Smart Water Workshop

Stavanger, 14 September 2018

Eni- NIOR Center

Smart Water Workshop

Agenda

- ***9:00-10:30***
  - **1.** Highlights from The National IOR Centre of Norway - What do we know now regarding Smart Water flooding that we did not know four and half /
  - **2.** From the Centre - What is missing in our understanding of Smart Water flooding
- ***10:30-10:45***
  - **3**. From the Industry Partners - What is missing in our understanding/implementation of Smart Water flooding?
- ***10:45-11:00*** Coffee Break
- ***11:00-12:00***
  - **3**. From the Industry Partners - What is missing in our understanding/implementation of Smart Water flooding?
- ***12:00 -13:00*** Lunch with Discussion
- ***13:00 -13:45***
  - **4**. Group working
- ***13:45-14:00***
  - **5**. Presenting the results and sum up the Workshop

Smart Water EOR research

What do we know and future focus

Tina Puntervold and Skule Strand

Smart Water workshop

Stavanger, September 14th 2018

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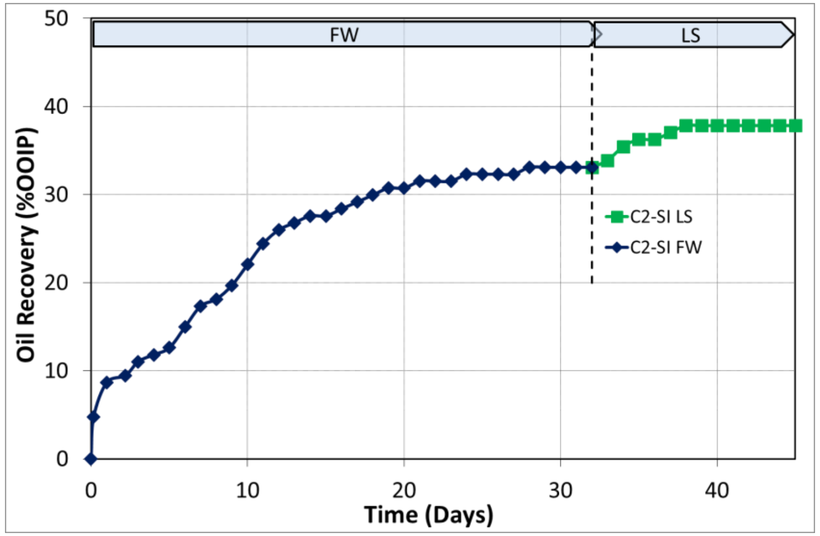
Background – what do we know?

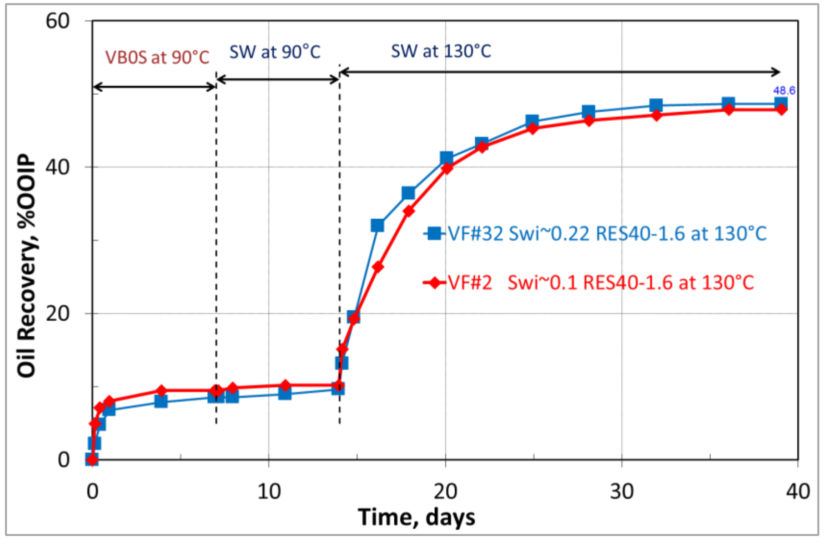
✓ The extra oil recovered by Smart Water is due to wettability alteration.

✓ Proven in both sandstone and carbonate systems.

Sandstone



Chalk



- Outcrop sandstone core
  - 10% Clay and 30 % Albite
  - S_{wi} =20% FW,
  - Sat and aged at 60°C in Crude Oil (BN =1.9)
- Spontaneous imbibition (SI) at 60 °C
  - FW – LS

- Outcrop Stevns Klint core
  - S_{wi}= 10 and 22 % FW
  - Crude oil (AN=1.9 mg KOH/g.)
- Spontaneous imbibition (SI) with FW and SW at 90 and 130 °C

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Understanding reservoirs

- **The role of the rock minerals**
  - Carbonates, chalk, limestone, dolomite, presence of clays etc.
  - Sandstones, quartz, clays, feldspars, carbonate cement etc.
  - Affinity for crude oil components
  - Surface charge in formation water
  - Formation water pH

Crude Oil	Brine	Rock
• Polar organic acids • Polar organic bases	• Formation Water salinity and Ion composition • Injection Water salinity and Ion composition	• Carbonate • Sandstone • Mineral surface reactions • Mineral dissolution

- **Formation water**
  - Ion composition influences pH
  - Ion composition influences crude oil adsorption

- **The crude oil components**
  - Polar organic acids and bases
  - Their charge at formation water pH

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Carbonate research

- Optimal core restorations are ~~important/~~crucial for estimating EOR potential
- Initial wetting
  - Affected by core cleaning - Initial sulfate may affect wetting.
  - Dictated by polar components in crude oil
    - Momentary adsorption of acidic crude oil components.
    - Aging less important
- Smart Water EOR in carbonates.
  - Low salinity brine is **not** a Smart Water in limestone!
    - Only observed with anhydrite in the matrix.
  - Seawater (SW) behaves as a Smart Water in chalk and limestone
    - Key ions are SO_4^{2-}, Ca^{2+} (and Mg^{2+})
  - Modified SW is even smarter!
  - Dolomite and dolomitic limestone behave differently.

Low pH High pH

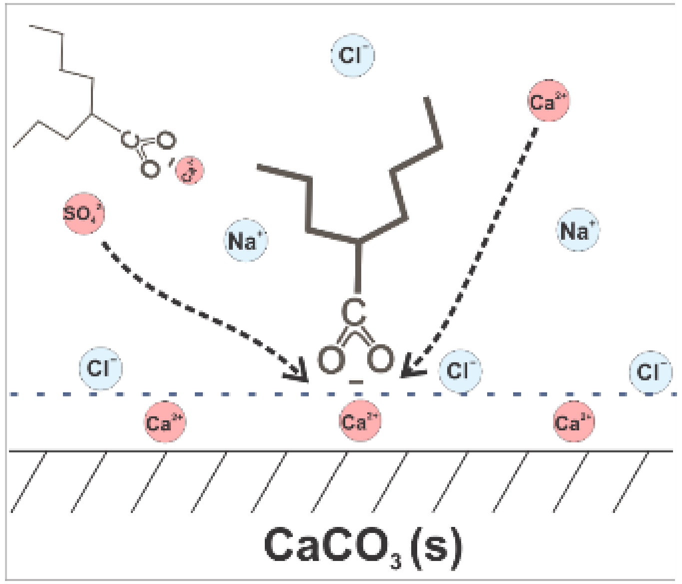
$$R_3NH^+ \rightleftarrows H^+ + R_3N:$$

pKa ~ 4..5 – 5.5

Low pH High pH

$$RCOOH \rightleftarrows H^+ + RCOO^-$$

pK_a ~ 4.0 – 4.5



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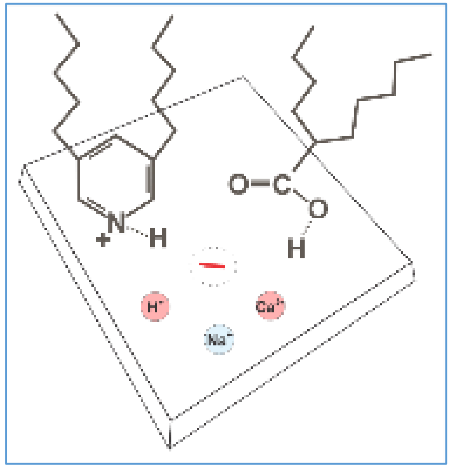
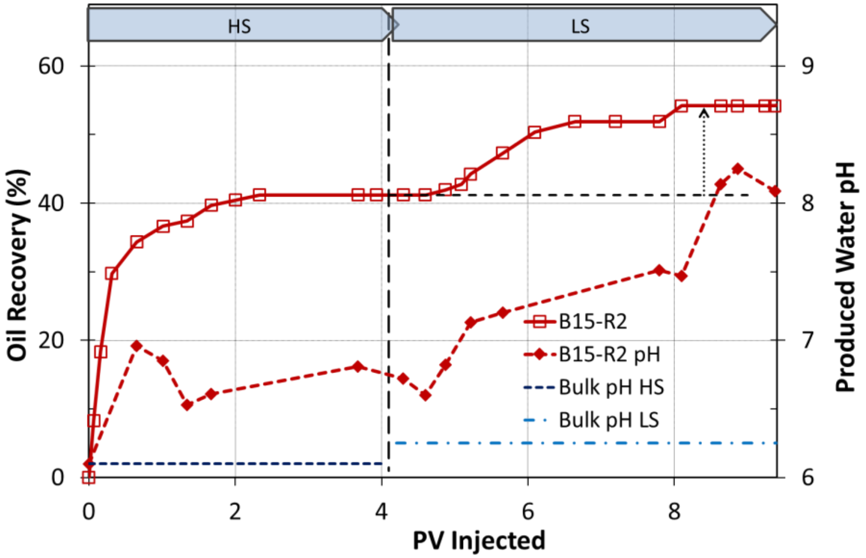
Sandstone research

- Optimal core restorations are ~~important/~~crucial for estimating EOR potential
- Initial wetting
  - Dictated by polar components in crude oil
    - Momentary adsorption of basic organic components.
  - Rock mineralogy is extremely important!
    - Clays are related to the initial wetting by adsorption of crude oil components.
    - Feldspars are able to influence the formation water pH.
      - Negative effect if FW salinity is low
      - Positive effect if FW salinity is high
- Smart Water EOR effects in Sandstones
  - Wettability alteration by local pH increase
    - injected water promotes cation exchanges at mineral surfaces
    - pH change at mineral surfaces affects the affinity of crude oil components
    - **The pH changes observed in PW samples in the laboratory**
  - **Ion composition is important, and not the salinity!**





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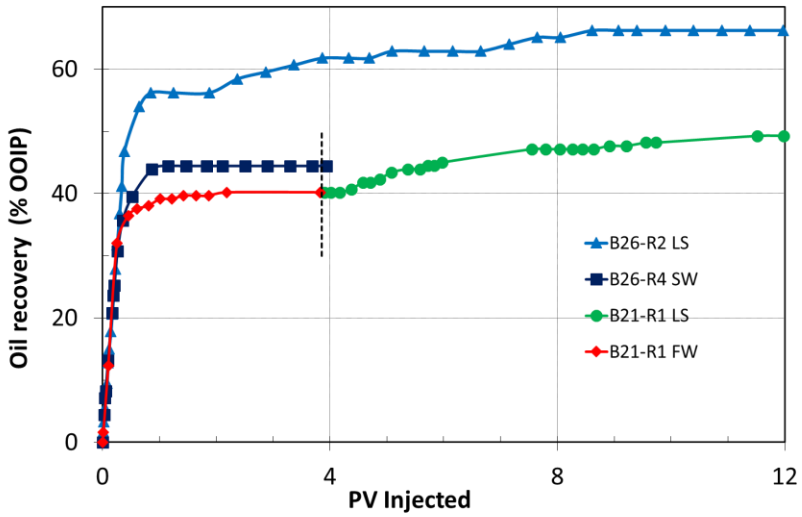
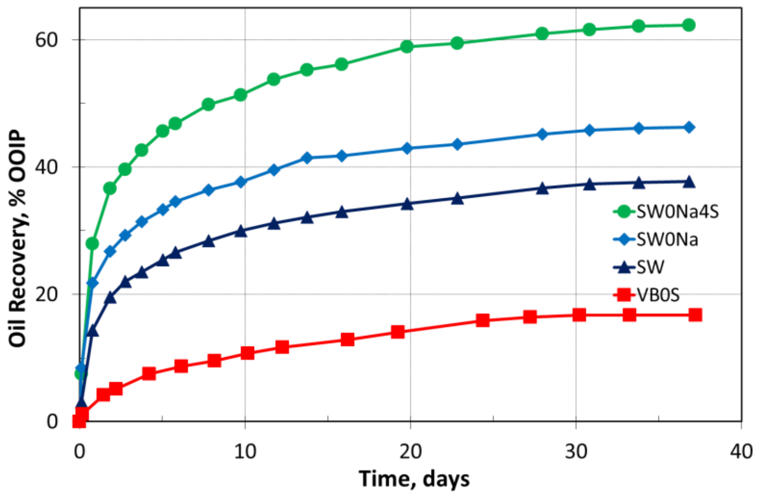
Injection strategies for Smart Water flooding?

Benefit from optimal crude oil – brine – rock interactions **as early as possible!**

Sandstone



Chalk



- Outcrop sandstone cores
  - S_{wi} = 0.2 with FW
  - Exposed to T-Oil (BN = 1.9)
- Oil recovery test at 60 °C
  - Secondary LS injection, 4 PV/D
  - Secondary SW injection, 4 PV/D
  - Secondary FW and tertiary LS injection, 4 PV/D

- 4 parallel Stevns Klint cores, 3-5 mD
  S_{wi}=10% with VB0S as FW; Crude Oil with AN=0.5 mgKOH/g
- Spontaneous imbibition at T = 90 ˚C,
- 4 different imbibing brines:
  - VB0S - FW
  - SW - Seawater
  - SW0Na - depleted in NaCl
  - SW0Na4S – NaCl depleted and 4 x SO_4^{2-}

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Wettability alteration by Smart Water

- Reservoir chemistry is completely different in carbonate and sandstone
  - they must be treated differently.
  - E.g. effect of seawater injection, effect of low salinity injection.

- The reservoir/core must be initially mixed-wet.
  - Too water-wet > No/Low Smart Water EOR potential
  - **A correct understanding of the initial wettability is crucial!**

- When we understand the parameters affecting initial wetting
  - we are able to optimize wettability alteration processes
  - and design the best Smart Water.

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Ongoing research in the Smart Water EOR group

- Carbonate and Sandstone reservoirs
- Develop increased competence and knowledge of:
  - Pore surface mineralogy
  - FW composition
  - Crude oil properties
- Initial wettability
- Wettability alteration - Smart Water EOR processes
- Chemical models describing EOR mechanisms
- Optimized injected water composition to maximize oil recovery.
- Developing prediction tools to evaluate Smart Water EOR potential for given reservoirs
- Injection strategies combining Smart Water EOR with other EOR techniques
  - WAG
  - Polymer
  - Surfactants
  - Alkaline flooding

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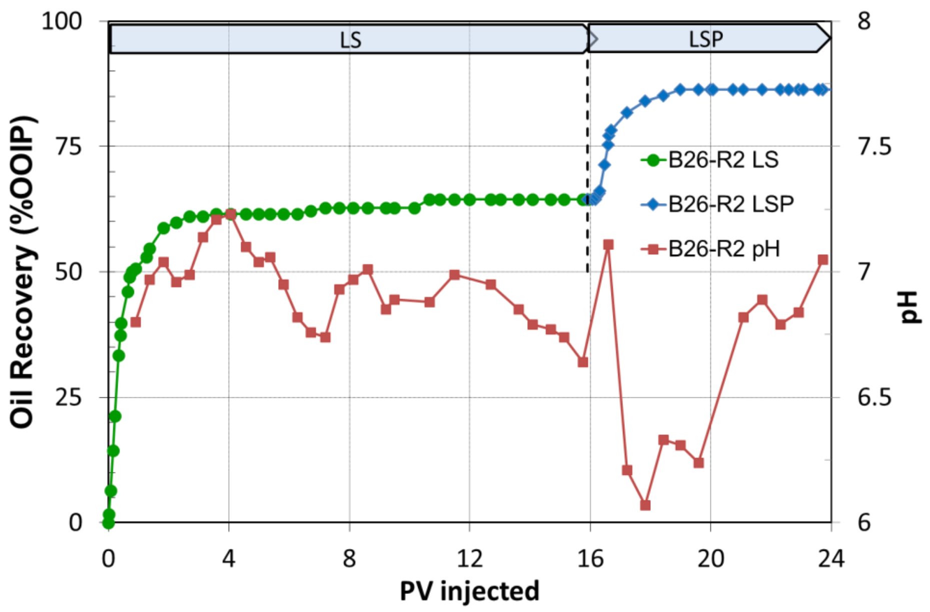
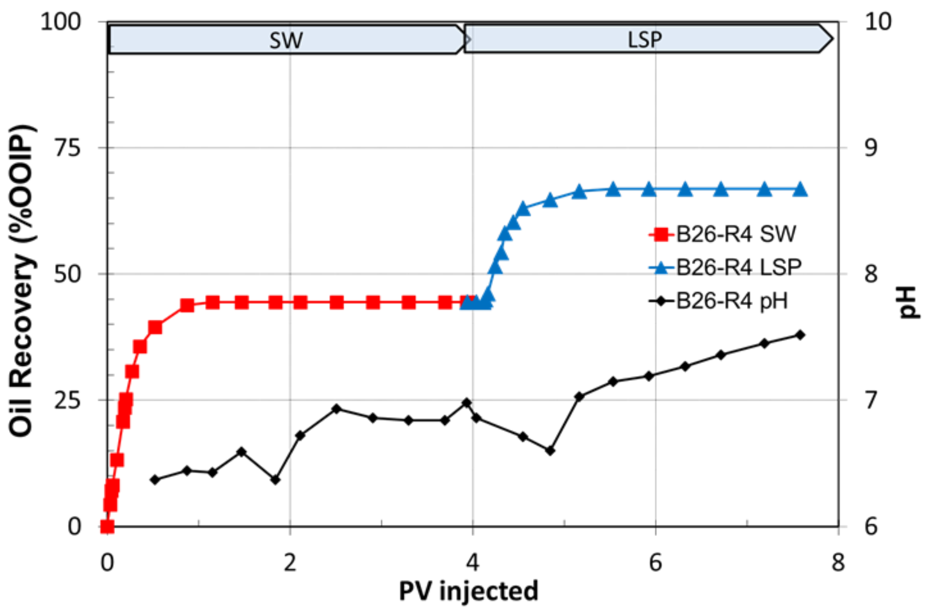
Synergistic effects – hybrid EOR effects

With low salinity and polymer



- Ultimate recovery secondary LS 66 %OOIP
- Ultimate recovery tertiary LSP 86% OOIP
- Trapped residual oil after LS is efficiently displaced with Polymer
- More mobile residual oil after LS (redistribution and oil-entrapment)

With seawater and polymer



- Ultimate recovery with secondary SW of 44 %OOIP)
- Ultimate tertiary LSP of 67 %OOIP (2.5 PV LSP needed)
- Reduced displacement efficiency without wettability alteration

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Main goal/Further work

- Prediction of initial reservoir wettability from:
  - Known reservoir data; crude oil, formation water, rock mineralogy, reservoir temperature
  - Microscopy
  - Simple and fast core screening tests.

- Confirm initial wettability and Smart Water EOR potential from reservoir cores.

- Understand all main parameters affecting wettability.
  - Identify the parameters/processes that need to be included in reservoir models and simulation tools

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Acknowledgements

BP

Total

Wintershall

Talisman

Saudi Aramco

Talisman Synoptics

DNO

TaQa

Maersk

Petoro

Shell

Core Specialist Services

Conoco Phillips

NFR

The 2018 user partners and observers:

NEPTUNE ENERGY

wintershall

TOTAL

eni

eni norge

HALLIBURTON

Schlumberger

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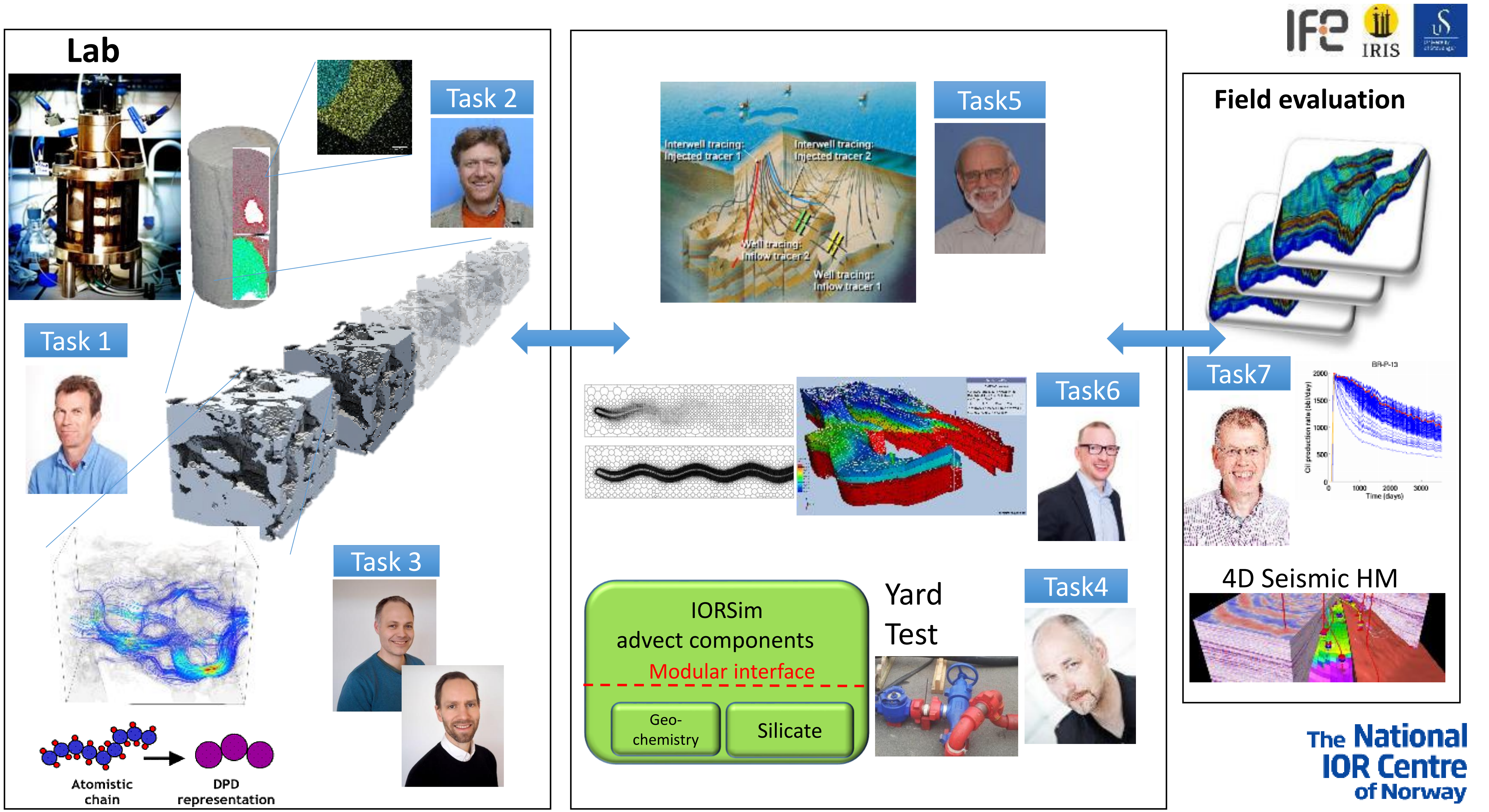
IRIS
Lab
Task 2
Task 1
Task 3
Atomistic chain
DPD representation
Interwell tracing: Injected tracer 1
Interwell tracing: Injected tracer 2
Well tracing: Inflow tracer 2
Well tracing: Inflow tracer 1
Task5
Task6
IORSim
advect components
Modular interface
Geo-chemistry
Silicate
Yard Test
Task4
Field evaluation
Task7
Time (days)
4D Seismic HM
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Research questions

- Do we understand the EOR effect of smart water?
- How to link core scale recovery to changes in mineral/brine/oil properties?
- At which conditions does improved core scale recovery translate to improved field recovery?

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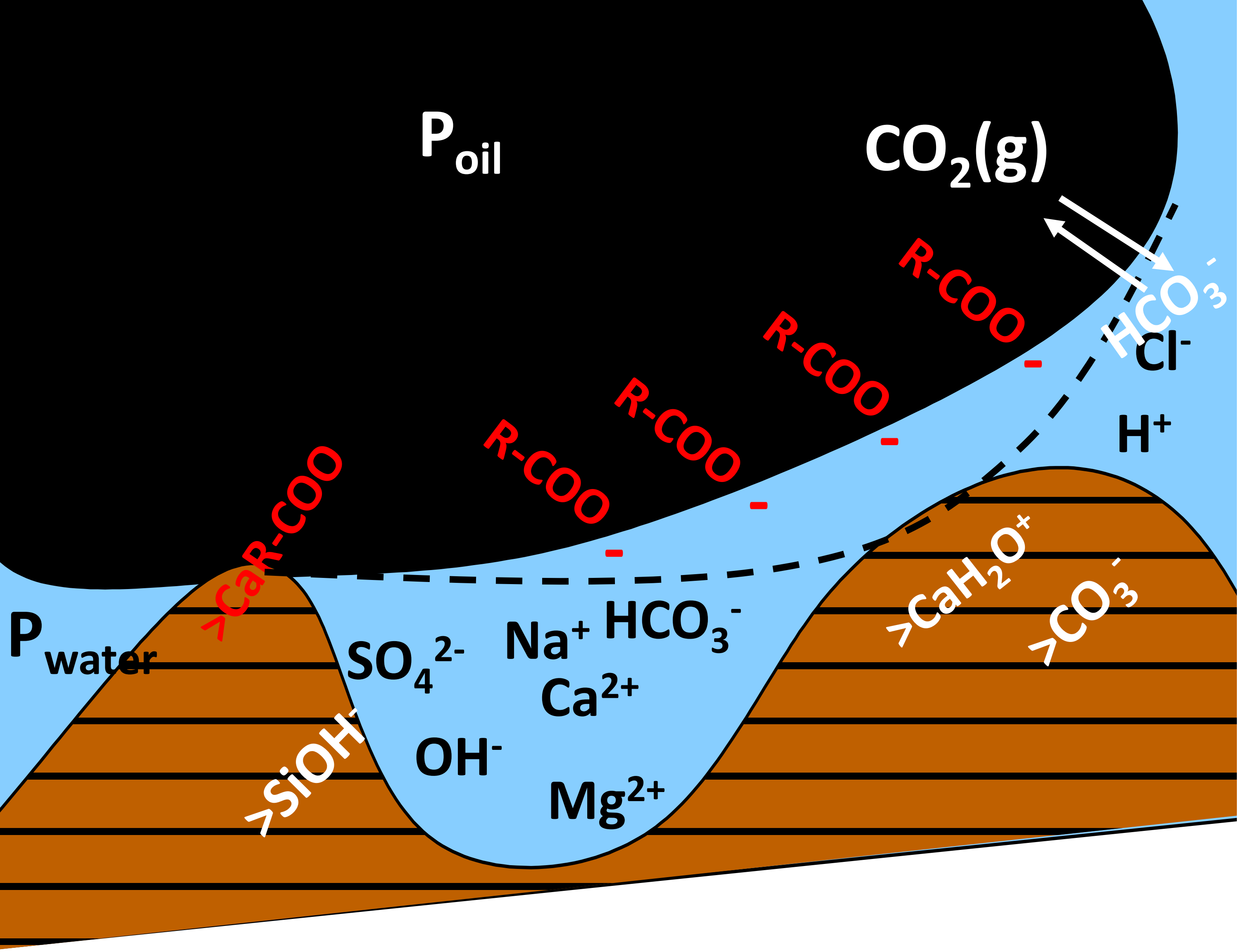
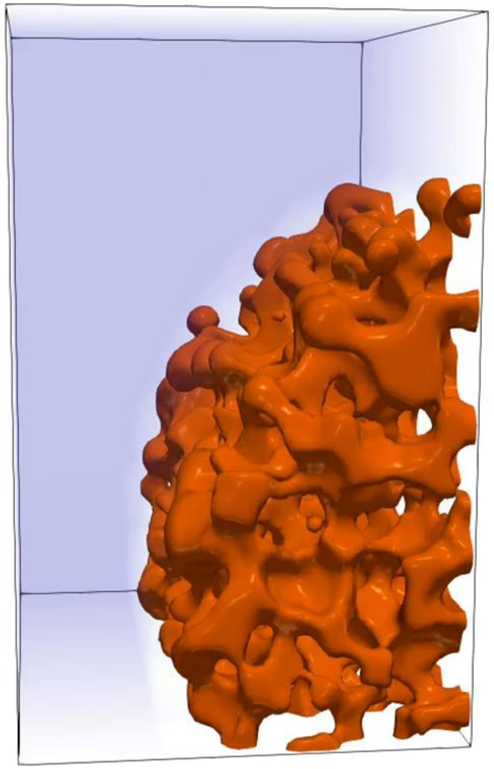


Salinity, pH, surface potential, oil chemistry is important

Highlights from The National IOR Centre of Norway - What do we know now regarding smart water flooding that we did not know four and half years ago?

- Mechanisms still not verified, but it is generally agreed:
  - System behavior changes to more water wet
  - Surface charge/potential for both rock/brine and oil/brine important
  - Different potential determining ions in carbonate and sandstone
- Insight from pore scale simulations and investigations are necessary
  - Correlation between mineral contact angle and oil production
  - Preliminary pore scale studies reveals that changing to smart water during production gives similar recovery as starting with smart water



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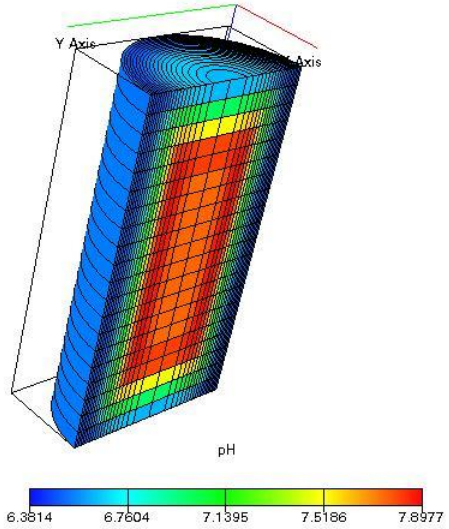
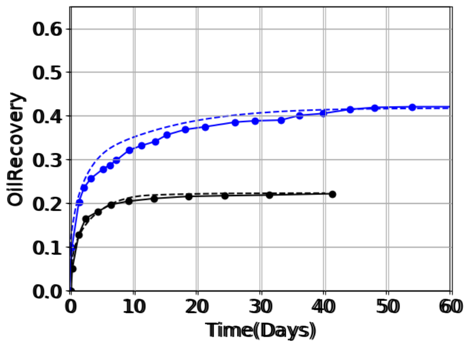
Highlights from The National IOR Centre of Norway - What do we know now regarding smart water flooding that we did not know four and half years ago?

- Improved tools to analyze experiments and upscale assumed mechanisms.
  - Geochemical models implemented in IORSim and IORCoreSim
    - Predict changes in brine composition due to
      - Mineral dissolution/precipitation
      - Ion exchange / surface complexation
    - Track changes in rock surface potential and solution pH





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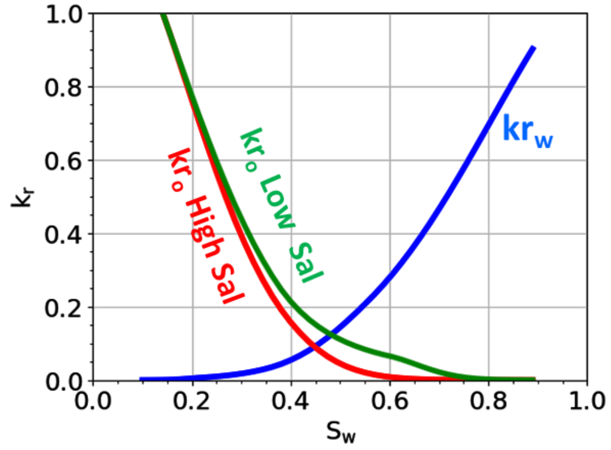
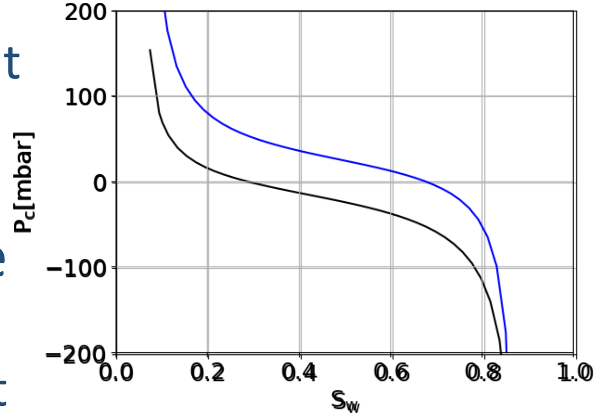
Highlights from The National IOR Centre of Norway - What do we know now regarding smart water flooding that we did not know four and half years ago?

- IORCoreSim prepared for relevant laboratory experiments
  - A major part of smart-water experiments is spontaneous imbibition experiments. IORCoreSim offers easy simulation of spontaneous imbibition experiments with different boundary conditions
  - Saturation and temperature dependent diffusion. Diffusion allowed across core surface boundary. Composition of surrounding water in imbibition cell is tracked, due to flow trough and exchange with the core
  - Flexible interpolation model for saturation functions (relative permeability and capillary pressure). Easily extended to test out different assumptions
- Preliminary finding is that the Smart Water recovery from spontaneous imbibition (SI) experiments are consistent with the timescale of molecular diffusion
  - SI good for mechanistic studies, information about rel perm is important for field recovery





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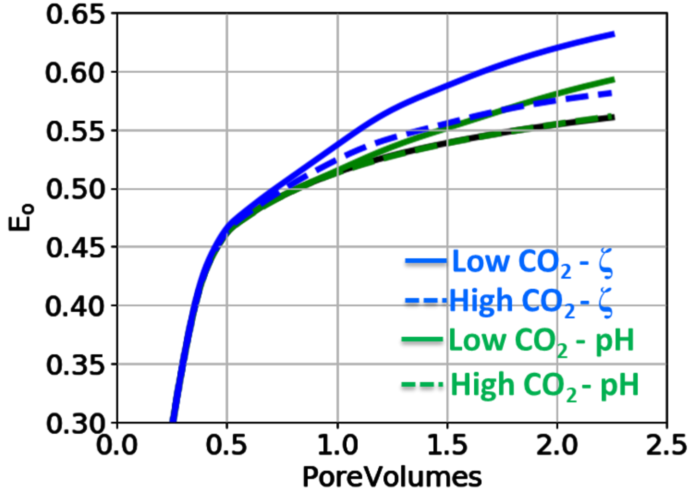
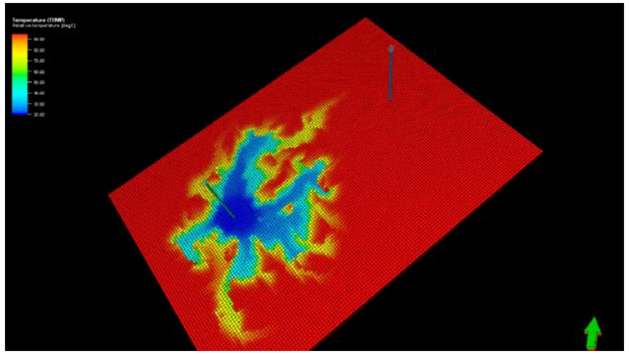
Highlights from The National IOR Centre of Norway - What do we know now regarding smart water flooding that we did not know four and half years ago?

- Pore scale mechansims are important for field recovery
  - Field chemistry is different than core chemistry (T-gradients, flooding history)
- It is possible to simulate geochemistry with ECLIPSE (IORSim)
  - Effect if CO2 in oil phase
- It is possible to pass information back to ECLIPSE and emulate effect of Smart Water
  - Rel perm/pc - interpolation
  - pH changes, Surface potential, Adsorption, Ion exchange, Mineral dissolution/precipitation
  - Can simulate temperature profiles





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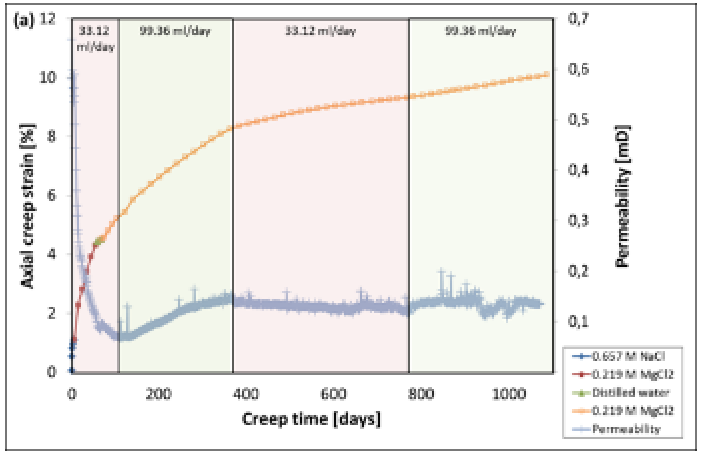
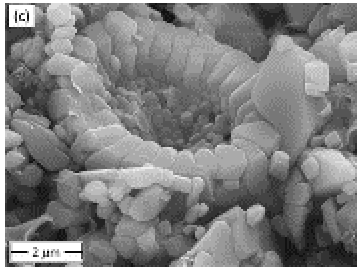
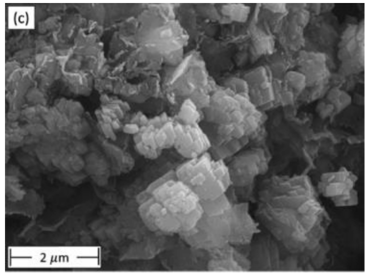
Highlights from The National IOR Centre of Norway - What do we know now regarding smart water flooding that we did not know four and half years ago?

- Compaction and Smart Water (chalk)
  - Compaction during flooding with reactive brines is insensitive to the rock`s wetting state
  - Temperature, fluid composition and mineralogy dictate compaction, porosity and permeability evolution
  - At reservoir temperatures:
    - SO_4^{2-}adsorbsion reduces elastic and plastic strength properties
    - Mg^{2+}reduces the strength in the plastic creep phase
    - Fractures change fluid-flow and delay water weakening

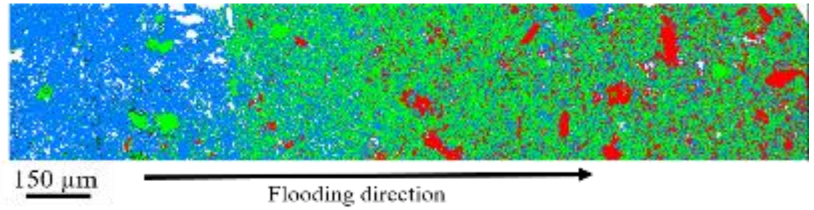




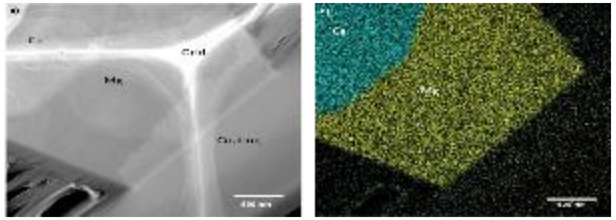


Highlights from The National IOR Centre of Norway - What do we know now regarding smart water flooding that we did not know four and half years ago?

- We know a lot more about textural changes in rock before and after flooding
  - Scanning of entire cores after flooding: visualising mineral changes and fluid flow
  - Quantify mineral changes – detailed composition



  - Routine methodologies for SEM-TEM-RAMAN-XRD and MLA
  - Raman as an ideal (quick, cheap, non-destructuve) tool for mineral identification in flooded rocks for EOR experiments
  - Positive identification of magnesite in-situ beyond doubt via nanoSIMS



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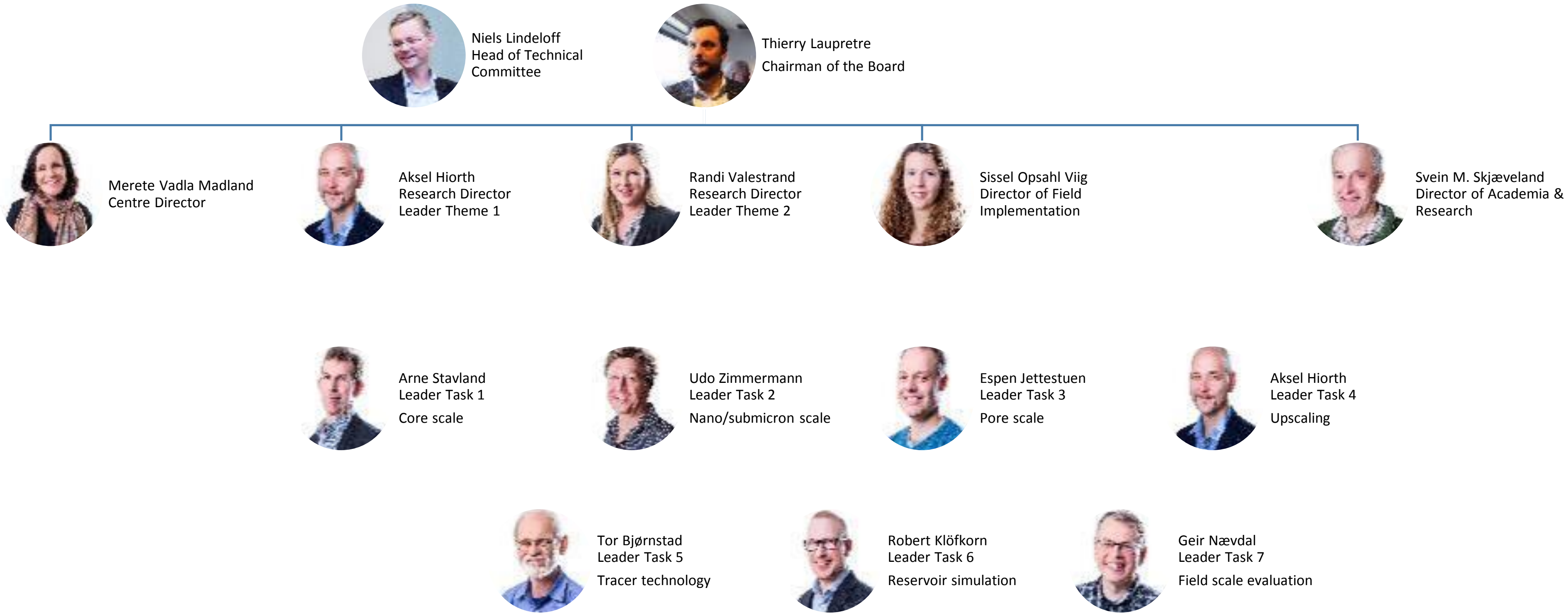
From the IOR Centre - What is missing in our understanding of smart water flooding?

- More experiments must be analyzed.
  - Necessary for
    - qualification/rejection of assumed mechanisms
    - increasing our understanding and improving models
    - implications for scaling up
- What is common for smart-water, low-salinity and alkaline flooding? Or is completely different mechanisms involved?
- Why does e.g. low salinity work for some sandstone formations and not others?
- Fractured reservoirs
  - Importance of changes in capillary pressure versus changes in relative permeability
    - in early and late stages of the field production

From the IOR Centre - What is missing in our understanding of smart water flooding?

- Large scale design considerations:
  - Smart Water before or after field temperature gradients have passed through a reservoir section?
  - Reservoir compaction and Smart Water – Smart Water before or after compaction?
    - Can compaction change the wetting state by redistributing oil- and water-wet surfaces
- More data from larger scale – callibrate models
  - Interplay between capillary forces, viscous forces and fracture/matrix

The organization



The 2018 user partners and observers:

Acknowledgement:

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Research questions

- What is missing in full field simulators to efficiently simulate smart water flooding on field scale?
- How important is the improved resolution, given by higher order methods, when simulating smart water flooding at field scale?
- Do higher order methods have a big impact on decision making for improved oil recovery?

Highlights from The National IOR Centre of Norway - What do we know now regarding smart water flooding that we did not know four and half years ago?

- We have established higher order finite volume methods for polyhedral grids (corner point) grids
- The higher order methods work in a fully coupled fully implicit setting which is standard in reservoir simulation
- Implementation in open source code OPM is ongoing

From the IOR Centre - What is missing in our understanding of smart water flooding?

- Combination of new technologies, higher order methods and ensemble based history matching & optimization & forecasting
- Fine scale numerical simulation of smart water flows for improved understanding and derivation of upscaled models
- Coupling and upscaling of reservoir mechanics to field scale simulation in an efficient way

Research questions

Field scale evaluation and history matching

- How can a set of history matched models taking all available information into account, in particular 4D seismic, improve smart-water flooding?
- How can we optimize smart-water flooding given an ensemble of (history matched) reservoir models?

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Highlights from The National IOR Centre of Norway - What do we know now regarding smart-water flooding that we did not know four and half years ago?

- Developed tools necessary for history matching utilizing 4D seismic data
  - Methodology successfully demonstrated on first real field data set
- Improved methodology for production optimization given an ensemble of reservoir models
  - Better theoretical understanding of methodology

From the IOR Centre - What is missing in our understanding of polymer flooding?

- Studies on optimization of smart-water flooding given (an ensemble of) reservoir model(s)
- Make optimization robust, given uncertainties in characterization of reservoir, uncertainty of critical factors for smart-water models, uncertainty in the chemical modeling, etc.
    - Temperature
    - Absorption of ions
    - Wettability
- Monitoring and history matching of fields having applied smart-water flooding

The organization

The National IOR Centre of Norway

The 2018 user partners and observers:

NEPTUNE ENERGY

wintershall

TOTAL

eni norge

With funding from The Research Council of Norway

HALLIBURTON

Schlumberger

ConocoPhillips

Lundin Norway

equinor

DEA

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Smart Water

Initial Wettability and Performance of Smart Water Flooding

Farzad Shariatpanahi, PhD.
Principal Reservoir Technology
Improved Recovery and Reservoir Studies
DPN OTE PTC

Core Preparation

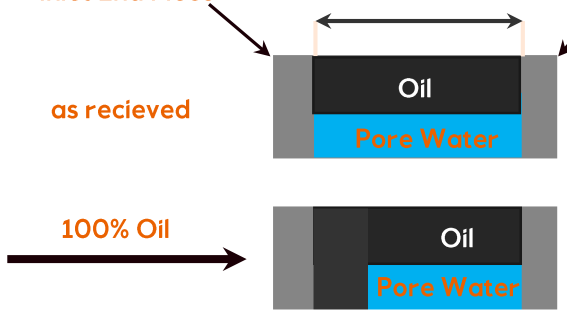
PRESERVED

Inlet End Piece

ΔP

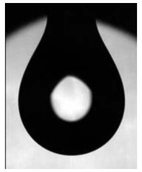
Outlet End Piece

as recieved



100% Oil

Sample collected from 'pore water'



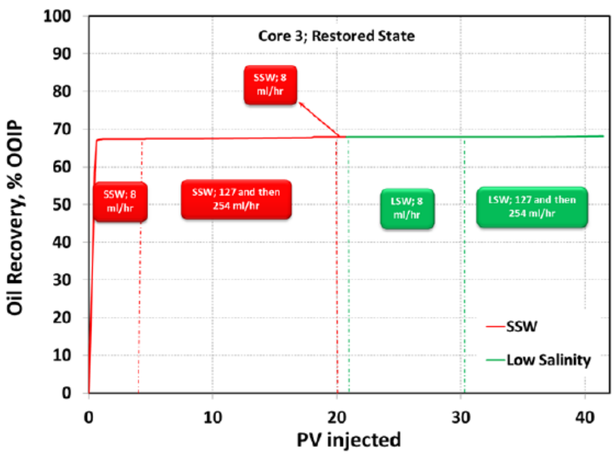
IFT measurement @ Troom

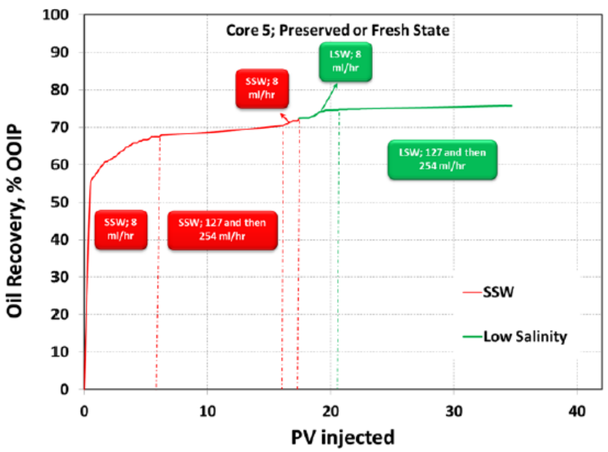
- PW-Oil vs. SW-Oil

14 vs. 19 dynes/cm

PRESERVED; wettability as received:

RESTORED wettability:





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Learnings from Laboratory work
Understading the initial wettability is a key

- At present it is not possible to predict whether a field/formation will show an effect or not *i.e.* it is necessary to test each individual formation in the laboratory.
- Initial wettability of the rock is one of the most important factor controlling the efficiency of LSW flooding.

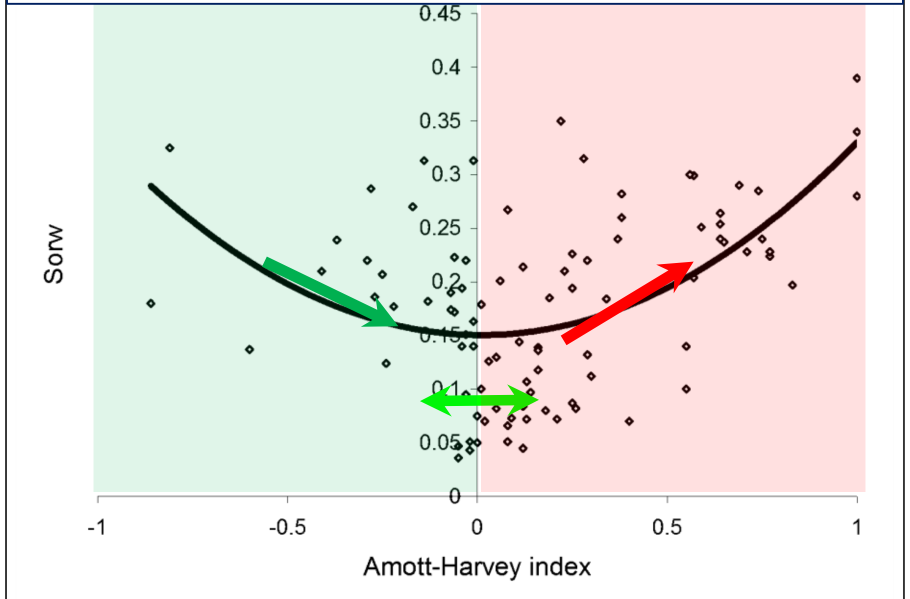
North Sea reservoir samples (SCA-2002-12)

- >350 core-floods
- 30 different reservoirs

Amott Wett. Index:

- Majority of sandstones in NCS:

Alteration of wettability is not included



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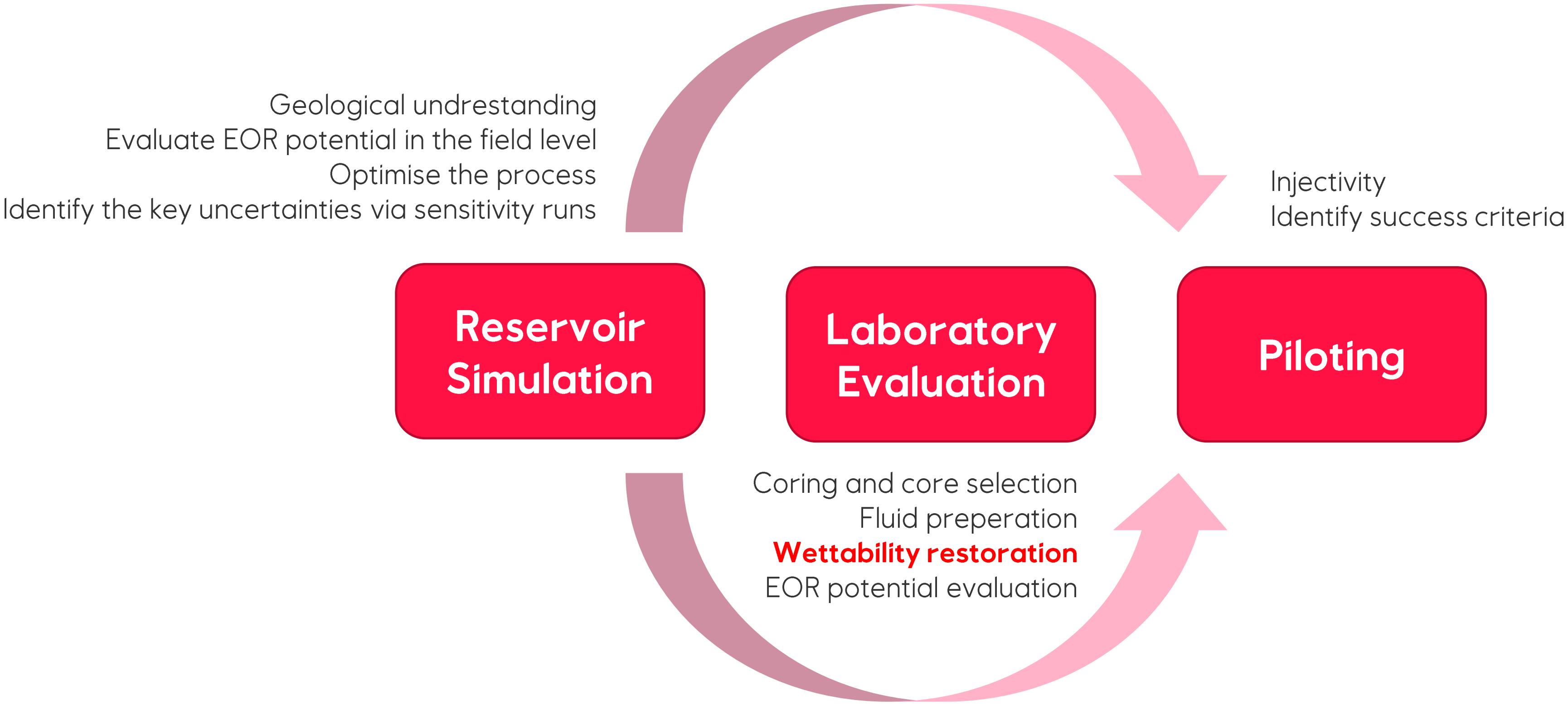
Technical evaluation of Smart Water



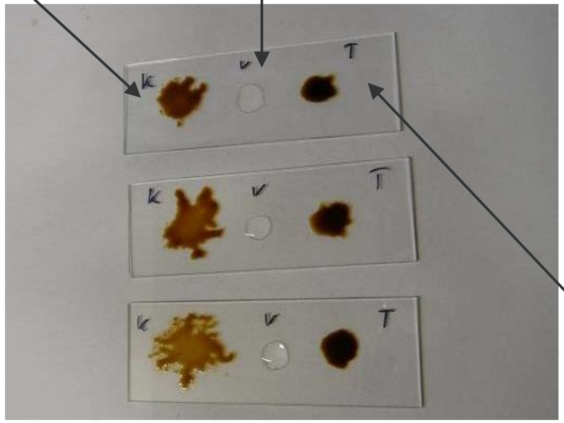
Source: Statoil

Laboratory requirments and uncertainties (I)

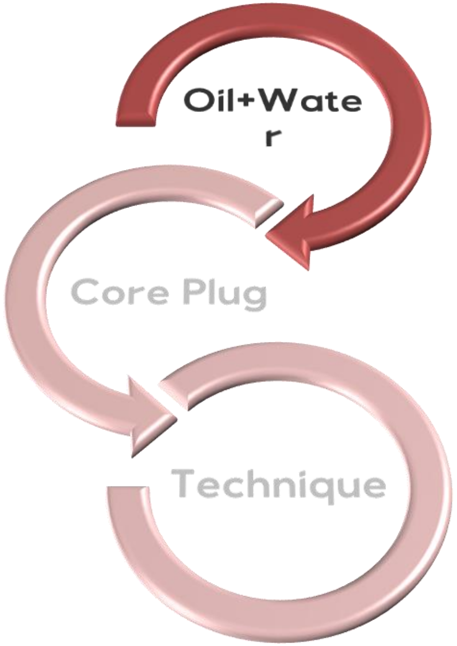
- Exposure of oil to the air and wettability alteration!!
- Bacterial growth in the experimental set-up

Taken from a production line with minimal exposure to air

Water



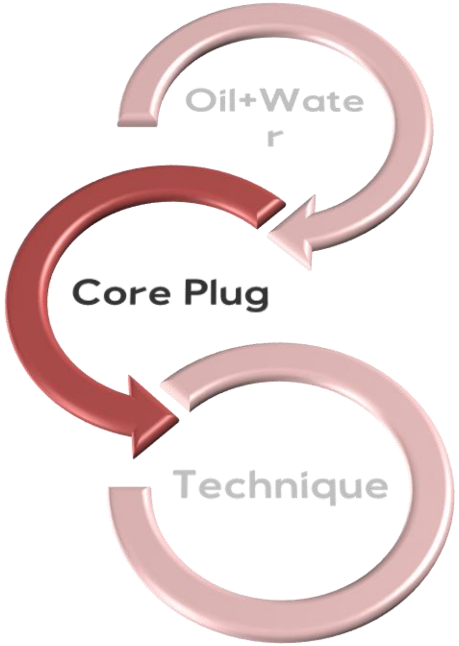
3 months exposed to air and light



Laboratory requirments and uncertainties (II)

Coring

- Irreversible change in physical properties of the core due to pressure and temperature changes (ø , k)
- Irreversible change in rock surface properties due to scale and heavy component precipitation
- Mud contamination

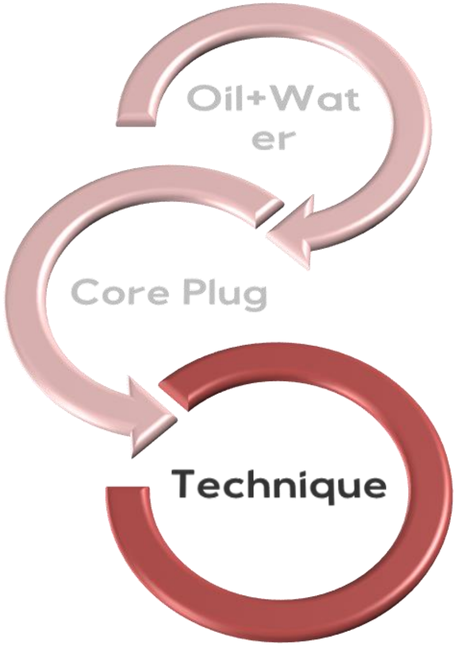


Activity	Method	Target
Core selection	CT iamge/measurment/log	representative of reservoir

Laboratory requirments and uncertainities (IV)

Wettability restoration

Activity	Method	Target
Core cleaning	Using solvent	Obtain Water-wet core (!!!)
Initial water saturation	Porous plate/flooding/decicator	Stablish the same Swi as reservoir
Oil Flooding and ageing	Contact core with oil for a few weeks	define COBR interaction

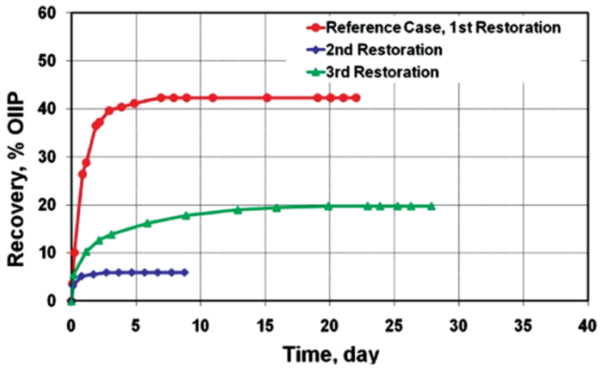


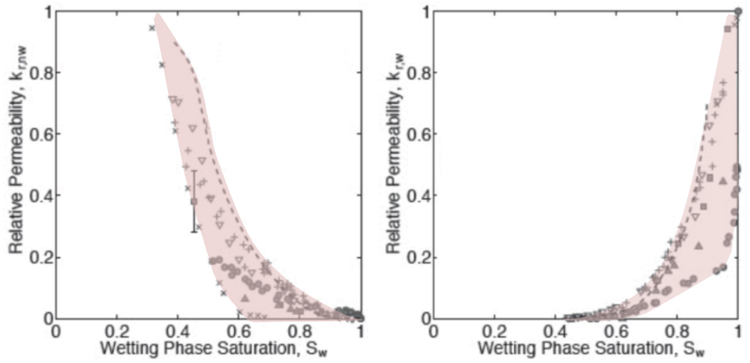
Example:

1st restoration: mildly cleaned preserved cores

2nd restoration: cleaning by toluene/methanol injection

3rd restoration: toluene/MeOH+wettability modifier





Shariatpanahi et al., 2012

equinor

Suggestion from Equinor

Experimental:
Equinor suggests NIOR to focus more on initial wetting condition and improve our understanding about it as it defines EOR prize of smart water

- Interaction between rock minerals, oil and water components under physical conditions of reservoirs

Modeling:
Pore-scale imaging and modeling of phases distributions (wettability)

Smart Water

Initial Wettability and Performance of Smart Water Flooding

Farzad Shariatpanahi, PhD.
Principal Reservoir Technology

ConocoPhillips

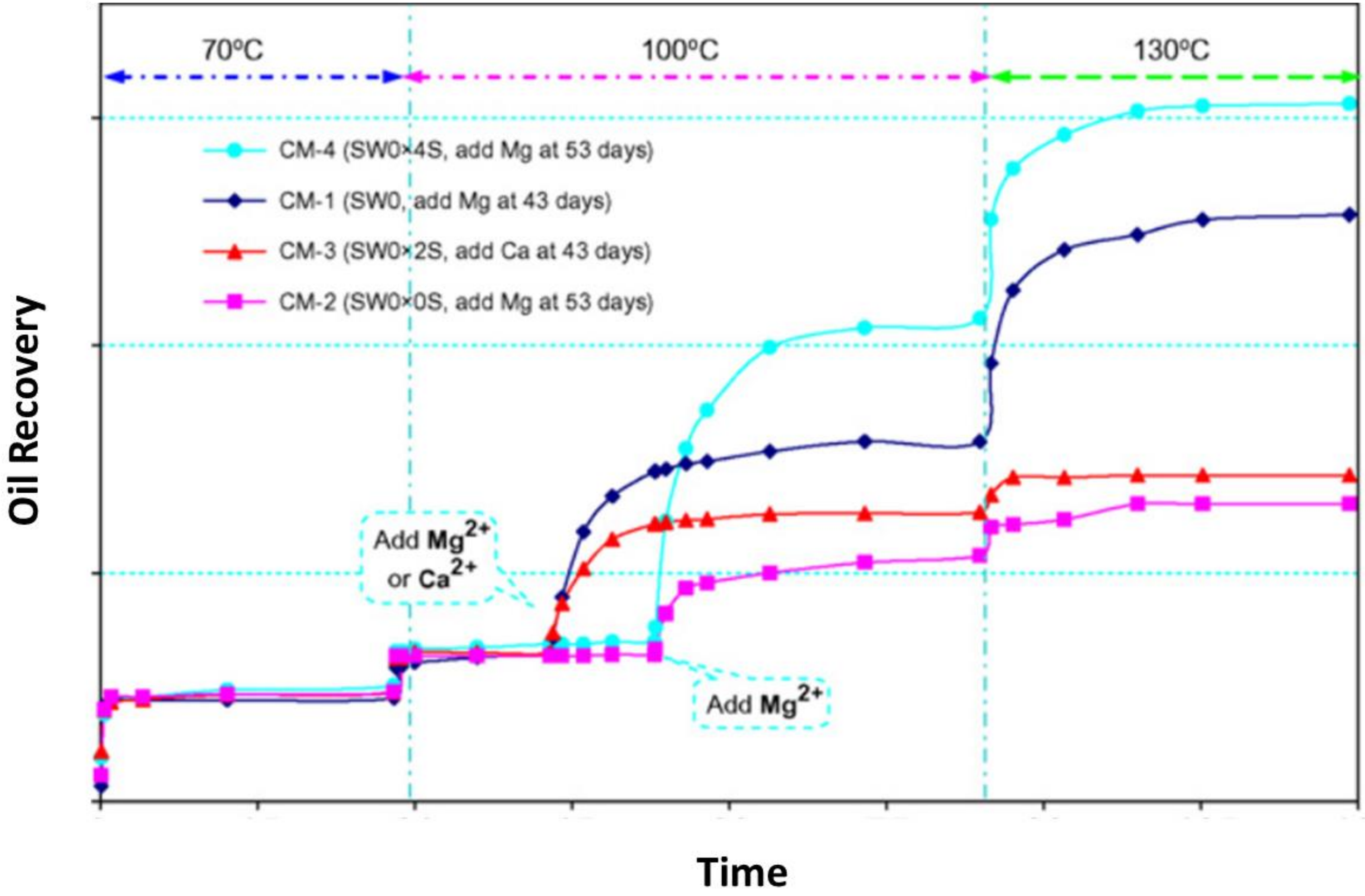
Smart Water

NIORC, Stavanger September 14th 2018

September 24, 2018

Smart Water Historical Results

- The mineral interactions between water, oil and rock have been studied extensively over the past 15 years for different applications
  - Geomechanics
  - Stimulation/scale squeeze
  - EOR



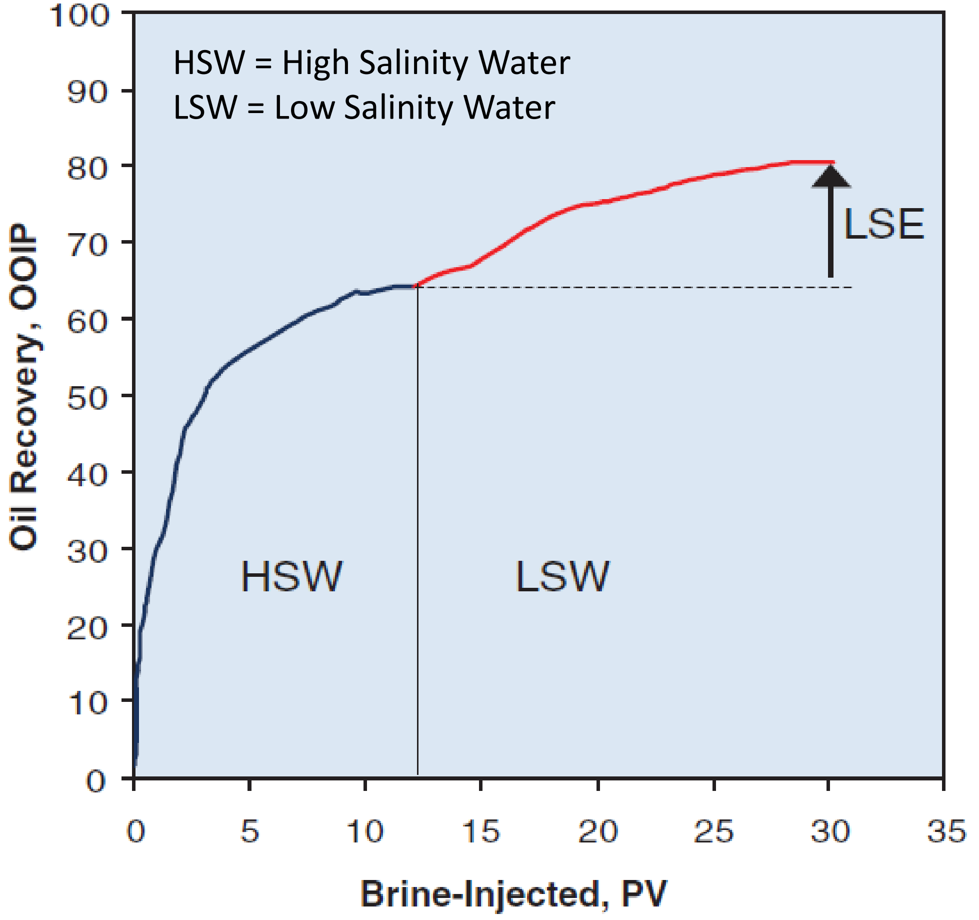
ConocoPhillips

Smart Water for Field Application

- Field observations
  - Recovery mechanism is a combination of both spontaneous imbibition and viscous displacement
  - Oil recovery by seawater injection is already better then the smart water potential previously demonstrated by spontaneous imbibition

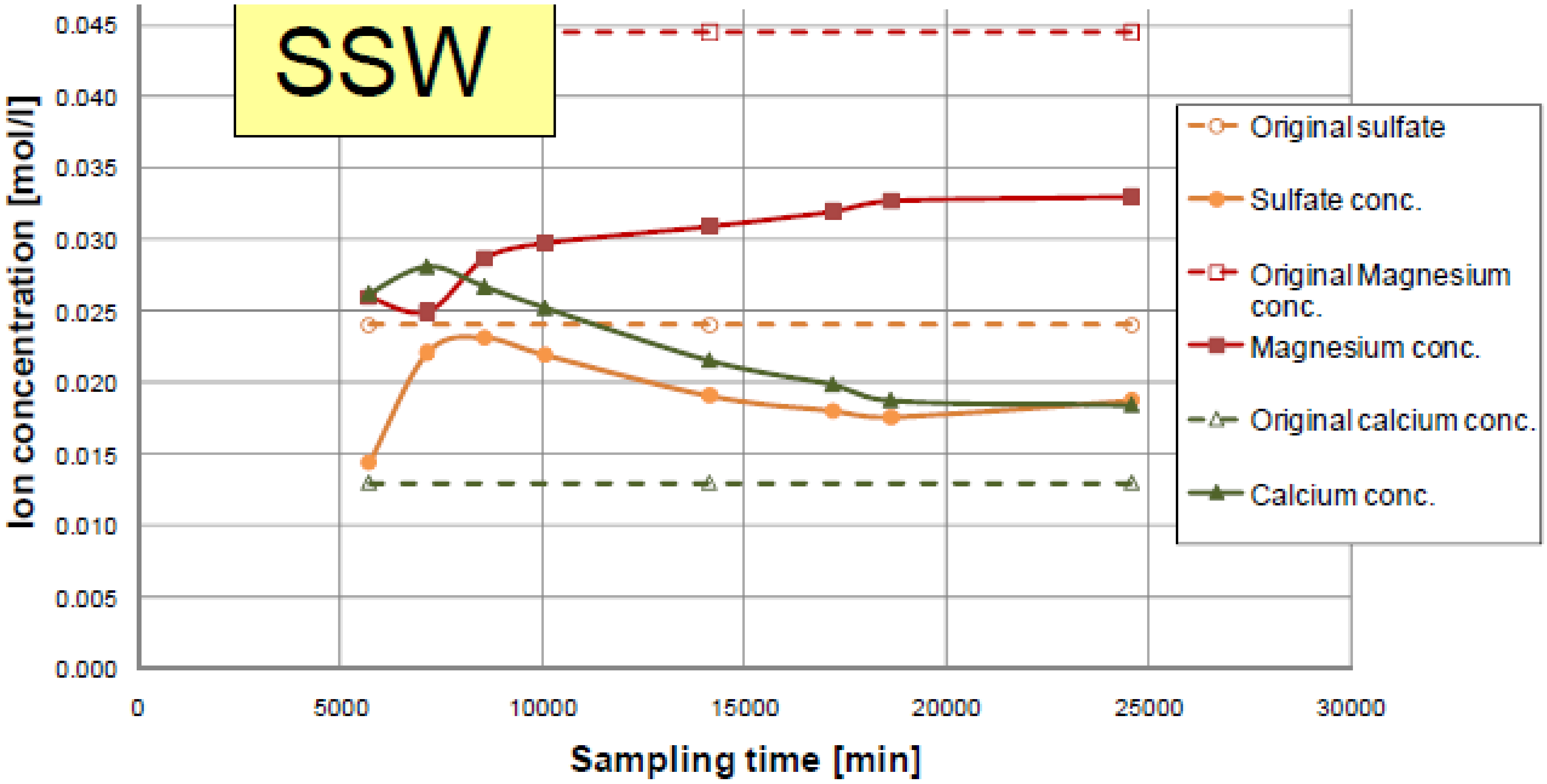
- Low salinity for sandstone has shown potential for achieving very low residual oil saturations

<u>Need to demonstrate the potential for smart water to also achieve low residual oil saturation</u>



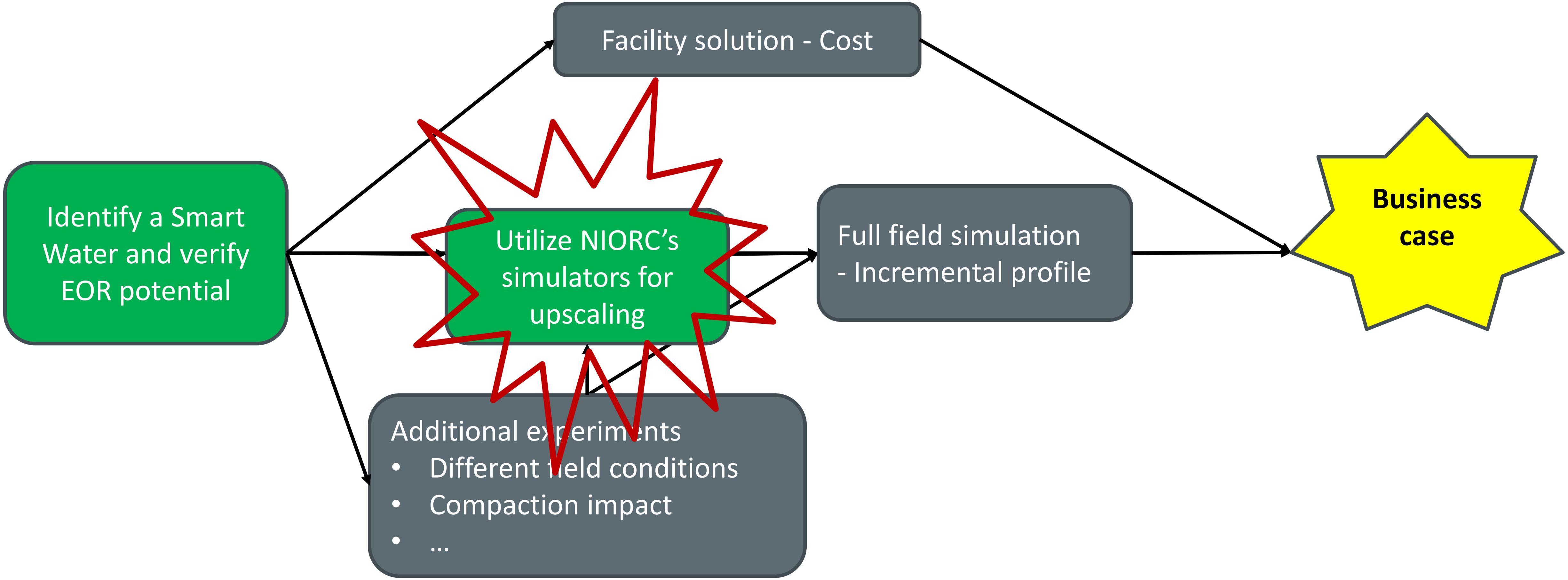
From N. Morrow and J. Buckley, JPT May 2011
Low salinity results in sandstone

Lab Results vs Field Observations



Field observations shows the same trend as demostrated in the lab

Path Forward



Low Salinity Water Injection: Eni Experiences

13th September, 2018

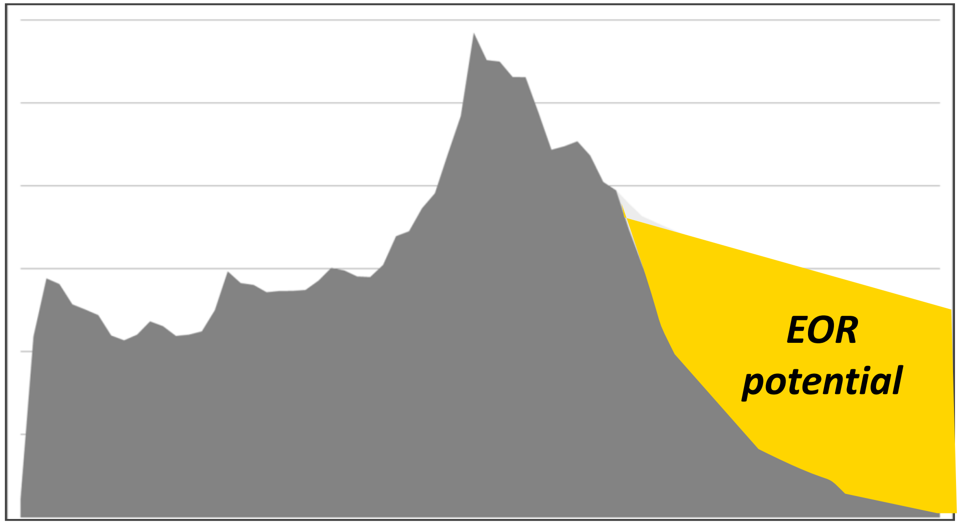
Smart water/Low Salinity water Workshop – Stavanger

11 years of Eni's Experience in Low Salinity

Key EOR Opportunity to improve oil recovery in green and brown fields

Maximize Oil Production

Arrest Production Decline



Field Development Strategy

Increase Reserves

THE HISTORY …

- ***2006 Laboratory Studies & Field Screening***
- ***Accurate Modeling & Predictions***
- ***2007 1st coreflooding tests in-house***
- ***2008 1st Log-Inj-Log***
- ***2013-2014 SWCTT Pilots***
- ***2016 Inter-well Application & Monitoring***

… THE NEXT

- ***Full Field Extension & New Studies***
- ***Continous Research & Process Optimization***

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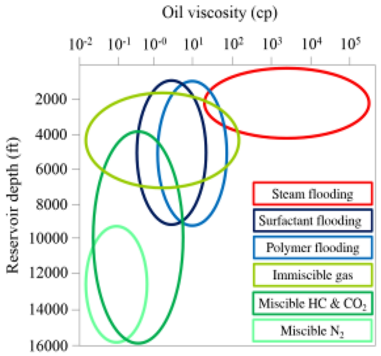
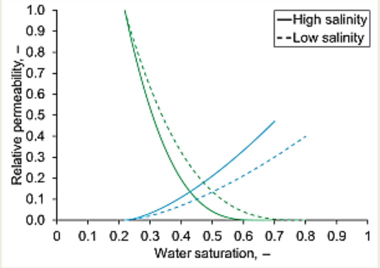
Summary of Eni's Workflow and Best Practices

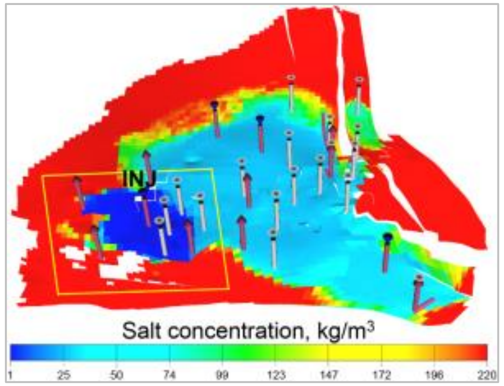
Screening Phase → **Lab Analyses & Simulation** → **Reservoir Simulation** → **Pilot Test @ well scale** → **Inter-well Test** → **Full Field EOR**



- Selection of EOR processes through in-house tools
- Optimal pilot area



- Fluids/Rocks Characterization
- Corefloods
- Core Numerical interpretation



- EOR simulation at reservoir scale
- Accurate Predictions
- Uncertainty Quantification
- Multiple Realizations

- Single well pilots: design, analytical and numerical interpretation
- Multi-well trials & Monitoring

- Phased Approach: from Pilots to Full Field Extension
- Continuous 3D model update
- EOR optimization and field management

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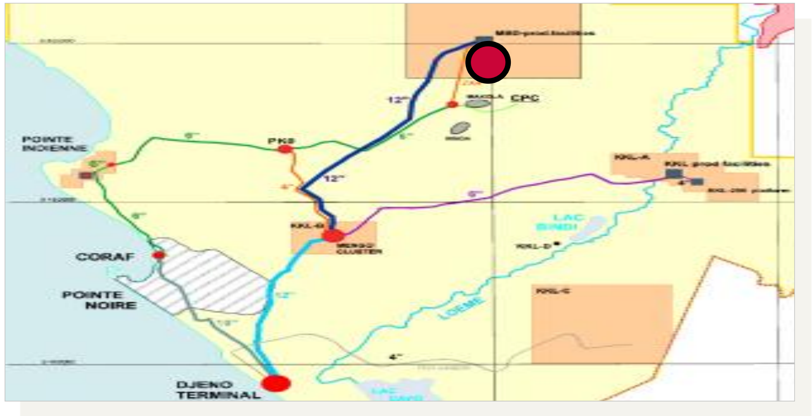
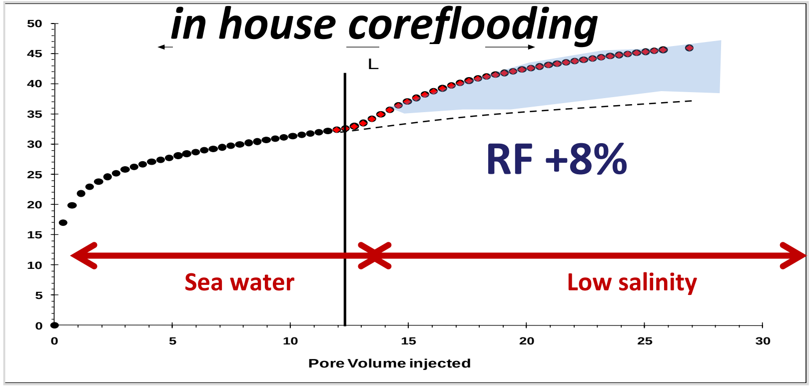
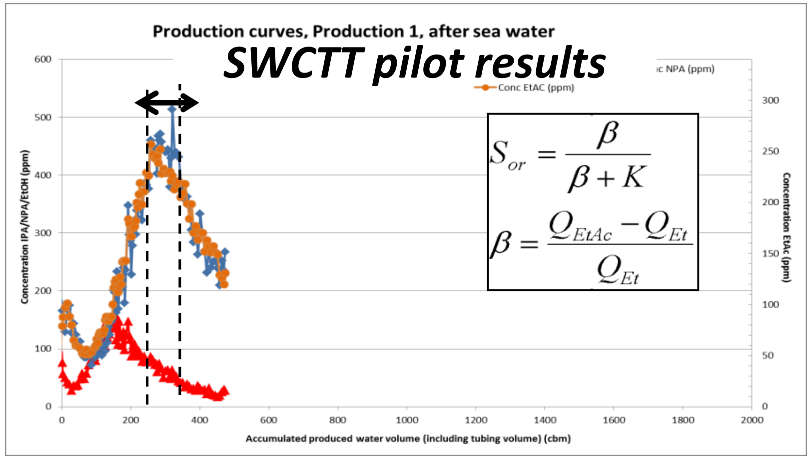
Project in Republic of Congo: On-Shore Field

- **Reservoir Characterization:**
  - Clastic reservoir, complex structural setting, heavily faulted
  - Fine to coarse sandstones and conglomerates with illitic dispersed clay
  - **Light Oil**: 39°API - 0.6 cP at reservoir conditions
  - **HighTemperature:** areal gradient (70-110 °C)
  - **Water salinity**: FW 27-87 g/l; SW 30-35 g/l
  - Put on stream in 2002 and developed by **water injection since 2007**
  - More than **200 wells** drilled up to date

- **Low Salinity History:**
  - **2006**: Project start-up to investigate mechanisms of low salinity EOR
  - **2009**: Lab studies and core flooding experiments
  - **2010**: R&D Project for low salinity + surfactant / polymer injection
  - **2012**: Feasibility/economical study for on-site desalination plant
  - **2013**: SWCTT with low salinity





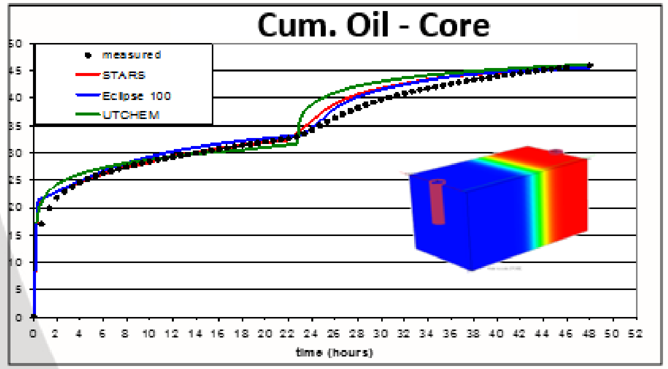


Maximize Sweep Efficiency for a Complex Highly Faulted Asset

Project in Republic of Congo: 3D Modeling

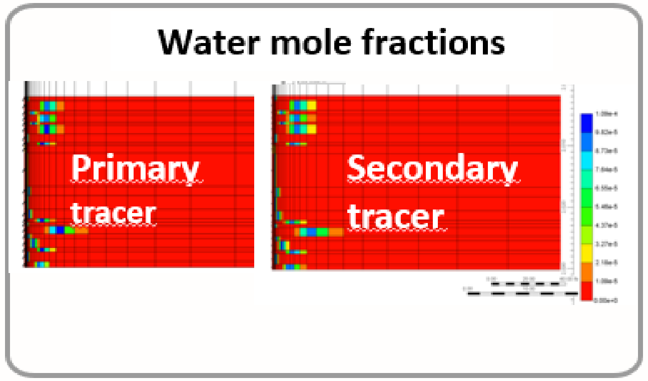
Core scale

- 1D model, realistic rock/fluid properties & lab conditions
- Reproduction of lab data



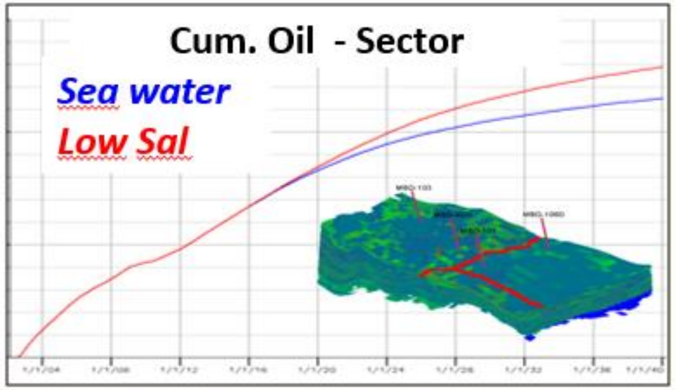
Well scale

- Single Well Tracer Test Design
- Chemical reactions (STARS/UTCHEM/ARTSIM)

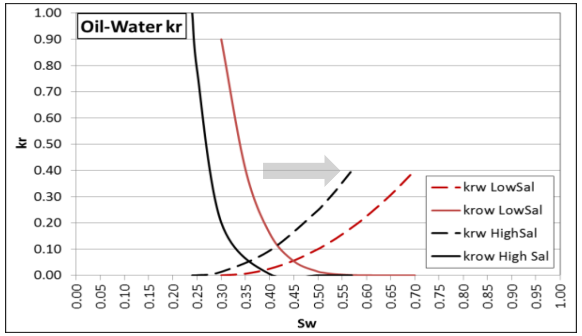


Sector scale

- Fine grid 3D model of pilot area
- EOR forecast scenarios & Optimization strategy



✓ **Dedicated chemical EOR modules in different tools: ECLIPSE, STARS, UTCHEM**



Eni’s Project in Republic of Congo

Log-inj-log equipment, WA, 2008

SWCTT field layout, WA, Dec 2013

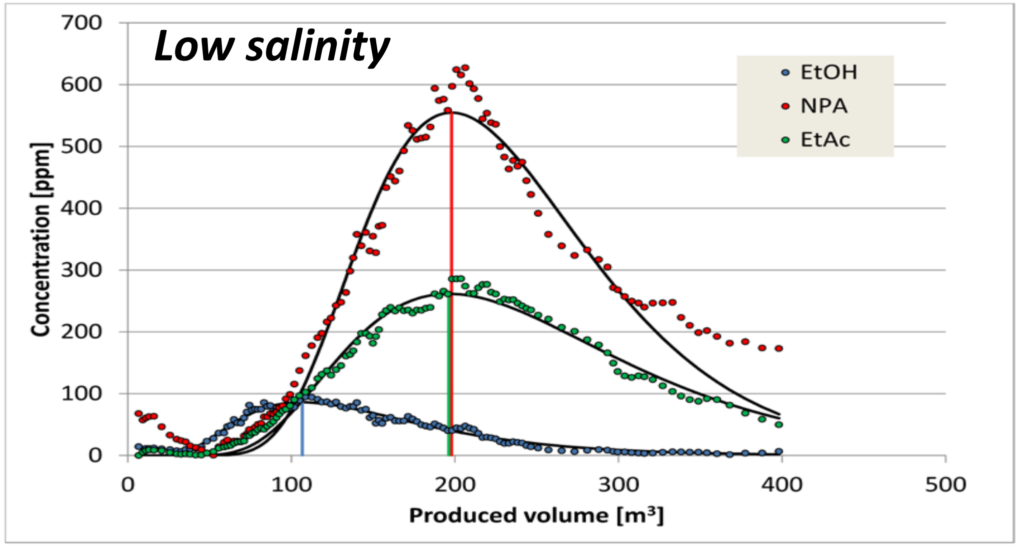
SWCTT field layout, NA, Aug 2014

Desalinization technology for inter-well and full field application:

- ✓ analysis of current industrial techniques
- ✓ feasibility and economical studies

Project in Republic of Congo: SWCTT Field Application

- **First Eni SWCTT** to measure **residual oil saturation** in the near well area, using the **tracer technology**
- Successful tests in 2013 with peculiar program: 3 injection/shut-in/production with sea water, low salinity & surfactant



- **SWCTT results:**
  - Sor after sea water **21 ±2 %** in line with SCAL data
  - **Unexpected minor EOR effects** of **low salinity** water Sor **21 ±3 %**
  - **Gained knowledge** for next SWCTT design & applications

WHY unchanged Sor with Low Salinity?

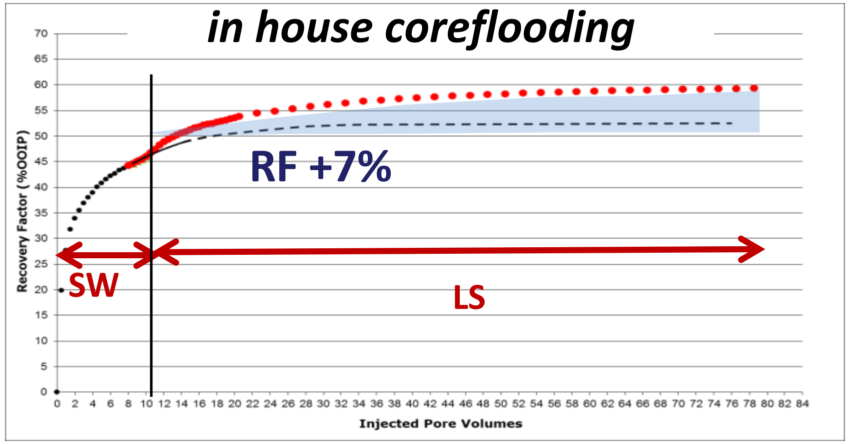
- **Mineralogy** with low clay content
- Action for EOR treatment: possibly **more PV of low sal water** needed
- Optimal **water composition** not reached

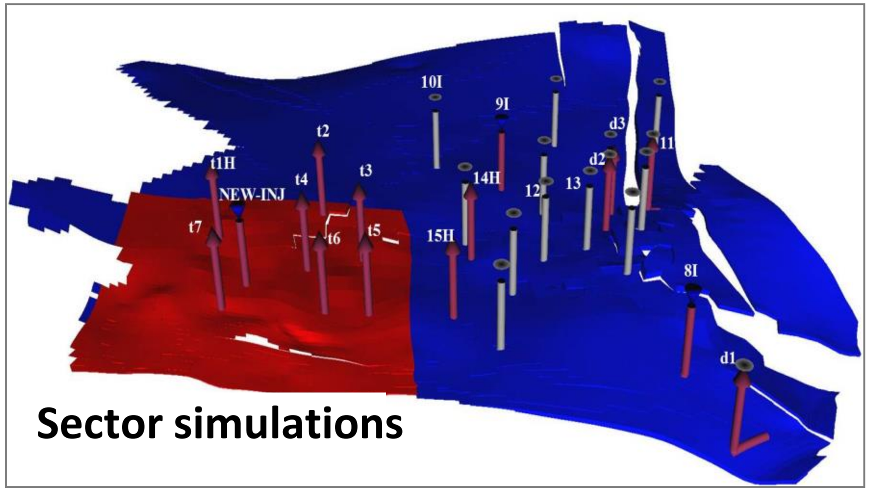
Project in Egypt: On-Shore Field

- **Reservoir Characterization:**
  - Giant brown field - **12 reservoirs**, on–shore sandstone environment
  - **High salinity**, high temperature
  - **Medium-viscous oil** (20 °API) with 3-8 cP viscosity @ RC
  - Start-up in **1955**, peripheral sea water injection **since 1985**
  - More than 400 wells

- **Low Salinity History:**
  - **2011 R&D chemical EOR** project: **low salinity water & polymer**
  - **2012-13 screening, corefloods, dynamic modeling**
  - **2014 SWCTT** with low salinity: robust interpretation
  - **2016** inter-well test pilot start-up
  - **2017**
    - Pilot monitoring ongoing
    - New reservoir study ongoing to plan future full field EOR extension
    - Phased EOR Approach

Rejuvenation program for a giant brown field

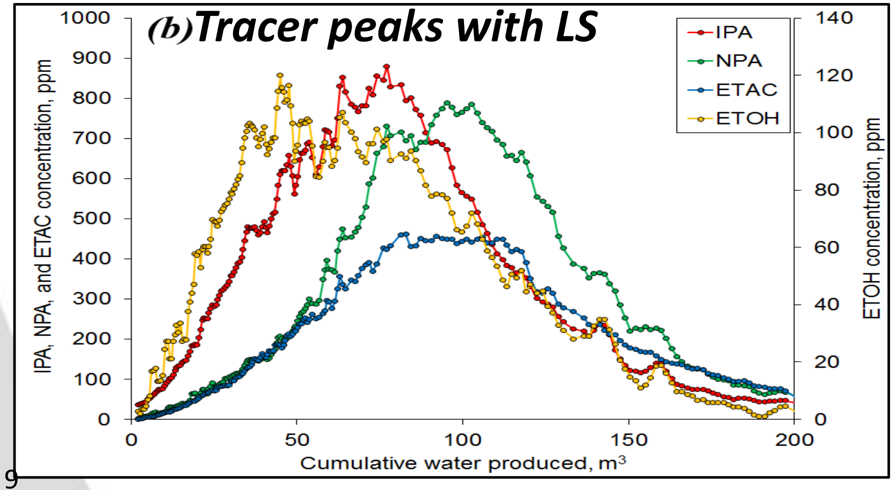




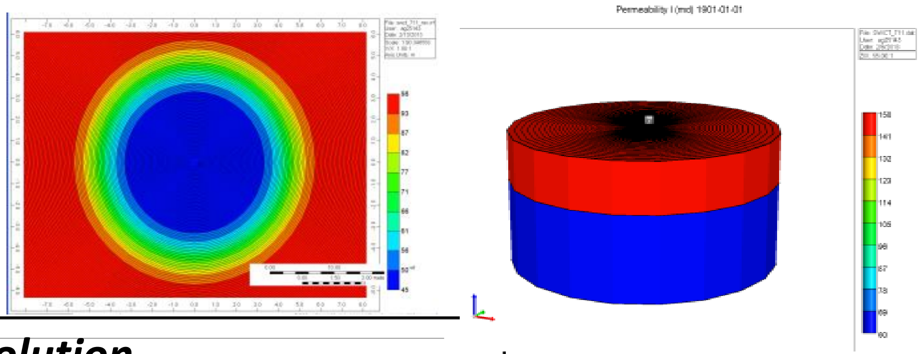
Project in Egypt: SWCTT Pilot Results & Interpretation

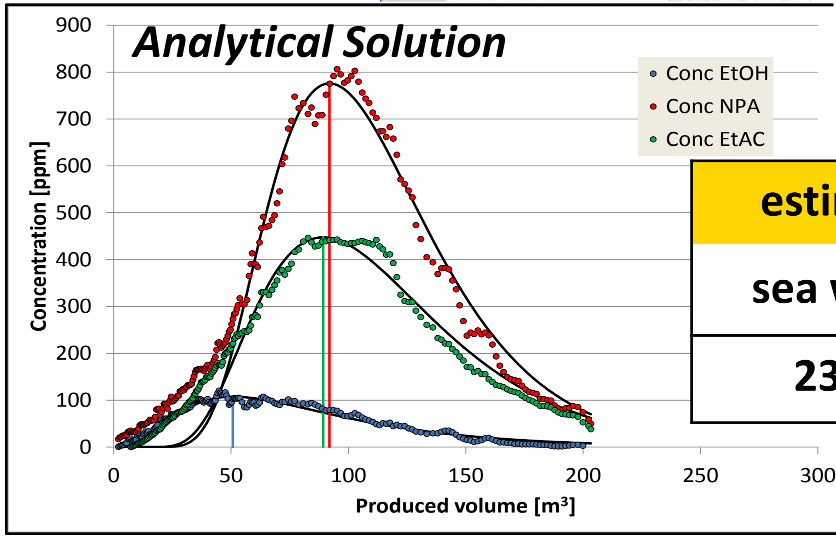
- Two **SWCTTs** in 2014 - clear effects of low salinity with **Sor reduction of 5-9 saturation units**
- 6 PV of **sea water pre-flush** and 6 PV of **low salinity** (mix of osmotic water with sea water)
- **Challenging tests** with **non-ideal tracer peaks**: contribution of secondary layers→ numerical simulation required to confirm analytical solution

Field layout



Simulation

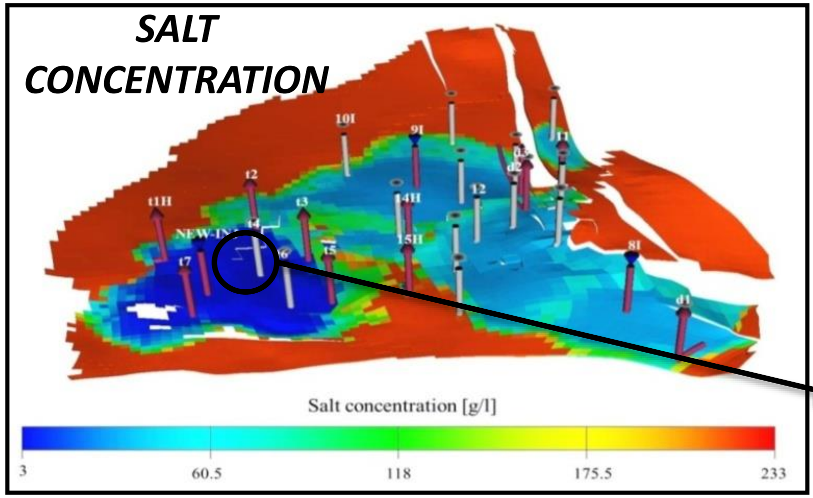


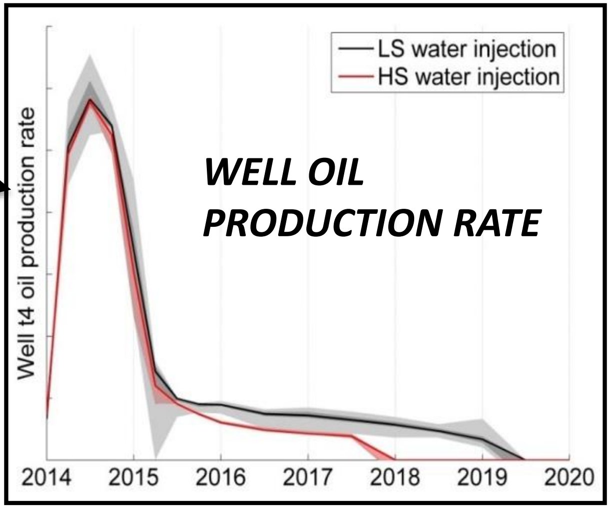


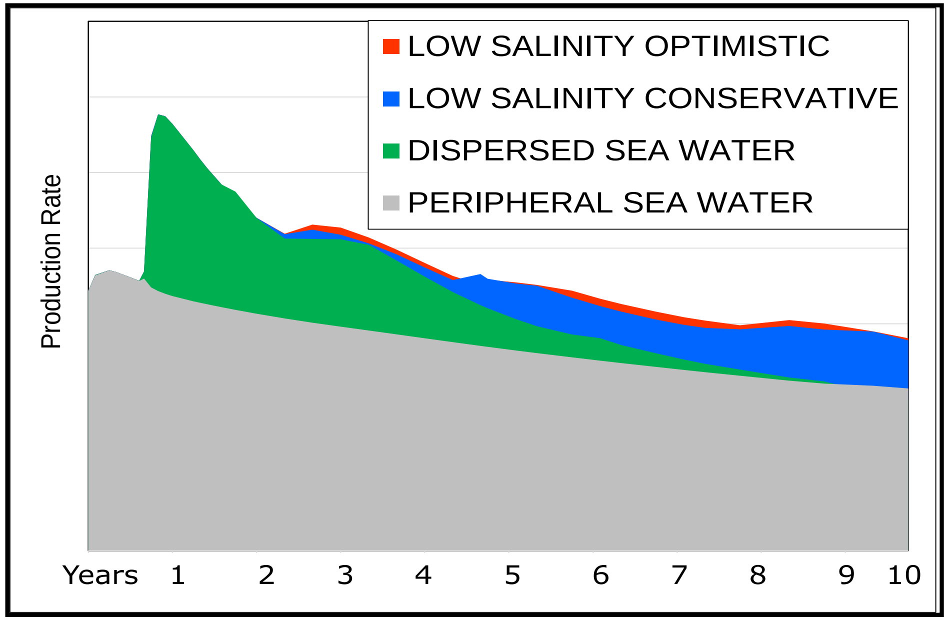
estimated residual Sor %	
sea water	low salinity
23 ±3	18 ±4

Project in Egypt: Inter-well Pilot

- **Inter-well trial to evaluate low salinity at a larger scale** - screening criteria:
  - **Fluid/Rock properties favorable for low salinity effects: mixed wettability, proper initial salinity and pH**
  - Already flooded area with dispersed injection scheme - connected high WCT producers in the zone
- **Sector model simulations** - scaling of low salinity parameters from core tests/SWCTT results to reservoir scale
- **Uncertainty quantification** studies and **multiple realizations approach** for robust forecast scenarios and increase power of prediction
- **Combination of low salinity with polymer**

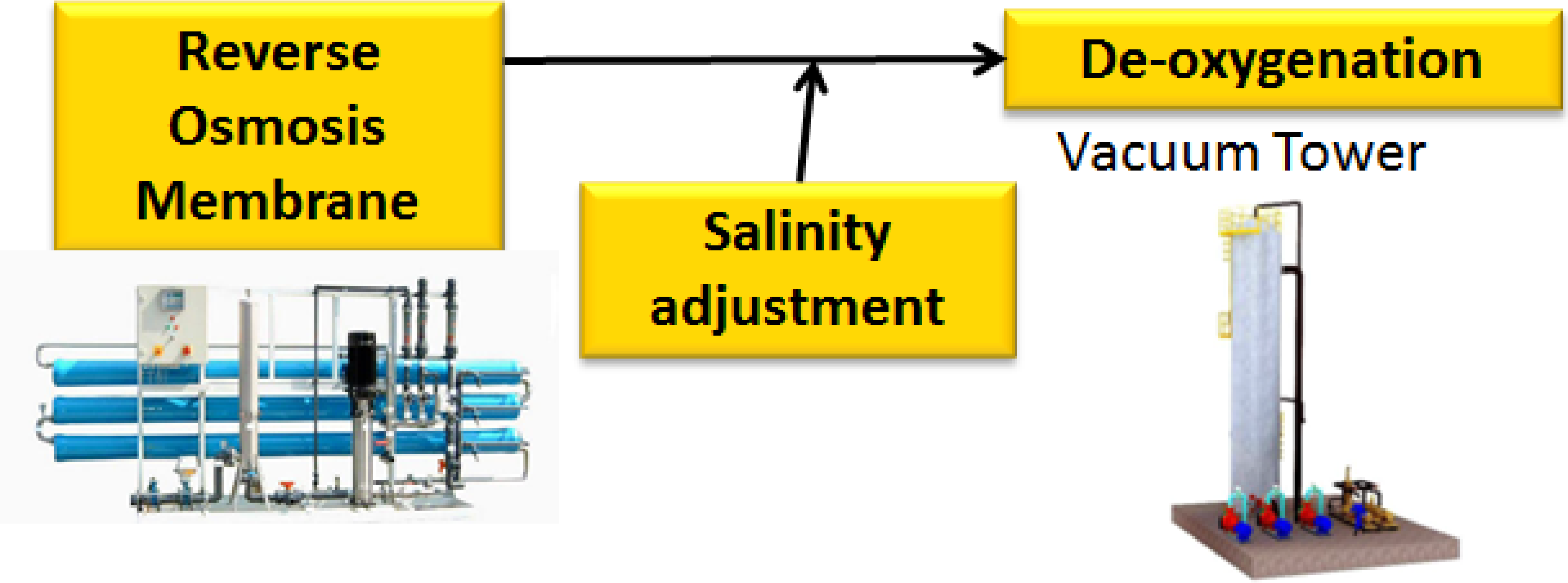






Project in Egypt: LS pilot test currently on-going

- Being among the **fewest chemical EOR projects ongoing in Africa**
- **Desalination plant for civil purposes upgraded for EOR: Synergic integration with existing facilities** for project cost reduction
- Low salinity target **1 g/l**, by salinity adjustment stage (osmotic water + sea water)



Conclusions & Way-Forward

- **Conclusions:**
  - **Eni** considers **low salinity water a key EOR method** to improve oil production in many company's assets
  - A robust **internal workflow** was developed to evaluate low salinity EOR performance at different scale
  - Several assets selected for low salinity EOR studies and currently the **1st Inter-well Pilot is ongoing in North Africa (brown giant oil field)**
  - In **11 years experience**, foundations for successful full field implementations were established to increase field RFs

- **Way-forward**
  - **Continous Research & Process Optimization**: tailoring water composition for clastic and carbonate reservoirs, low salinity + polymer investigation
  - **New Reservoir Studies** incorporating low salinity option in new generation simulators
  - **Full Field Implementation** integrating desalination equipment in existing facilities

Cooperation

Integrated work

KEY SUCCESS FACTORS

Sharing technical issues

Know How

Research questions

- All reservoirs have unique rock mineralogy, oil and formation brine composition. These properties vary within the reservoir
  - No EOR fluid will work in all reservoirs
  - Important to use core material that is representative for the specific reservoir
    - How can we determine that initial wettability is correct?
    - Study all aspects of a water flood with representative core material, i.e. imbibition, viscous flooding, compaction and mineralogy alteration
  - Understand which mechanisms are important on field scale

The National IOR Centre of Norway

Research questions

- We need to understand why or why not something works in the lab. And why may it or may not work at field scale. Need to use a practical starting point in the lab
- Important to develop modelling tools to improve the understanding on how injected fluids with specific compositions will affect reservoir mineralogy, temperature gradients, wettability alteration
- Make a library/database over effects of different fluids on different rocks etc.. LoSal: Perhaps not suitable as tertiary recovery method? Is there a limit for when LoSal works: 50 000 ppm?
- Can we predict Rel Perm? Dynamic saturation?

Pilot/reservoir management group

- IOR methods work in the lab (upscaling is on its way)
  - Need large scale testing
  - In many cases uncertainty is reduced by having an on-shore pilot
- Improved work-flow:
  - Instrumentation in new fields
  - Integrated model, reservoir model + economic evaluation
  - Include all important uncertainties in the ensemble based HM: e.g. wetting conditions
  - Work-flow and optimization, injection strategy
- Feasibility and safety
  - Environmental aspect of the pilot
- Data
  - Need all types of data
  - Tracer is a good idea, need data!
    - Simulate weak tracers on field scale
    - Explore different scales
- Pilot test to validate the tools, **IOR Centre: Implementation of reservoir model, going from the lab to field.**

Smart Water Workshop

Stavanger, 14 September 2018

Eni- NIOR Center

Smart Water Workshop

- Workshop on Smart Water at Quality Hotel Pond, **Stavanger**
- Workshop was leaded by eni (**Martin Bartosek** and **Paola Ceragioli**)
- **48** participants from industry and research.
- Participating industry **partners**:

equinor eni ConocoPhillips eni norge DEA TOTAL Schlumberger AkerBP IFE Universitetet i Stavanger IRIS The National IOR Centre of Norway wintershall

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Agenda

- ***9:00-10:30***
  - **1**. Highlights from The National IOR Centre of Norway - What do we know now regarding Smart Water flooding that we did not know four and half /
  - **2**. From the Centre - What is missing in our understanding of Smart Water flooding
- ***10:30-10:45***
  - **3**. From the Industry Partners - What is missing in our understanding/implementation of Smart Water flooding?
- ***10:45-11:00*** Coffee Break
- ***11:00-12:00***
  - **3**. From the Industry Partners - What is missing in our understanding/implementation of Smart Water flooding?
- ***12:00 -13:00*** Lunch with Discussion
- ***13:00 -13:45***
  - **4**. Group working
- ***13:45-14:00***
  - **5**. Presenting the results and sum up the Workshop

1. and 2. : The National IOR Centre Presentations - Experimental issues

- It was confirmed the fundamental role of wettability alteration towards water-wetness for low salinity performances:
  - *Essential is the knowledge of initial reservoir wettability, which strictly depends on the core pre-treatment;*
  - *Understand all the main processes, with their corresponding crucial variables, affecting wettability changes.*
- Imbibition's mechanism is essential to oil recovery:
  - *Spontaneous imbibition tests has been reported as the most suitable experiment to study smart water performances.*
- Crucial role of initial formation water's pH and the reliability of its measurement:
  - *All the measurements needs to be carried on at the same time;*
  - *If possible, measurements should be performed immediately after the water sampling; otherwise, the sample should be sealed as soon as it is picked up and the measurements can then be performed in the laboratories;*
  - *Still under discussion is how to obtain pH 's estimate at reservoir conditions.*
- Identify the parameters/processes that need to be included in reservoir models and simulation tools.

1. and 2. : The National IOR Centre Presentations - Modeling issues

- **IORCoreSim**, which is devoted to simulate relevant laboratory experiments, with the main involved processes:
  - *Spontaneous imbibition experiments with different boundary conditions*
  - *Diffusion, which is allowed also across core surface boundary, depending on saturation and temperature.*
  - *Flexible empirical interpolation model for Leverett's saturation functions (relative permeability and capillary pressure).*
- **IORSim**, which is a geochemical module to simulate reservoir geochemistry:
  - *It performs geochemical calculations conformal to those performed by PHREEQC;*
  - *It can be coupled to Eclipse;*
  - *Flexible interpolation model for Leverett's saturation functions (relative permeability and capillary pressure).*
  - *It takes into account pH changes, Surface potential, Adsorption, Ion exchange, Mineral dissolution/precipitation.*
- **4D seismic data,** Developed tools necessary for history matching utilizing 4D seismic data
  - *Methodology successfully demonstrated on first real field data set*
- **Upscale**
  - *Molecular diffusion time scales need to be changed (and lowered) for upscaled systems.*
  - *Geochemical reactions should also be set differently at different scales.*
- **Higher order simulation**
  - *Ongoing implementation of higher order finite volume methods for polyhedral grids (FI) in open source code OPM.*

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3. : Industry Partners Contribution

- **Equinor:**
  - **Main presented points:**
    - *Core treatment: strong differences between the experiments carried on "preserved" cores (only initially flooded by reservoir oil) and "not preserved core" (cleaned);*
    - *Initial wettability and restoration as a key factor to be understood and take into consideration.*
  - **Suggestion for NIOR:**
    - ***Experimental:***
      - Proper determination of initial wetting and understanding on the aspects by which is affected;
      - Further insight into interaction among rock minerals, oil and water components under physical reservoir conditions and more capabilities, both imaging and modelling, about for Pore-scale phases distributions.
    - ***Modeling:***
      - Pore-scale imaging and modeling of phases distributions (wettability).

3. : Industry Partners Contribution

ConocoPhillips

- **Conoco-Philips**
  - **Main presented points:**
    - Comparison between field and laboratories results: ion concentration in the produced water was in agreement with laboratory predictions.
  - **Suggestion for NIOR:**
    - Need to demonstrate the potential for smart water to achieve also low residual oil saturation
- **eni**
  - **Main presented points:**
    - Eni considers low salinity water a key EOR method to improve oil production in many company's assets
    - A robust internal workflow was developed to evaluate low salinity EOR performance at different scale
    - Several assets selected for low salinity EOR studies and currently the 1st Inter-well Pilot is ongoing in North Africa (brown giant oil field)
    - In 11 years experience, foundations for successful full field implementations were established to increase field RFs
  - **Suggestion for NIOR:**
    - Continuous Research & Process Optimization: define the optimal smart water composition for clastic and carbonate reservoirs

- **Wintershall**
  - **Main presented points:**
    - Initial wettability important
    - Should agree on initial wetting, core preparation and cleaning procedures
    - Important with field cases. Data from single well tests should be used to calibrate models
- **Total**
  - **Main presented points**
    - Wettability and initial wetting state. Wetting is changing within the reservoir
    - Mechanisms varies for different cases
    - Upscaling to get reliable predictions
- **Schlumberger**
  - **Main presented points**
    - Coupling of field scale simulators to lab scale simulators. Modelling and experiments hand-in-hand.
    - What type of measurements during EOR pilot? 4D experiments locally around well combined with tracer data, temperature data to evaluate effect of smart water injection

4. : Group Working

- **The participants divided in 3 groups based on individual choicesas:**

	Laboratory Group
1	Roar Kjelstadli
2	Luis Genolet
3	Leili Moghadasi
4	Patrizia Pisicchio
5	Dag Standnes
6	Åsmund Haugen
7	Christian Burmester
8	Ingebret Fjelde
9	Udo Zimmermann
10	Mona Wetrhus Minde
11	Reidar Korsnes
12	Christian Dye
13	Sissel Opsahl Viig
14	Edvard Omdal *

	Modeling
1	Vladimir Volkov
2	Robert Moe
3	Patrick Kowollik
4	Jarle Haukås
5	Martina Sambiase
6	Paola Ceragioli *
7	Niels Lindeloff
8	Arne Stavland
9	Jan Ludvig Vinningland
10	Robert Klöfkorn
11	Aruoture Voke Omekeh
12	Aksel Hiorth
13	Pål Østebø Andersen
14	Svein Magne Skjæveland
15	Doani Selvaggi
16	Caterina Topini

	Pilot/Reservoir Managment
1	Are Manneråk
2	Ana Todosijevic *
3	Lars Sønneland
4	Siroos Salimi
5	Alessandro Botteon
6	Martin Bartosek
7	Johanna N. Ravnås
8	Geir Nævdal
9	Randi Valestrand
10	Udo Zimmermann
11	Steinar Sanni
12	Remya Nair
13	Merete Vadla Madland

** Team leader*

5. : Presenting the results and sum up the Workshop

- **Laboratory Group:**
  - Core Pre-Treatment;
  - Crucial role of crude oil, formation water, rock mineralogy, reservoir temperature;
  - Importance of pH alteration during the core flooding test;
  - Optimal ion composition for smart water.
- **Modeling Group:**
  - Proper measurements of experimental relative permeability curves, possibly based upon also larger core; samples in order to provide indication of possible behavior in front of some inhomogeneity;
  - Exhaustive scientific framework to account of relative permeability variations;
  - Upscale issues (geochemical reactions, diffusion, flow rates, …);
  - Presence of fractures properly taken into account.
- **Pilots/field and reservoir management Group:**
  - IOR methods work in the lab (upscaling is on its way): need large scale testing;
  - Improved work-flow:
    - Instrumentation in new fields;
    - Integrated model, reservoir model + economic evaluation;
    - Work-flow and optimization injection strategy;
  - Feasibility and safety;
  - Data Quality;
  - Pilot test to validate the tools, IOR Center: implementation of reservoir model, going from the lab to field.