«Smart Water» EOR in carbonate and sandstone reservoirs, new reservoir screening techniques to evaluate increased oil recovery potential

Joining forces 2016

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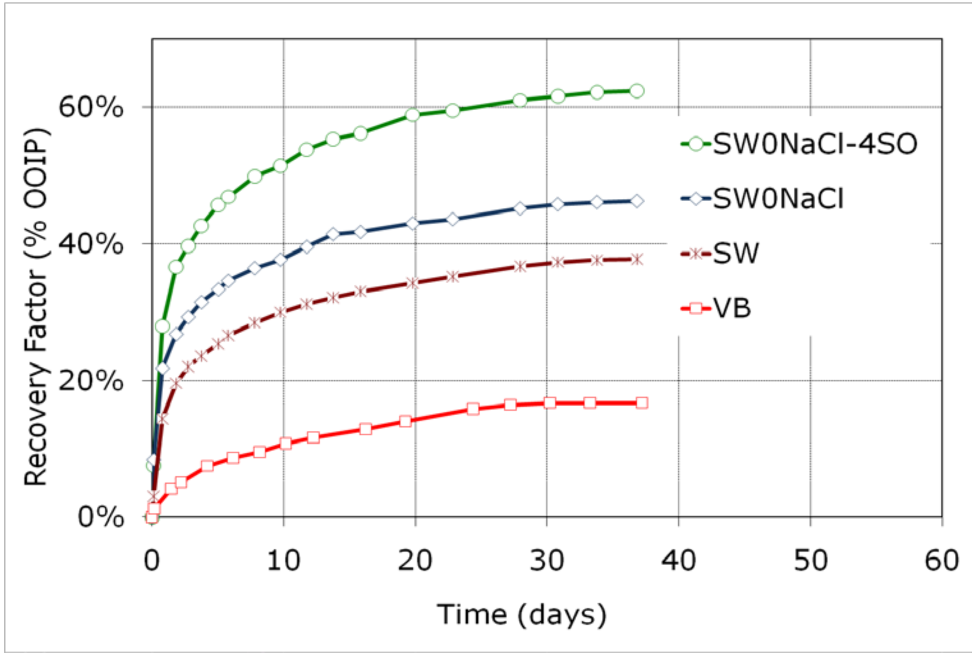
«Smart water» EOR in Carbonate

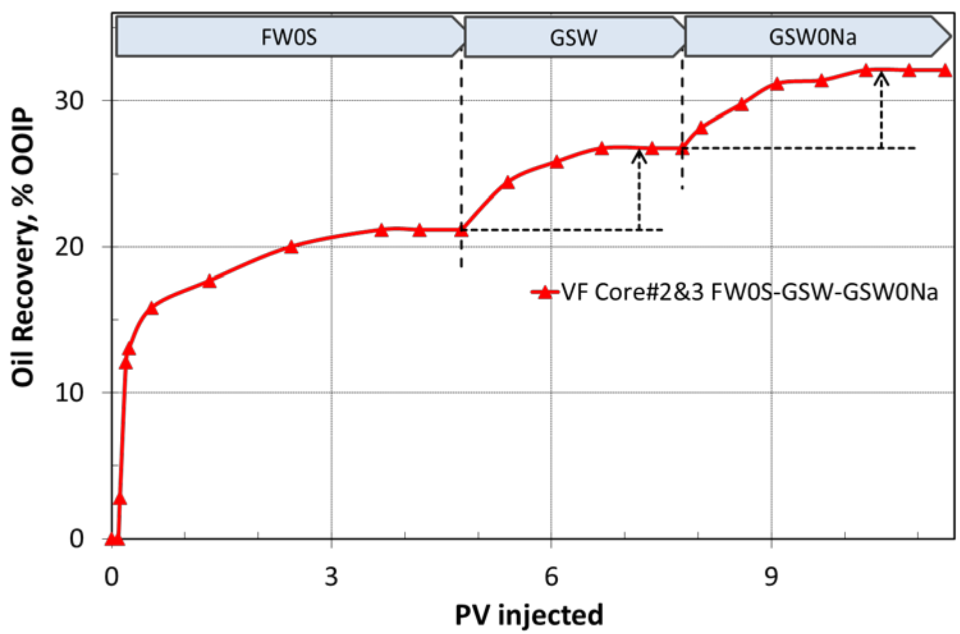
- Spontaneous imbibition in Chalk: K = 3-5 mD: S_{wi}=10%, Crude oil AN=0.5, T_{res}=90 ^{o}C;;



- Formation water: VB
- Seawater: SW
- Seawater depleted in NaCl
- Seawater depleted in NaCl and spiked with 4x sulfate

«Smart water» EOR, Reservoir Limestone

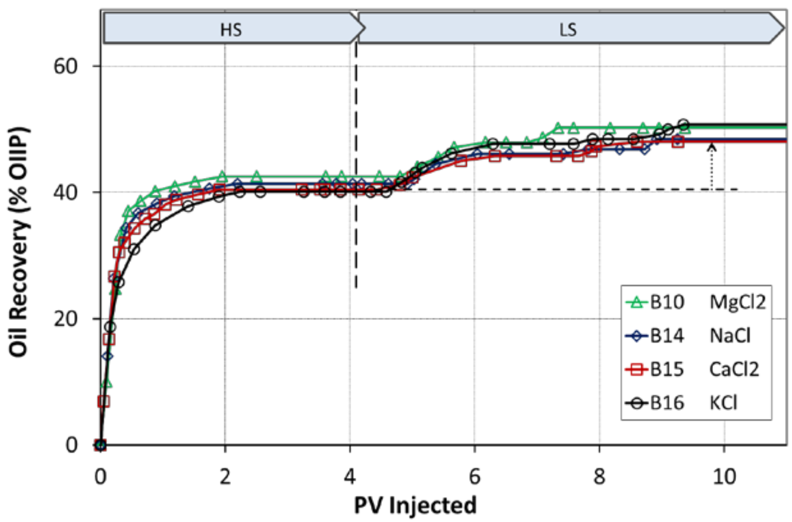
- Oil recovery by forced displacement at 100°C
  - Composite limestone reservoir core.
    - Swi = 10%. Reservoir Crude Oil.
  - Brine injection:
    - FW0S - GSW - SW0Na
    - Injection rate: ≈ 0.6 PV/D (0.01 ml/min)

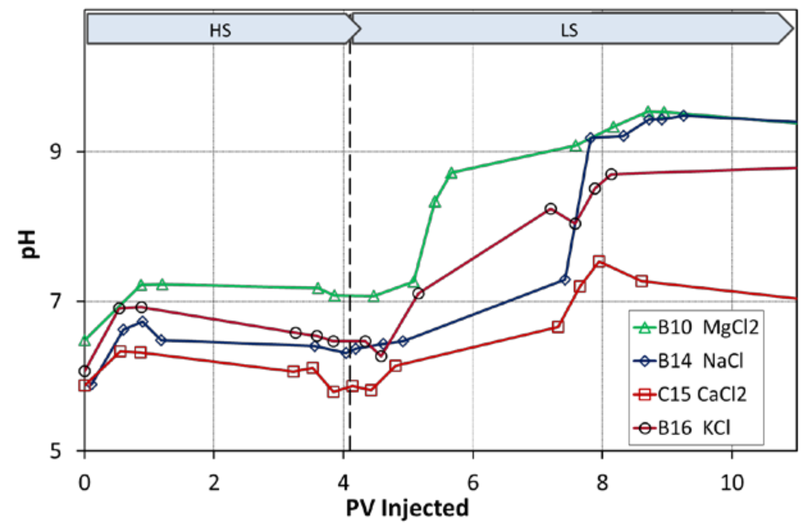


«Smart water» EOR in Sandstone

- Outcrop cores
  - Swi = 20%
  - Crude Oil with high BN
- Viscous flooding@40°C:
  HS - LS

Ions	HS mM	LS1 - NaCl mM	LS2 - $CaCl_2$ mM	LS3 - KCl mM	LS4 - $MgCl_2$ mM
Na+	1540.0	17.1	3.1	0.0	3.1
K+	0.0	0.0	0.0	17.2	0.0
Ca2+	90.1	0.0	4.7	0.0	0.0
Mg2+	0.0	0.0	0.0	0.0	4.7
TDS, g/l	100	1	0.7	1.28	0.63
IS	1.810	0.017	0.017	0.017	0.017



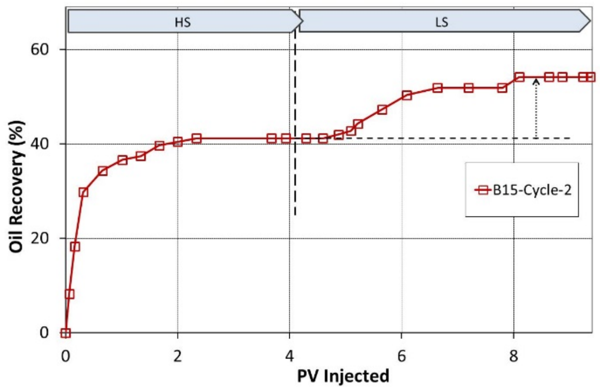


- ➢ Tertiary LS EOR effects observed for all LS Brines
  - ➢ Increased pH for all LS brines

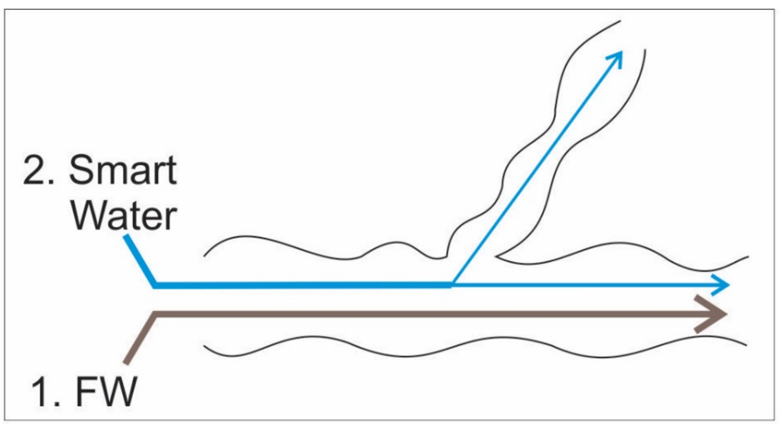
What is «Smart Water» ?

- «Smart water» improves wetting properties in oil reservoirs and optimize fluid flow/oil recovery in porous medium during production.
- «Smart water» can be made by modifying the ion composition.
  - No expensive chemicals are added.
  - Environmental friendly.
- Wetting condition dictates:
  - Capillary pressure curve; $P_c=f(S_w)$
  - Relative permeability; k_{ro} and k_{rw} = f(Sw)

How does «Smart Water» work?



- ✓ Minor changes in O/W IFT
- ✓ Same pore distribution, r = k
- ✓ Unfavorable sweep with LS
  - ✓ LS viscosity lower than HS
  - ✓ Still increased recovery
- ➢ Increased Microscopic Sweep



Wettability alteration towards more Water wet

$P_C > 0 \rightarrow$ Imbibition

Increased Microscopic sweep efficiency

$$P_c = \frac{2\,\sigma\,cos\theta}{r}$$

Reservoir Chemistry

- Chemical reactivity are temperature dependant. Reservoir Chemistry controlled by:

Crude oil

- Polar organic acids
- Polar organic bases

Brine

- Formation Water salinity and Ion composition
- Injection Water salinity and Ion composition

Rock

- Mineral surface reactions
- Carbonate
- Sandstone

- Reservoir Chemistry effects:
  - Initial Reservoir wettability
  - wettability alterations by «Smart Water»
  - Scaling

Crude Oil chemistry

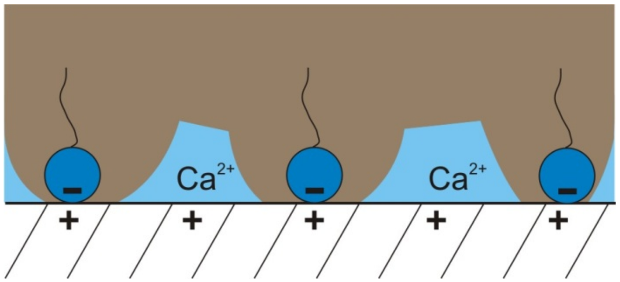
- Crude oil consists of thousands of different components:
  - Liquid fraction
  - Resins
  - Asphaltenes

Contain polar organic molecules

⇩

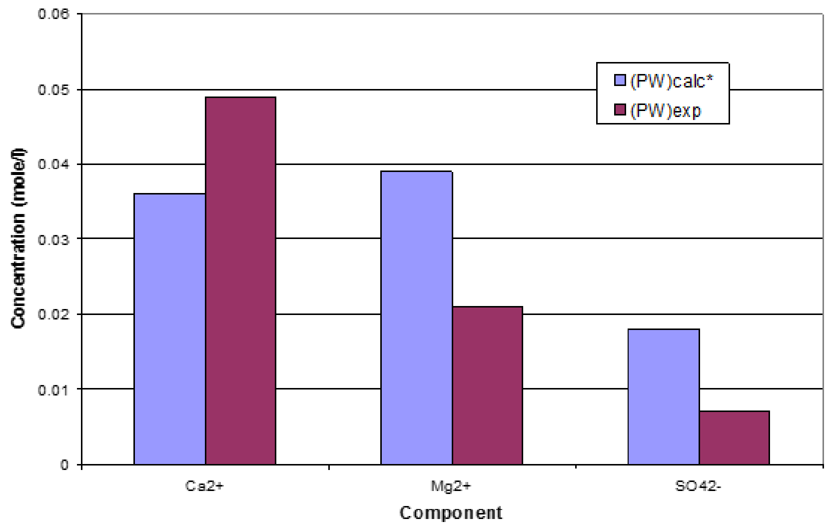
- Polar Organic Bases :
  $R_3NH^+ \leftrightarrow H^+ + R_3N$ pKa ~4.5-5
- Polar organic Acids :
  $RCOOH \leftrightarrow H^+ + RCOO^-$ pKa ~4.5-5

- ➢ Surface reactivity of Polar organic Acids and Bases are pH dependant
- ➢ Polar organic Acids and bases interacts with charged rock surfaces
- ➢ serve as anchor molecules for the Oil phase towards Rock surface



Brine chemistry

– Injection water disturbs the chemical equilibrium in the reservoir



Chemical interactions at Ekofisk, 130°C, During SW injection:

– PW contained 73.6 vol% SW and 26.4 vol%FW (based on Na Cl mass balance)

– Mg^{2+} substitutes Ca^{2+}

– SO_4^{2-} adsorbs (and precipitates $CaSO_4$ (S))

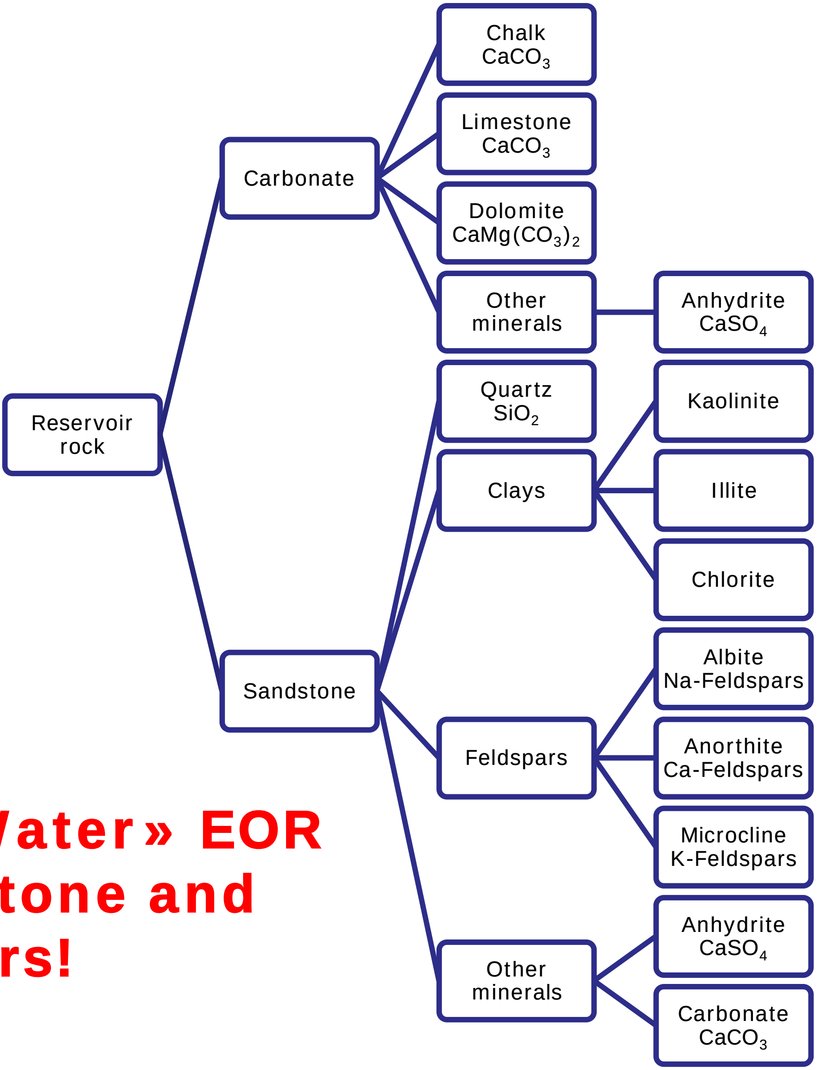
➢ **Field observations**
=
Laboratory observations

Rock chemistry

- Carbonates:
  - positive surface charge
- Sandstones:
  - negative surface charge

  - Different ions and chemistry involved
    - Initial wetting
    - Wettability alteration

➢ **Different «Smart Water» EOR chemistry in Sandstone and Carbonate reservoirs!**



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«Smart Water» EOR Group at UiS

- Systematically worked with the chemical understanding of «Smart Water» EOR effects:
  - Sandstone reservoirs
  - Carbonate reservoirs
- Outcrop core systems :
    - systems for Sandstone
    - Systems for Carbonate
  - Contributed Fundamental understanding of
    - Crude Oil effects
    - Mineral effects
    - FW effects
    - Wettability alteration effects by «Smart Water»

«Smart Water» EOR industry projects

- Reservoir systems screened for EOR effects:
  - More than 30 Carbonate reservoirs/formations
  - More than 10 Sandstone reservoirs/formations

Special thanks to :

BP, UK

Total, France & Total, Norway

Talisman, Norway

Talisman Synoptics, UK

Lundin, Norway

Saudi Aramco, Saudi Arabia

Petoro, Norway

TaQa, UK

Maersk, Qatar

Shell, Netherlands

Wintershall Holding GmbH, Germany

Wintershall Noordzee B.V.Northsee, Netherlands

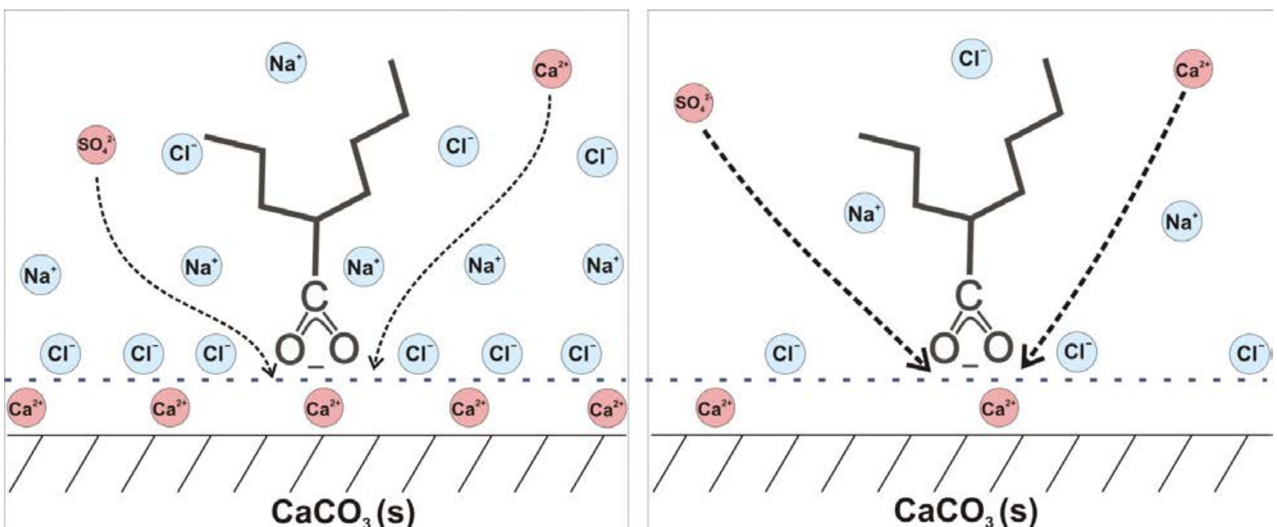
DNO,UAE

JSC "Zarubezhneft, Russia

«Smart water» EOR in Carbonate

-Chemical wettability alteration Mechanism

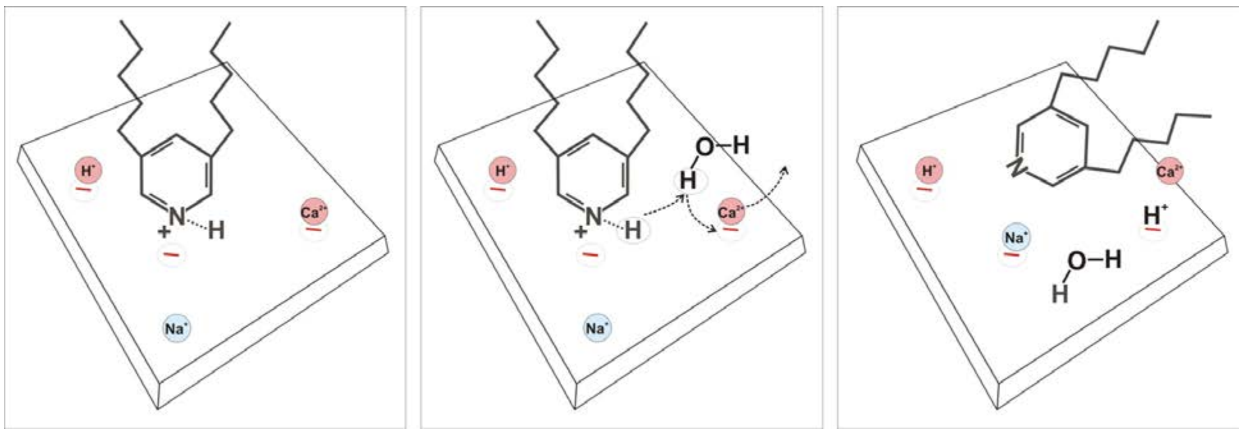
- Wettability alteration mechanism in Carbonates
  - Acidic components strongly attached to surface
  - Need to be chemically reacted away
    - Wettability alteration catalysed by SO_4^{2-}
    - Ca^{2+} interacts with the R-COO$^-$ and releases it from surface
      - R-COO$^-$ **---** Ca^{2+} bonding ~10 times stronger than
      - R-COO$^-$ - - Mg^{2+}
    - Reactivity increases with reduced salinity



«Smart water» EOR in Sandstone
-Chemical wettability alteration Mechanism

- Wettability alteration Mechanism in Sandstone
  - Clays are the main wetting mineral in Sandstone
  - Wettability alteration linked to pH increase, FW vs. «Smart water»

  Model for Basic polar organic material:



1. SPE 129767-PP, Tulsa 2010. Austad, et al.
2. Energy & Fuels 2011, 25, 2151-2162 RezaeiDoust et.al

  - Desorption of Cations by low salinity water (Rate determining step)

    $\text{Clay-}\ Ca^{2+} + H_2O = \text{Clay-}H^{+} + Ca^{2+} + OH^{-} + \text{HEAT}$

  - Wettability alteration induced by pH increase ,Basic material

    $\text{Clay-}R_3NH^{+} + OH^{-} = \text{Clay} + R_3N + H_2O$

«Smart Water» EOR potential
-Reservoir screening prosedure

- **3 stage «Smart water» EOR Screening of Reservoirs:**
  1. Desk evaluation on available reservoir data
     - Reservoir history
     - FW salinity and composition
     - Rock properies, Mineralogy
     - pore distribution/heterogenity
     - Crude Oil properties
     - Reservoir temperature

  ➢ Evaluating if the reservoir are a «Smart Water» Candidate

  2. Experimental Screening with reservoir cores and FW + inj. Brines
     - Surface reactivity tests on reservoir rock/core
       - Chemically induced Brine – Rock interactions
       - Possible Wettability effects

  ➢ Evaluating potential for wettability alteration by «Smart Water»

  3. Oil Recovery tests on preserved reservoir cores
     - Compare recoveries with Smart Water and other brines
       - Spontaneous imbibition
       - Viscous flooding
       - Secondary /Tertiary mode

➢ Conclude/evaluate «Smart Water» EOR Potential

Ongoing/planned Research activities:
- «Smart Water» EOR Group

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- «Smart Water» EOR activities :
  - Type of Reservoirs
    - Dolomitic reservoirs
    - Limestone /Chalk reservoirs
    - Sandstone Reservoirs
    - Shale Oil Reservoirs
  - Reservoir heterogenity
    - Pore distribution / tracer tests on cores
  - Minerals
    - Chemical reactivity of minerals
    - QuemScan project together with Drilling and GeoScinece group at UiS
      - Type of minerals and distribution at pore surfaces
  - Crude Oil properies
    - Polar components/Asphaltenes
    - Crude Oil/ brine IFT at reservoir conditions
  - Reservoir wettability
    - Crude Oil species with high surface affinity
    - Chemical Reactivity / Surface Charge of reservoir minerals
    - FW ion composition and salinity
    - Temperature effects

Ongoing/planned Research activities:
- «Smart Water» EOR Group

- – Core cleaning / core restoration prosedures
  - Cleaning solvents / fluids
  - Crude Oil sat. /readsorption of polar components
- – «Smart Water» EOR
  - Reactivity of pore wall Minerals
  - Wettability and wettability alteration mechanisms
  - Optimizing Smart Water EOR Brine compositions
  - Design of new «Smart Water» EOR fluids
- – PennState University Collaboration (Group of Prof. Russel Johns)
  - Modelling of Chemical Wettability alteration processes

- Combined techniques with «Smart Water»:
  - – EOR chemicals will influence Reservoir Chemistry:
    - Polymers
    - Nano-particles
    - Surfactants
    - New

➢ We are open for Industry Knowledge building projects:
- – Reservoir Evaluation of «Smart Water» EOR potential
- – in combination with Fundamental «Smart Water» EOR studies