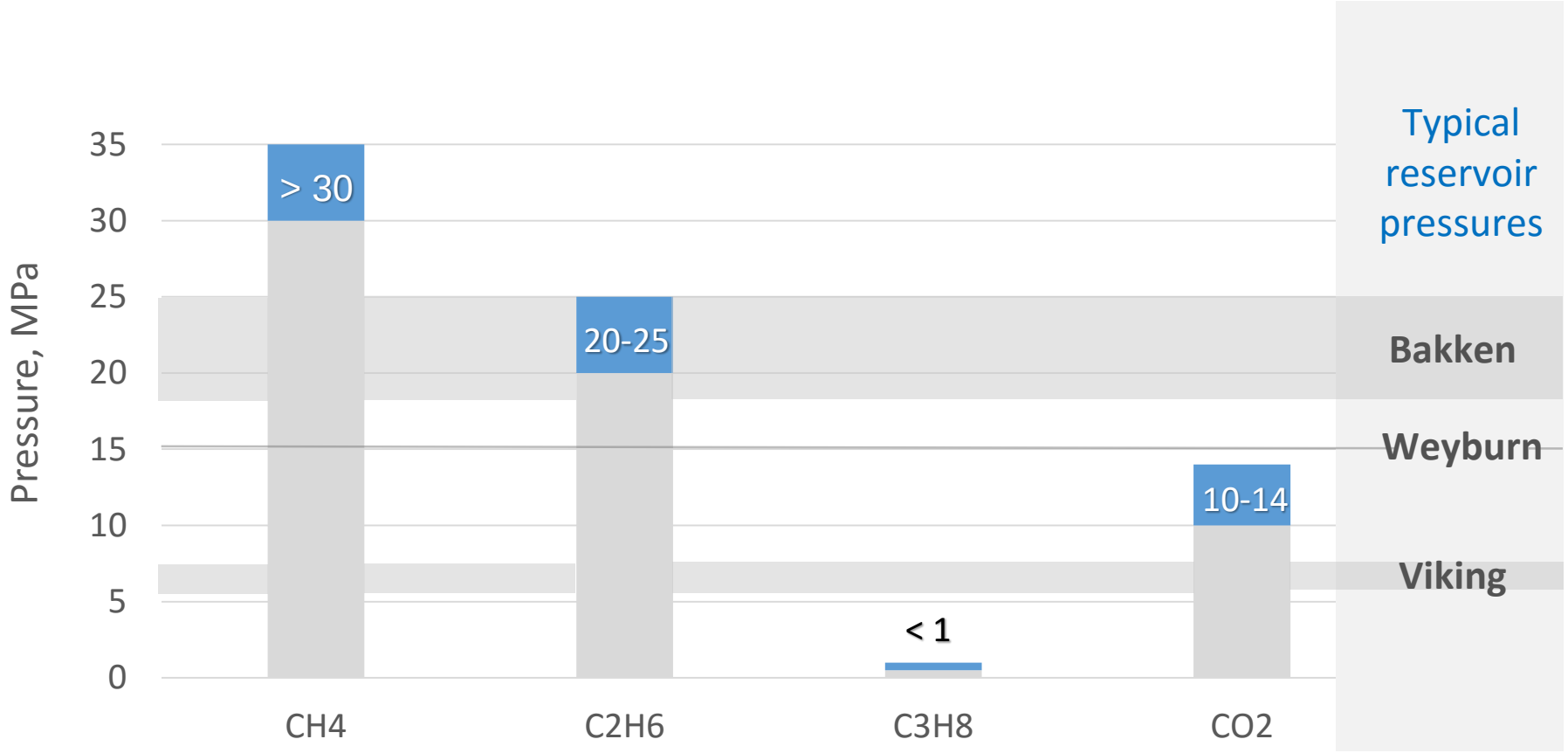
Gas Flooding

Typical miscibility and reservoir pressures in some Sask. reservoirs



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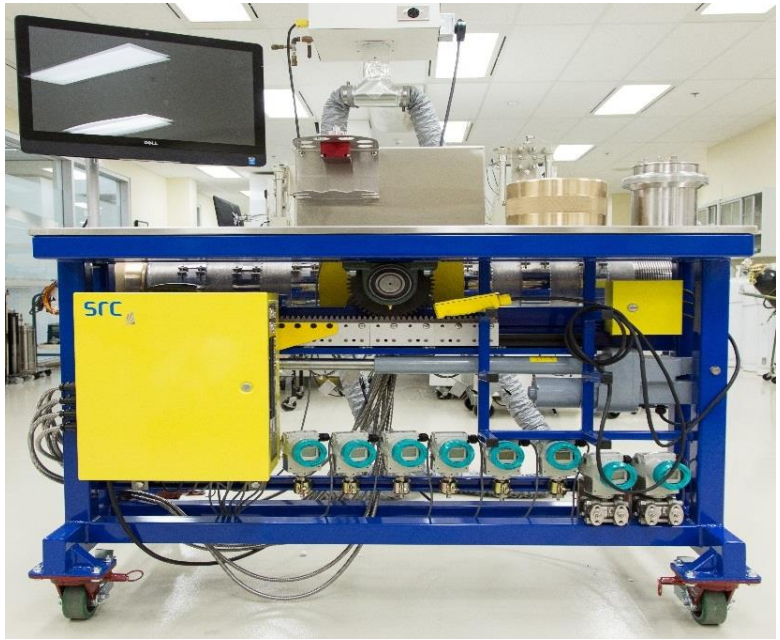
Dual-Permeability Matrix-Fracture Coreflood System

SRC has designed a new dual-permeability coreflood system that can be used with both synthetic and full diameter core systems.



Dual-Permeability Coreflood Apparatus

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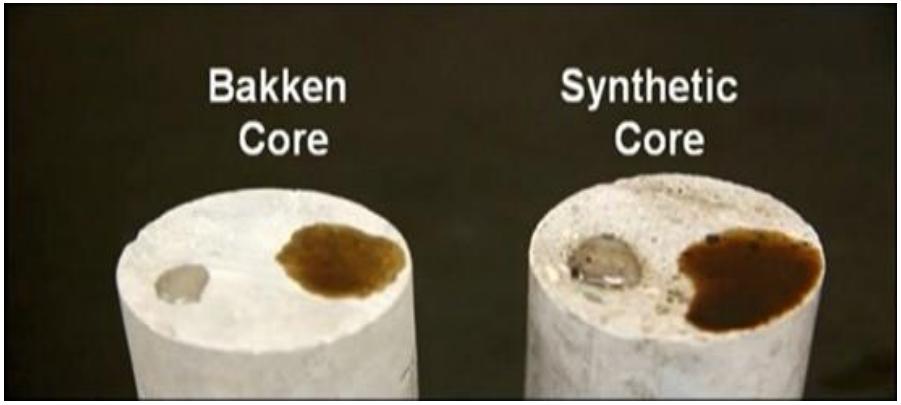
Dual-Permeability Coreflood System

- Max working pressure 35,000 kPa @ 200°C
- Accommodate up to 4-in. diameter and 59-in. length core
- The overburden pressure vessel can be set at any angle between horizontal and vertical position
- Multi-point automatic pressure and temperature logging
- Simulate actual fluid mass transfer between matrix and fractures



Qualitative Wettability Test for Reservoir vs. Synthetic Core

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New Tools and Techniques: Waterflooding

Challenges and New Approaches in Laboratory Evaluation

- ✓ Wide availability of water
- ✓ Spontaneous imbibition
- — Water compatibility/Injectivity
  - ➢ Compatibility Tests → Coreless Injectivity
  - ➢ Water-chemistry coupled geochemical modeling *(GeoBench software)*
- — Relative Permeability/Wettability
  - ➢ High-Speed Centrifuge
- — Induced fractures, microfractures
  - ➢ Smart" frac design
  - ➢ Dual-permeability modeling system
- — Water blocking
  - ➢ Wettability modification

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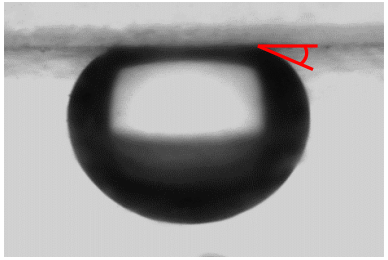
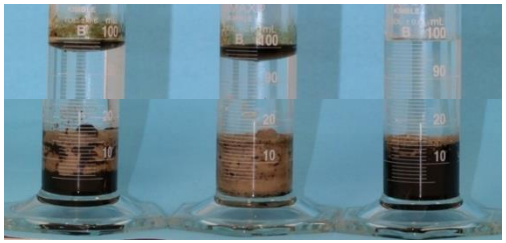
New Tools and Techniques: Waterflooding

Understanding Wettability

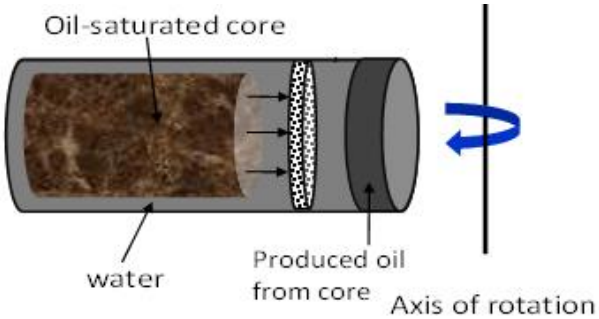
- Contact Angle Measurements
  - \+ Relatively quick and inexpensive
  - – Measures properties of one spot on the surface



- Imbibition Tests (Simplified Amott)
  - \+ Relatively inexpensive
  - – Time consuming, only qualitative, affected by both IFT and wettability



- Centrifuge Method (Amott/USBM)
  - \+ Measures bulk properties of the rock
  - – Requires high speed centrifuge, may be relatively expensive



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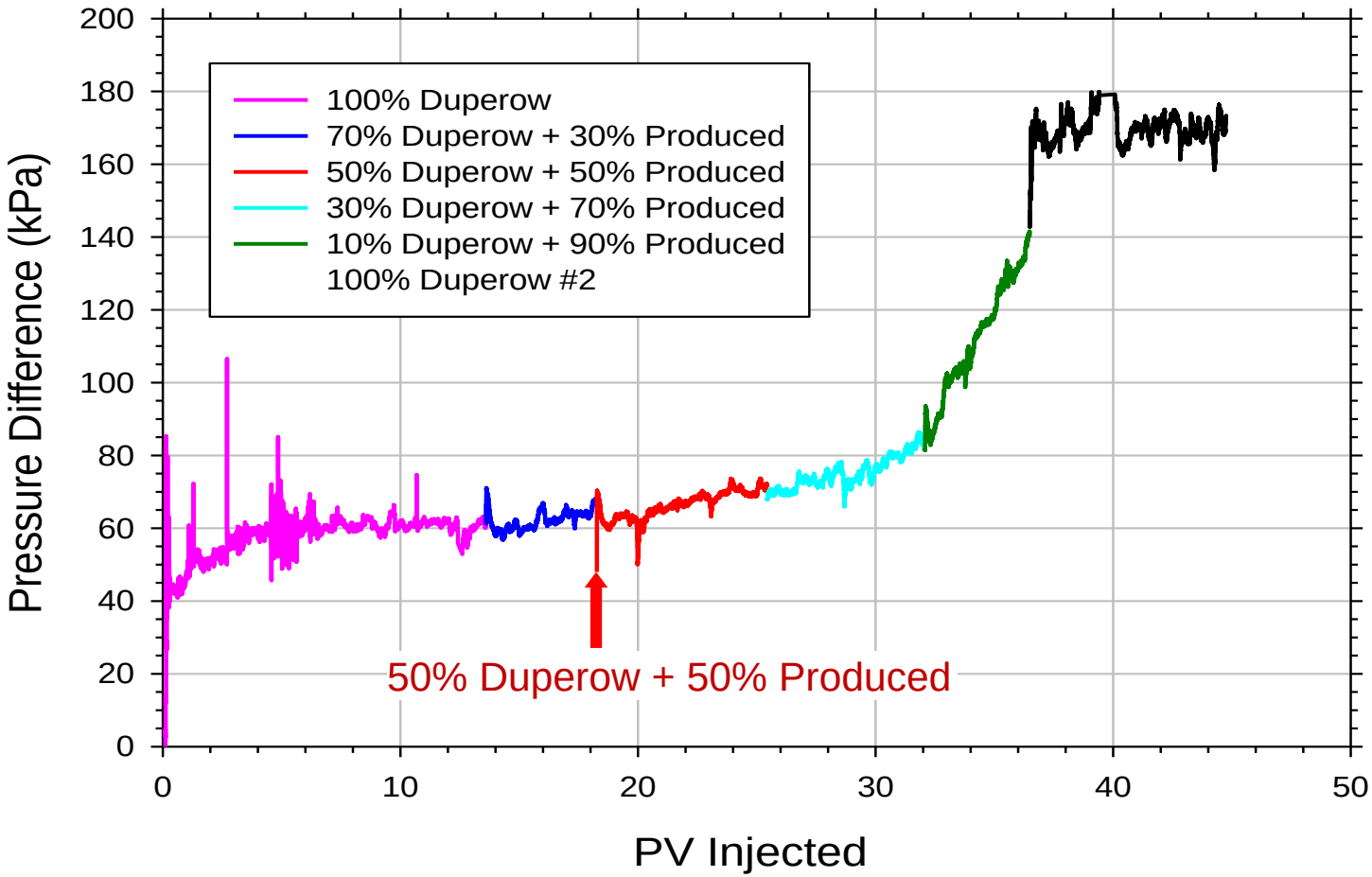
Water Flooding

Salinity Effect on Water Injectivity

Duperow TDS: 220,000 ppm;
Produced water TDS: 5280 ppm



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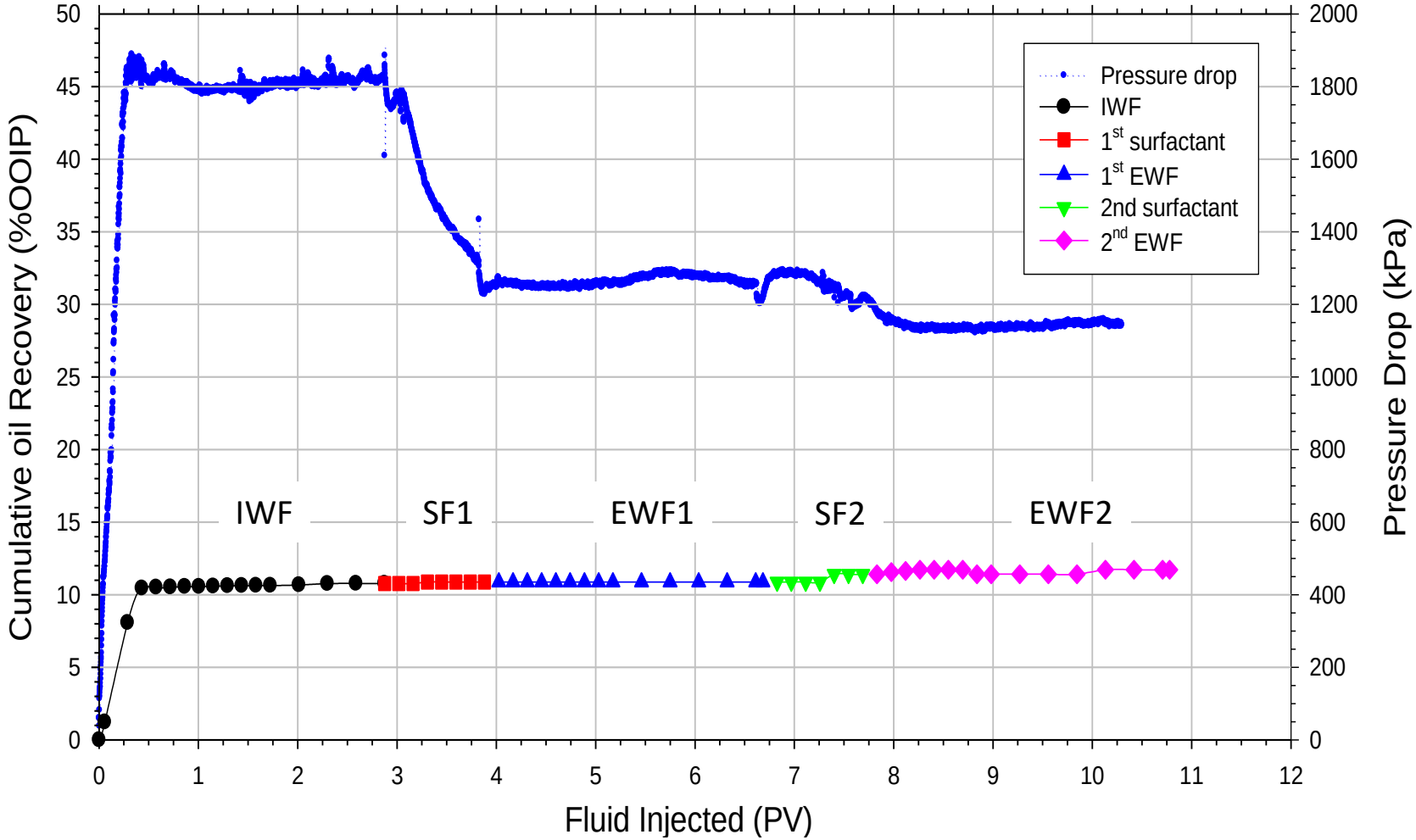
Water Flooding

Surfactants: Injectivity or Enhanced Oil Recovery

- Interfacial Tension
- Wettability



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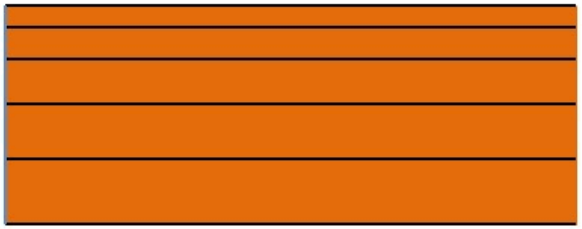
Surfactant Flooding

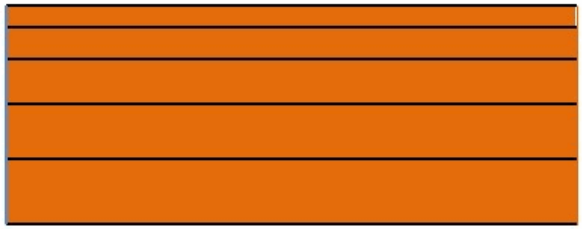
Improved conformance

Imbibition Process

Conventional reservoir,
With surfactants,
t = 0 s

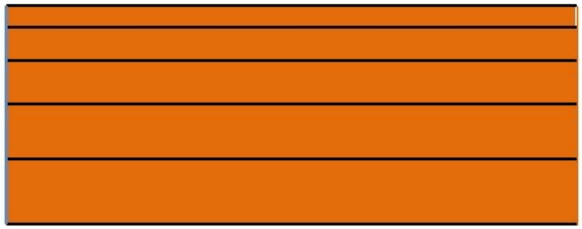


Conventional reservoir,
Without surfactants,
t = 0 s



Unconventional reservoir,
With surfactants,
t = 0 s

Unconventional reservoir,
Without surfactants,
t = 0 s



- Imbibition vs Drainage
- Conventional vs Tight
- Waterflood vs Surfactant

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Surfactant Flooding

Wettability

How to manage IFT and wettability to maximize oil recovery?

- $P_c = 4/D \times \boxed{IFT} \times \boxed{\cos(\theta)}$

Surface Tension Part

Wettability Part

IFT	cos(θ)	P_c
↓	↑	↑

- Surface active chemicals have various functional groups and structure.
  - Novel chemicals for wettability alteration – volatile surfactants for gas injection?
  - Need to continuously vary wettability to maximize oil recovery?

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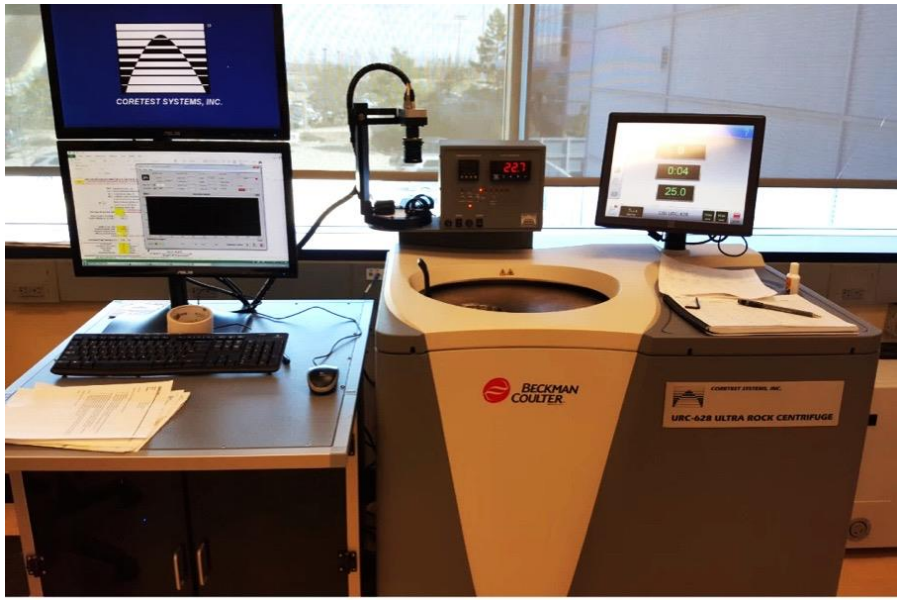
High-Speed Core Analysis Centrifuge

Features

- ✓ Accommodates 1- and 1.5-inch-diameter core plugs
- ✓ Confining pressure up to 5,000 psi
- ✓ Rotation speed up to 20,000 RPM
- ✓ Real-time saturation measurement
- ✓ Data analysis package to obtain capillary pressure and relative permeability curves



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The USBM Method for Wettability

- Calculate the area under drainage curve, A_1, and area under imbibition curve, A_2.
- Calculate wettability index:

$$W = \log\left(\frac{A_1}{A_2}\right)$$

- The absolute value of W indicates the wetting tendency

Water wet: W > 0

Oil wet: W < 0

Neutrally wet: W close to 0

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The Centrifuge Method

Advantages

- ✓ Actual reservoir oil and brine are used
- ✓ Non-destructive method
- ✓ Capillary pressure, wettability, and relative permeability can be obtained simultaneously
- ✓ 3 or 4 plugs for one set of measurements

Limitations

- ✓ Can produce misleading results if cores are water-sensitive
- ✓ May not work for very high perm (> 1 D) or low perm (<0.01 mD) cores
- ✓ Difficult to use with highly viscous oils

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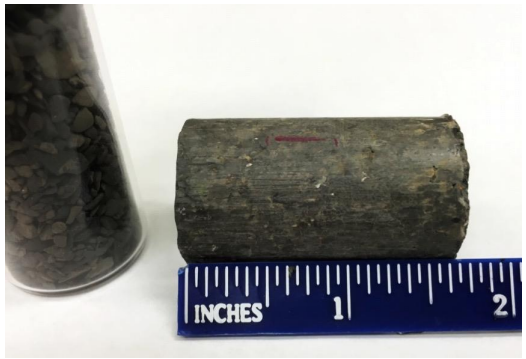
Coreless Injectivity Evaluation

(patent pending)



✓ Utilize drill cuttings from target well

- Drill Cuttings collected from specific wells
- Potentially multiple samples from each well

✓ Drill cuttings cleaned and processed

- Drill Cuttings can be systematically cleaned and restored for testing
- Packed into a specially designed core holder

✓ Injectivity tested under a variety of injection brines and conditions

- SRC believes that once optimized the test would provide a much quicker, low cost method for evaluating brine injectivity along the entire length of the completed interval

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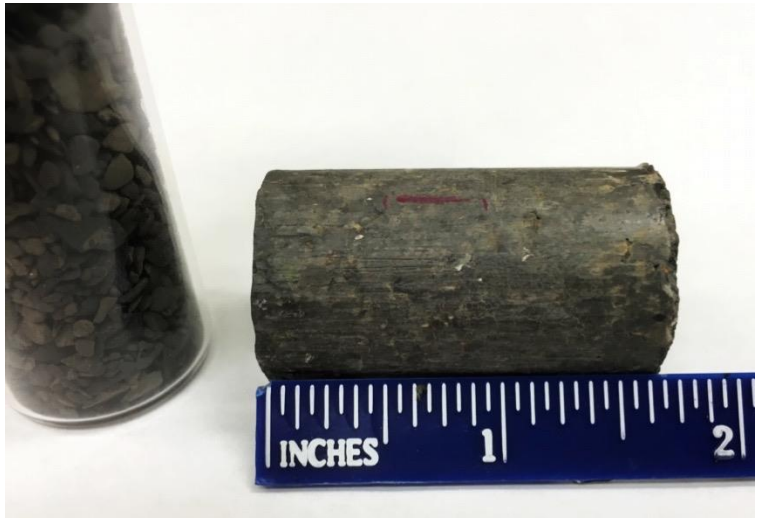
Coreless Injectivity Evaluation

(patent pending)

Drilling cutting samples compressed into a reconstituted core plug



	Air Permeability (md)	Air Porosity (%)
Core #1	**2.30**	**16.1**
Core #2	**2.80**	**16.2**

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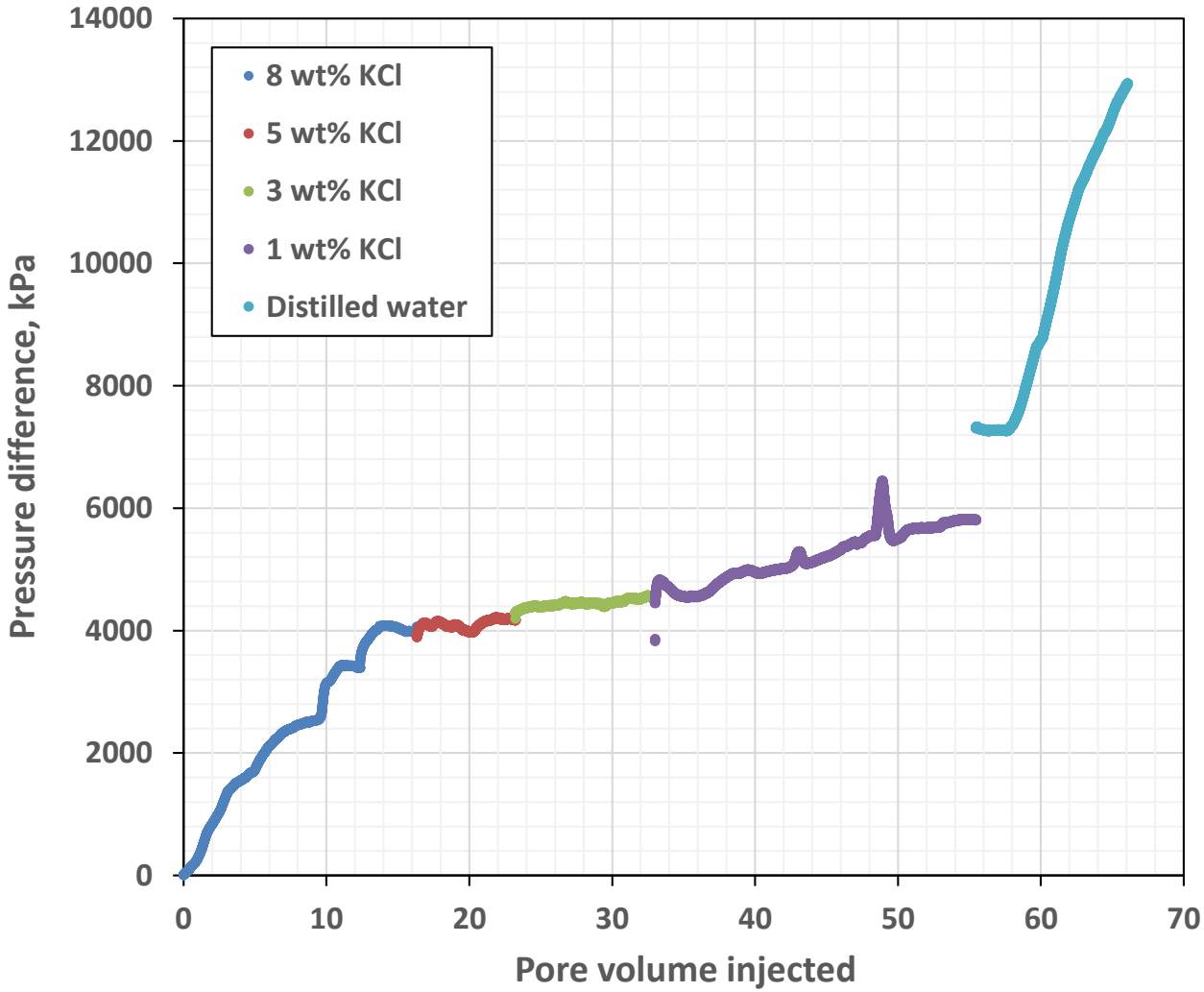
Uses drilling cuttings compressed into a plug

Coreless Injectivity Evaluation



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The Geochemist's Workbench®

Equilibrium and kinetic reactions in multicomponent systems

- Mineral precipitation and dissolution
- Gas transfer
- Complexation and dissociation
- Sorption and desorption
- Redox transformation
- Catalysis and enzymes

Mass and heat (reactive) transport: reactive transport in one and two dimensions

- Advection, dispersion, and diffusion
- Uniform or heterogeneous medium properties
- Dual porosity with free-flowing stagnant zones
- Heat transfer by advection and conduction

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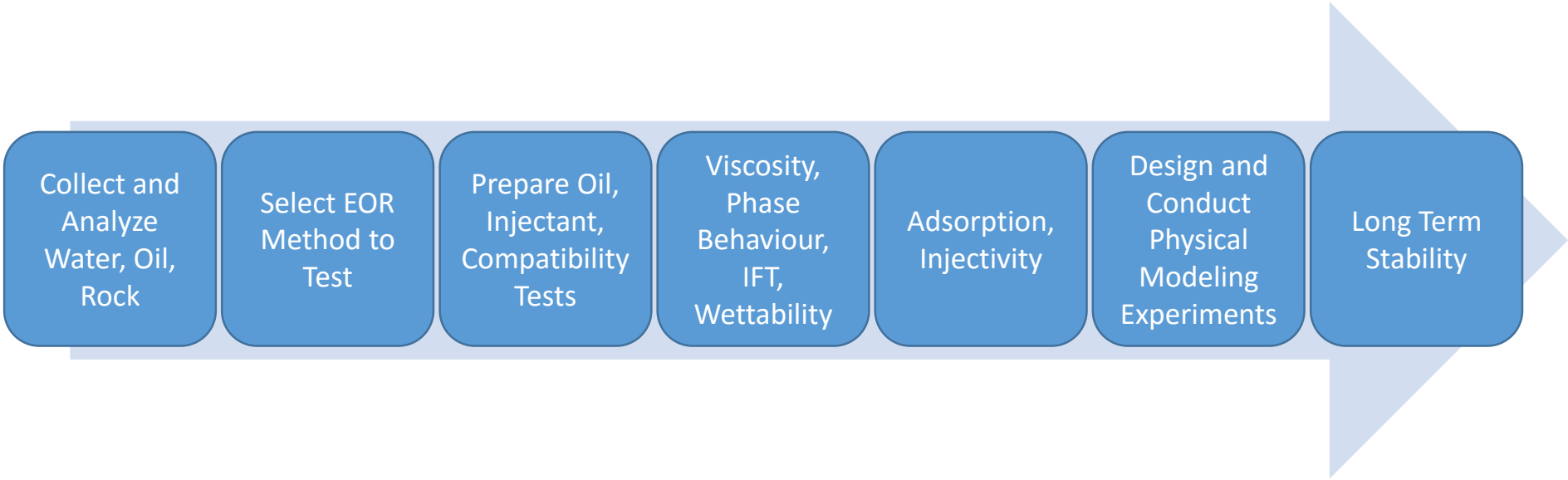
Block-Diagram for Evaluating EOR Process



- Every step of the screening process needs to be re-designed for the particular problem.
- The "basic", less glamorous steps are important and assure consistency and reliability.

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Summary and Conclusions

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Summary

- Knowledge of reservoir geology, mineralogy, facies distribution, lithologic variations is important when considering EOR methods for Bakken.
- Reservoir permeability and porosity can be enhanced by mineral dissolution/leaching, but also reduced due to mobile fines and metal carbonate precipitation during CO_2 flooding.
- Water flooding can improve the oil recovery from tight formations with relatively high permeability (>0.1-1 mD) but may be accompanied by injectivity and clay compatibility problems.

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Summary - continued

- Surfactant flooding can recover oil through interfacial tension reduction and wettability alteration but is expensive due to high surfactant adsorption and may not work well in cyclic processes
- Immiscible and particularly miscible gas flooding can significantly enhance oil recovery from tight formations
- New approaches to EOR and new research tools are necessary as traditional method don't always apply

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