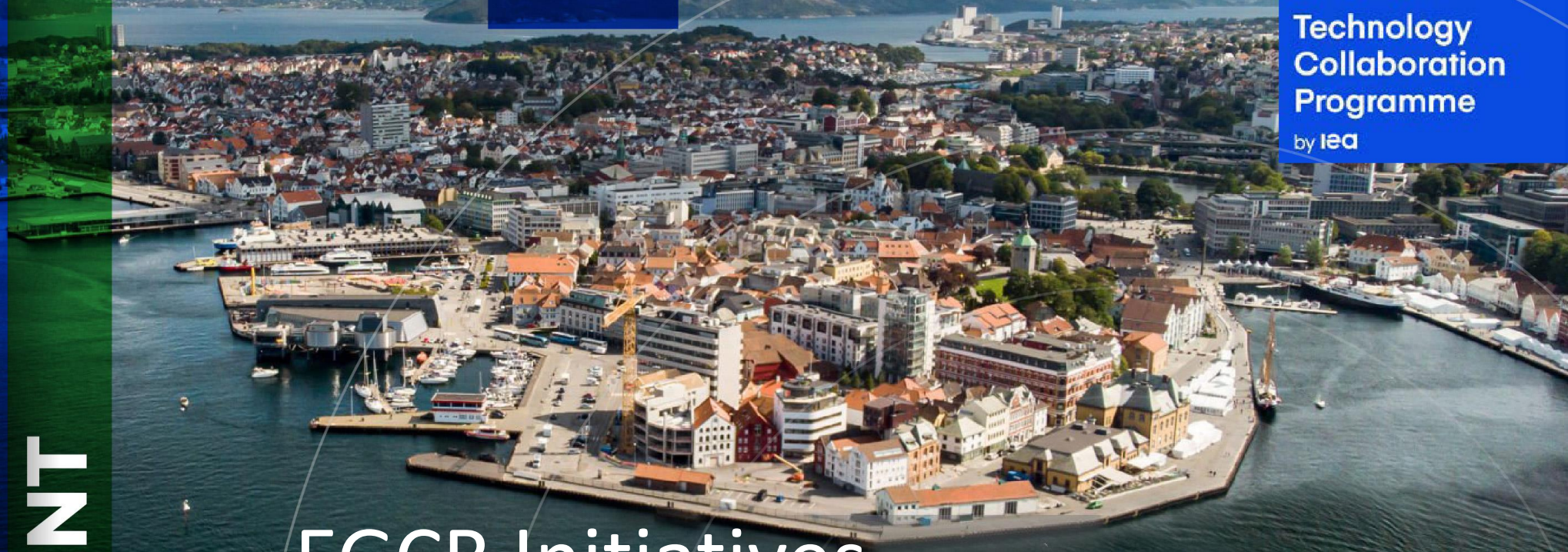
IEA EOR TCP

/// STAVANGER 2022

ANNUAL EVENT

21 – 24 Nov



Technology Collaboration Programme by iea

EGCR Initiatives

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Wintershall Dea AG, Germany

eor Enhanced Oil Recovery

wintershall dea

EGCR INITIATIVES

EGCR Definition

ENHANCED GAS/CONDENSATE RECOVERY (EGCR)

Application of low-cost technology in gas condensate reservoirs to remediate or avoid Condensate Blockage and Enhance the Gas and Condensate Recovery.

Enhanced Gas Condensate Recovery
A Digitalization & Technology Initiative

eor
Enhanced Oil Recovery

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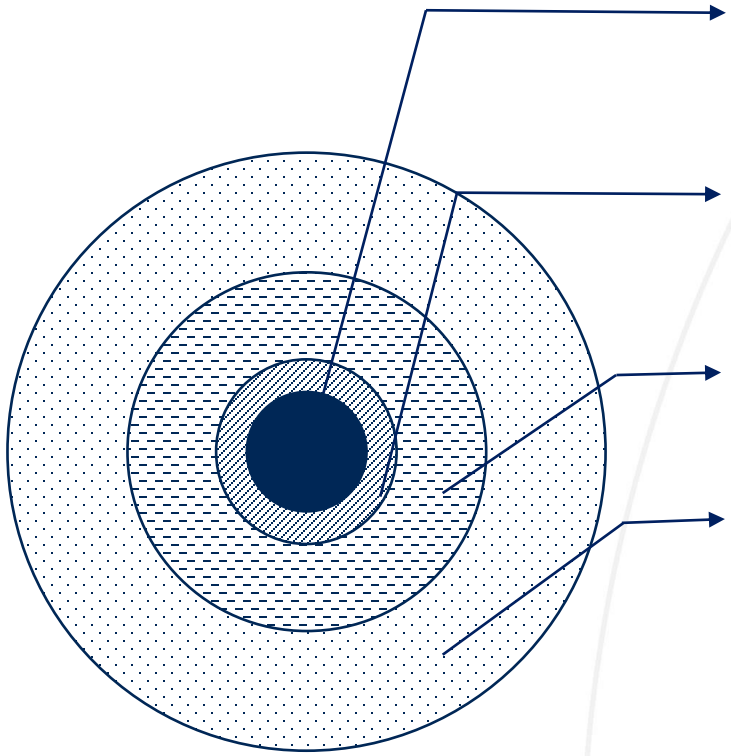
Condensate Blockage: Problem Statement

- Condensate dropout and blockage occurs when P_r or $P_{wf} < P_{dew}$
- Impacts gas well PI (deliverability) for both gas and condensate
- Maximum pressure drawdown occurs close to wellbore, maximum condensate dropout and blockage..!!



Region 4: Two Phase Flow Region
- Immediate Wellbore Vicinity
- Reduced Condensate Saturation
- Non-Darcy flow, high gas velocities
- Velocity Stripping effects; high N_c
- High IFT; Multiple imbibition/drainage cycles

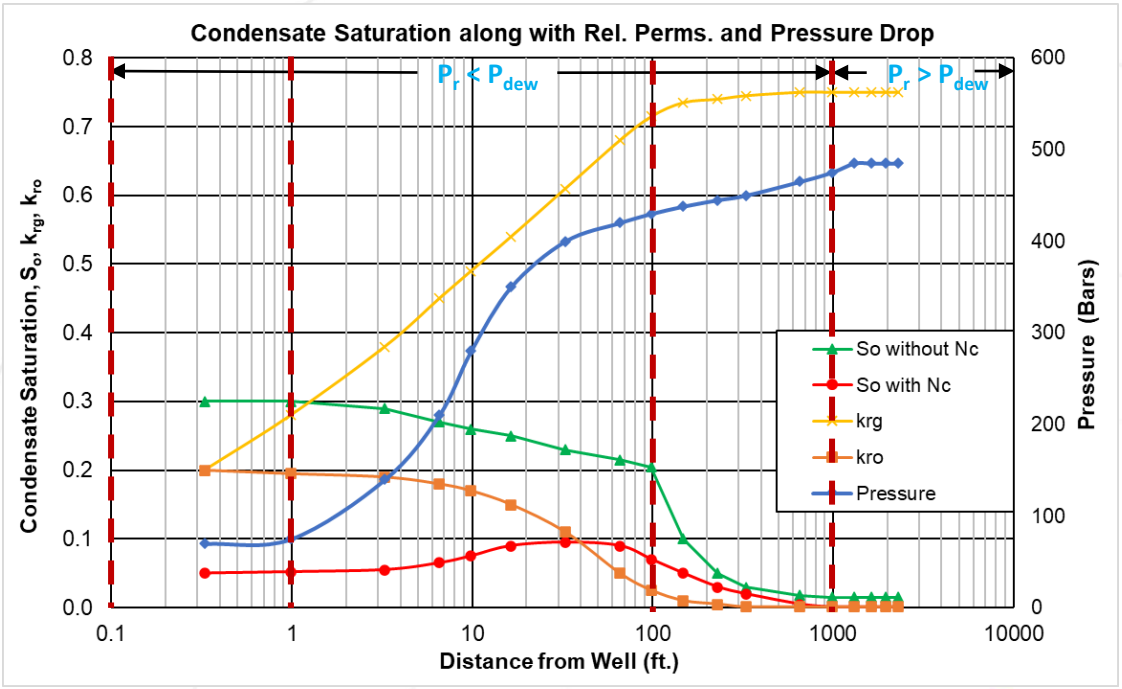
Key Problem Region..!!

Region 3: Two Phase Flow Region
- $S_o > S_{oc}$; up to > 100 ft.
- Steady State Flow
- Lower k_{rg}; reduced gas mobility
- Oil mobility controlled by k_{rg}/k_{ro}

Region 2: Single phase Gas Region
- Mobile Gas Phase
- Immobile Condensate Phase
- Low condensate saturation ($S_{oc} > S_o$)
- Below Dew Point Pressure

Region 1: Deep in Reservoir
- Single Phase Region
- Mobile Gas Phase
- Above Dew Point Pressure
- Low velocity, very low IFT
- Imbibition

Regions around the Wellbore



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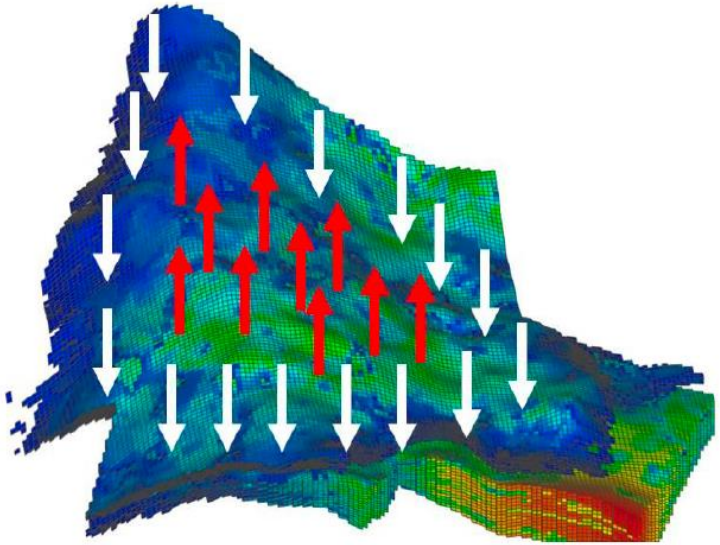
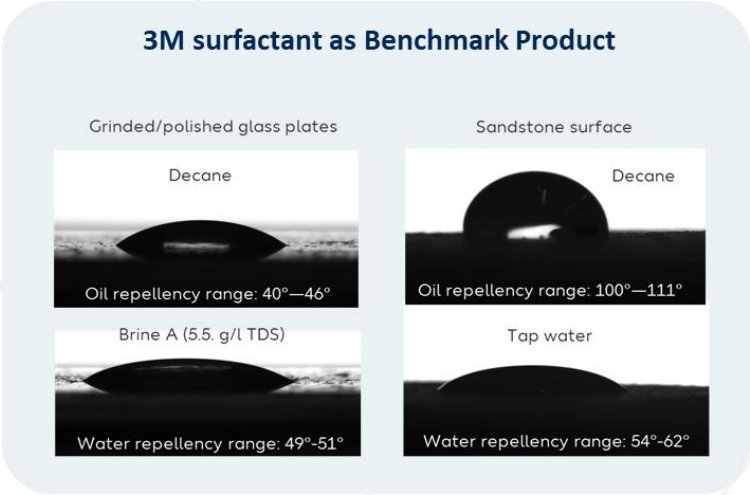
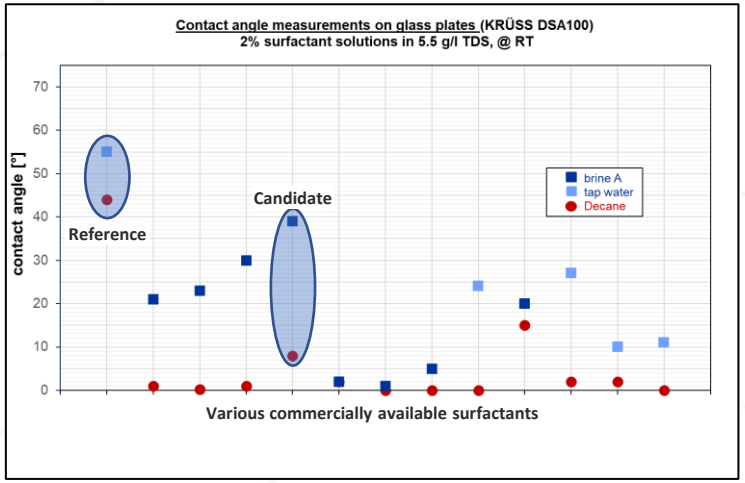
Screened Technologies

- Mitigation Options such as **Gas Cycling**, **Gas Injection** and **Wettability Altering Surfactants** evaluated







Gas Injection

- Huff'n'Puff application
- Dry gas injection
- Promising short-term results
- High operational effort
- Not economically viable

WAS results based on:

- Contact Angle Measurements
- Imbibition Test, Drainage Test
- Commercial Availability
- Environmental Aspects

- Screened over **20** commercial chemical formulations
- Good contact angles (CA) for water measured, no effect on oil
- *No suitable surfactant found*

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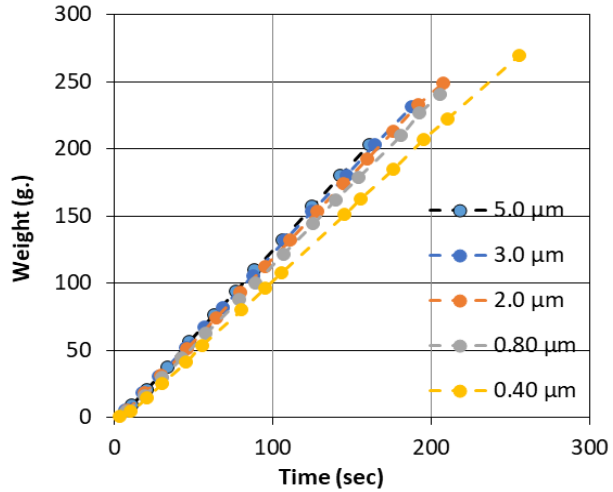
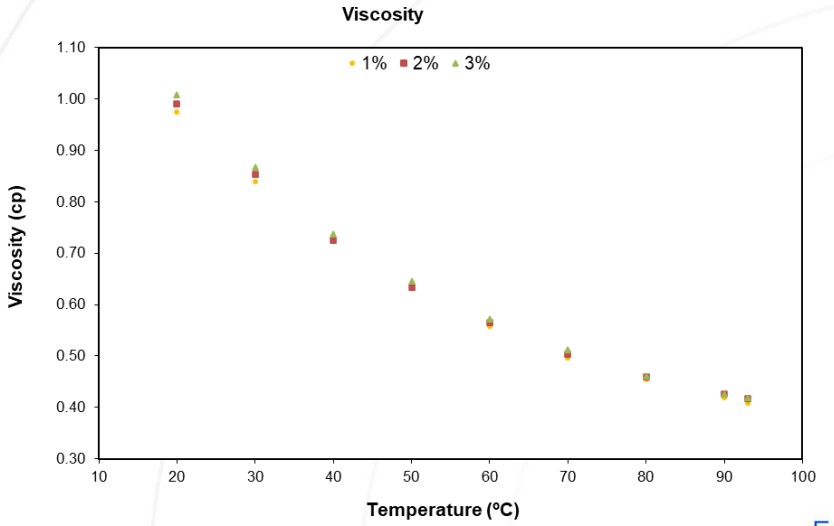
Focus on Nanofluids

- **What has been done ?**
  - Assessment of Nanofluids & alternate chemical systems
  - Seven different formulation tested till date
- **Treatment Type:**
  - Huff'n'Puff Injection in target wells (well squeeze)
- **Mechanism:**
  - Adsorption and wettability alteration
- **Selection Criteria:**
  - Long-term durability (high chemical and thermal stability)
  - Low operational implementation effort
  - Mostly cost effective and short pay-out time
  - Commercial Availability and Environmental Aspects
- **Key Characteristics:**
  - Solvent based chemical system
  - *PFOA* and *PFOS* free chemical formulation
  - Excellent Filterability, F.R. = 1 using 0.4µm polycarbonate filters





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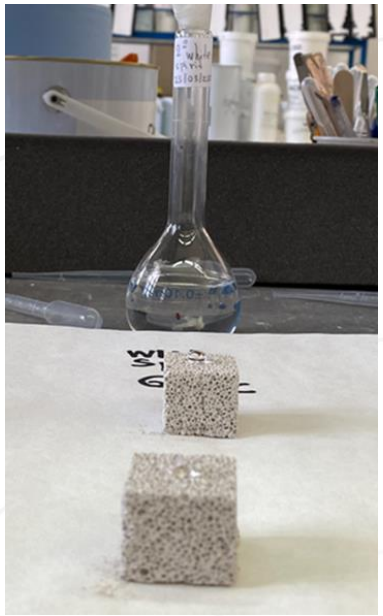
Qualification of Nanofluids

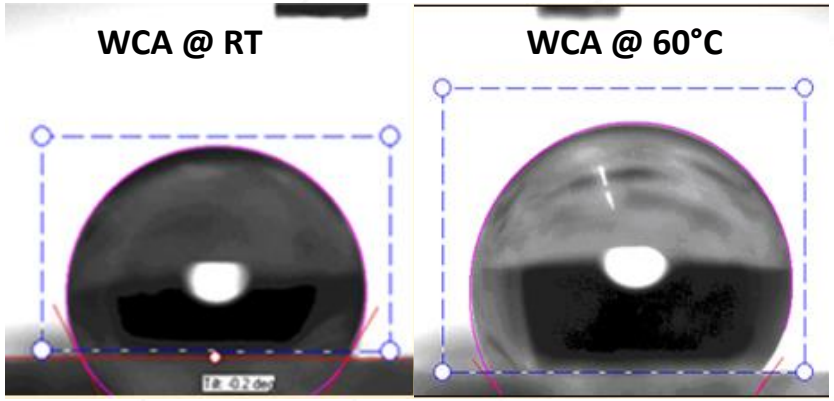
› How was it done ?

- Using outcrop cores (Berea) and model condensate systems
- Contact angle (CA) experiments performed on clastic rock samples
- Imbibition and drainage experiments performed on mini plugs
- Screening potential evaluated by 3D imaging analysis (using Digital Rock Technology)
- Proof of modified rel. perm. effect after treatment from HPHT experiments
- Standard corefloods to analyse impact of influencing parameters, e.g., S_{wi}
- Results incorporated into full field simulation models; treatment impact assessed



› What was the outcome ?

- *Product 'N'* showed promising results during all the different evaluations
- Robust business case validating the treatment concept



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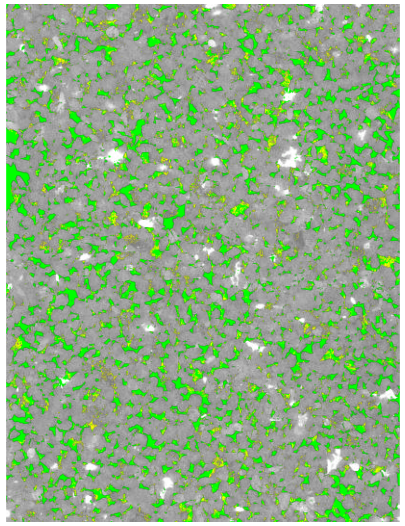
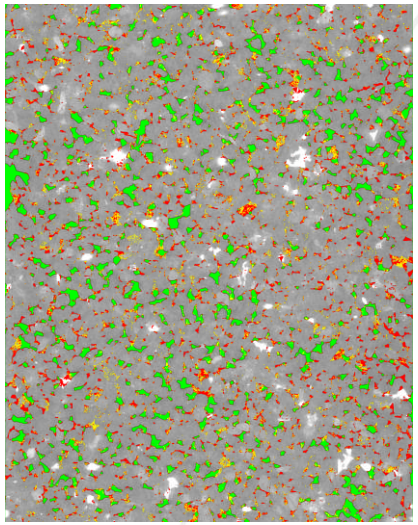
Digital Rocks – Image Analysis

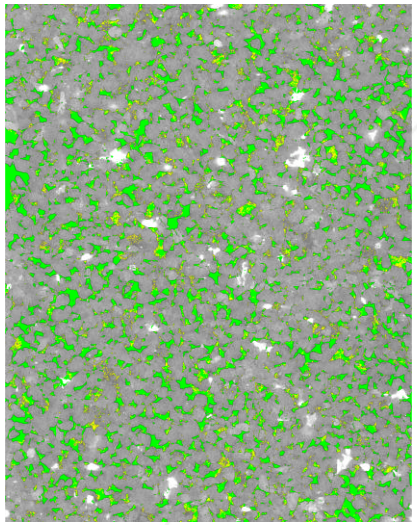
- Wettability change in Berea: Successful product 'N' treatment in *"remedial"* and *"preventive"* mode
- Residual gas saturation during forced imbibition lower than for untreated state
- Significantly higher gas(air) saturation after secondary drainage compared to untreated state



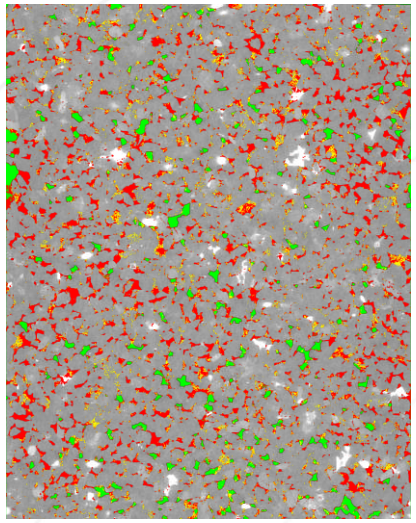
Untreated State



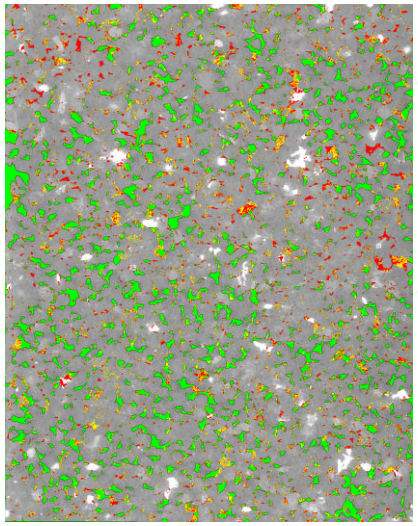
Spontaneous imbibition of oil - ***untreated***



Spontaneous imbibition of oil - ***treated***



Forced imbibition of oil by centrifuging



Secondary drainage of oil by air using centrifuging – ***treated***

Gas Oil Microporous

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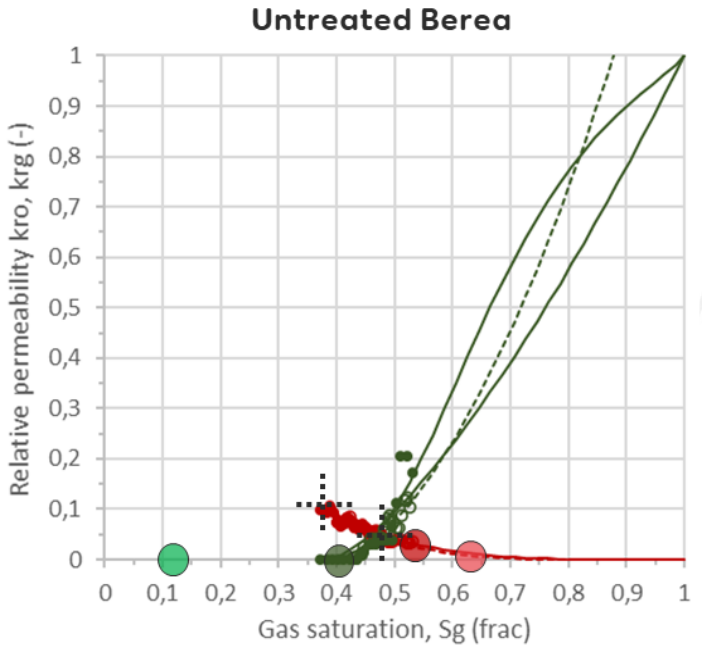
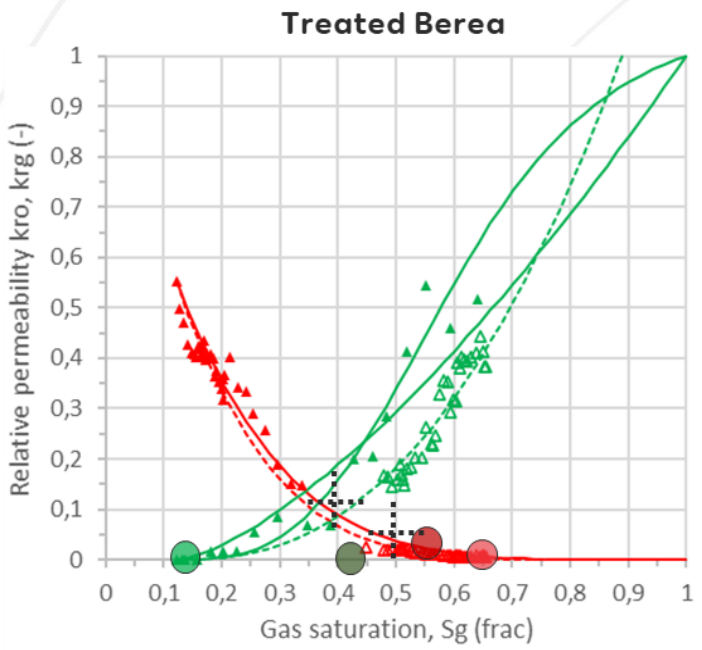
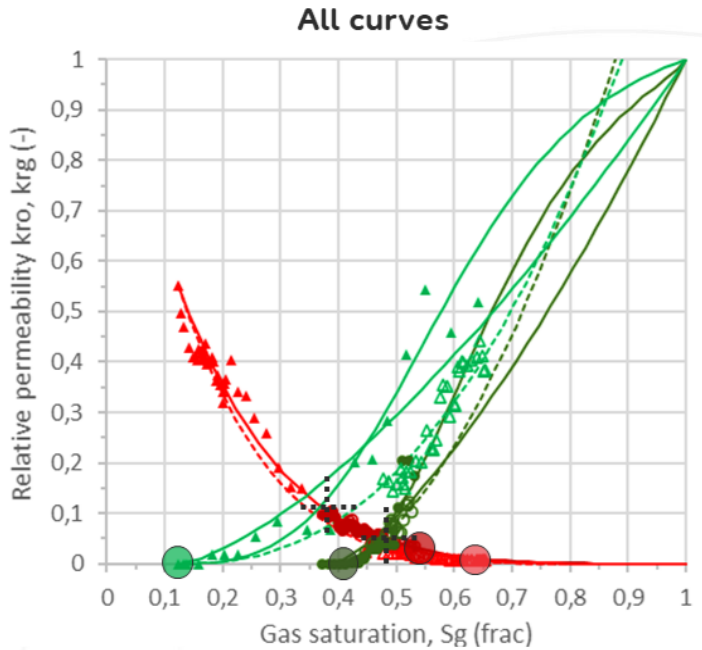
Digital Rocks – Relative Permeability Curves

- Calculated relative permeability curves from image analysis
- The simulation indicates gas flow at lower gas saturations
- Condensate flow is shifted to higher gas saturations
- The shifted crossover points also show the wettability change due to the treatment

Gas – untreated
Gas – treated
Oil – untreated
Oil – treated







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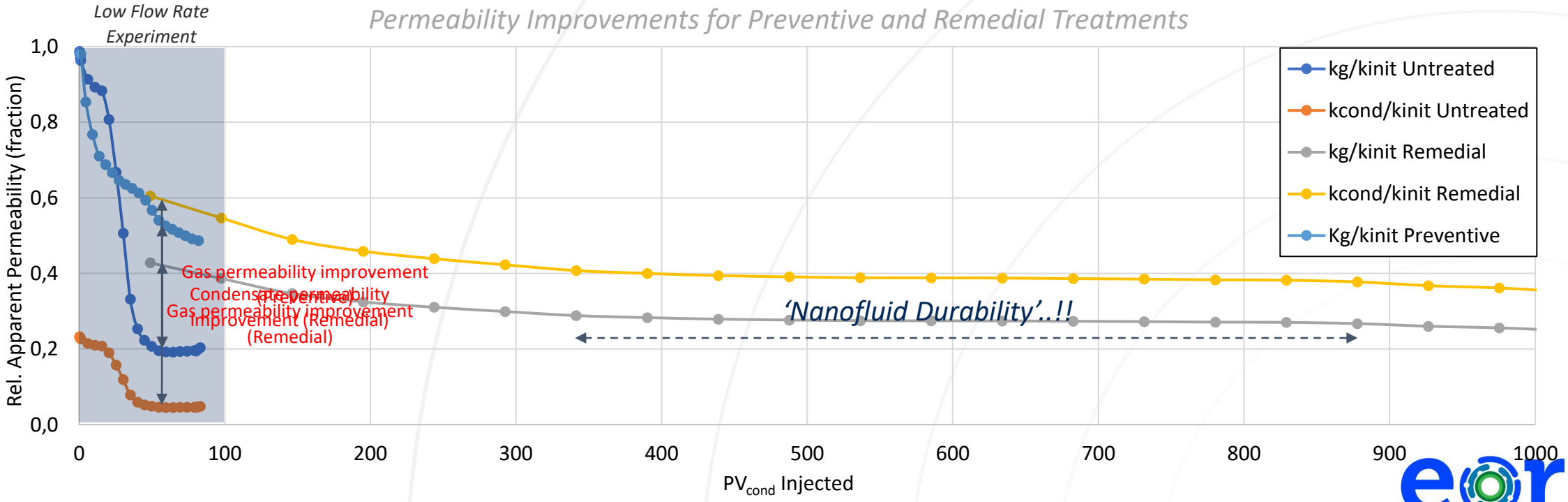
HPHT Flooding Results

- Outcrop core material with permeabilities **< 20 mD** used (Oberkirchner sandstone)
- Synthetic condensate used, runs are conducted below the dew point
- HPHT experiments are run at **80 °C**, **110 bars**
- Treatment in remedial mode enhances condensate permeability by a factor **3 to 4.5**
- Treated core exhibits about **2.5 times** higher gas permeability
- Treatment still effective after **12,000 PV** of gas/condensate injected



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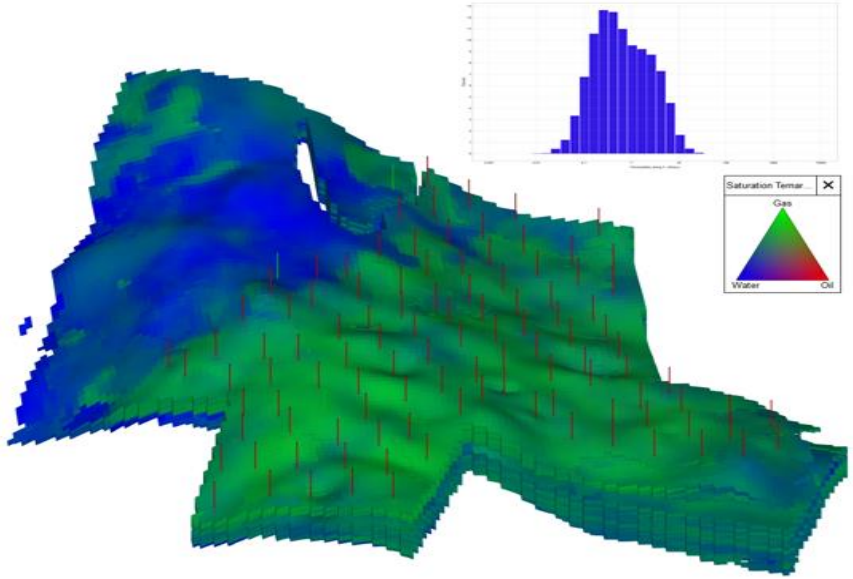
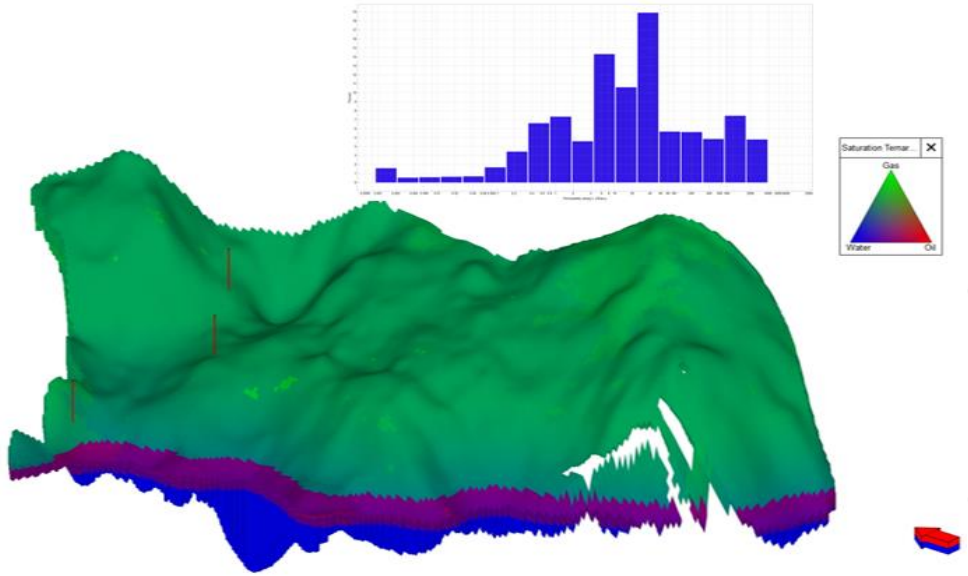
Field Candidates – Overview





Field A

- Sandstone
- >10 years production history
- Initial reservoir pressure: 600 bar
- Dew point pressure: 527 bar
- Avg. porosity: 16%
- Avg. permeability: 1.2 mD
- GIIP: 215x Field B
- Liquid dropout: 11 %
- Wells: >100 (hydraulically fractured)
- CGR: 120 STB/MMSCF
- 344,111 active blocks
- 10 component EOS
- 200m grid blocks

Field B

- Sandstone
- Green field, not in production
- Initial reservoir pressure: 285 bar
- Dew point pressure: 285 bar
- Avg. porosity: 16%
- Avg. permeability: 166 mD
- Liquid dropout: 19 %
- Wells: 3
- CGR: 95 STB/MMSCF
- 323,529 active blocks
- 8 component EOS
- 25m grid blocks, 3 LGRs

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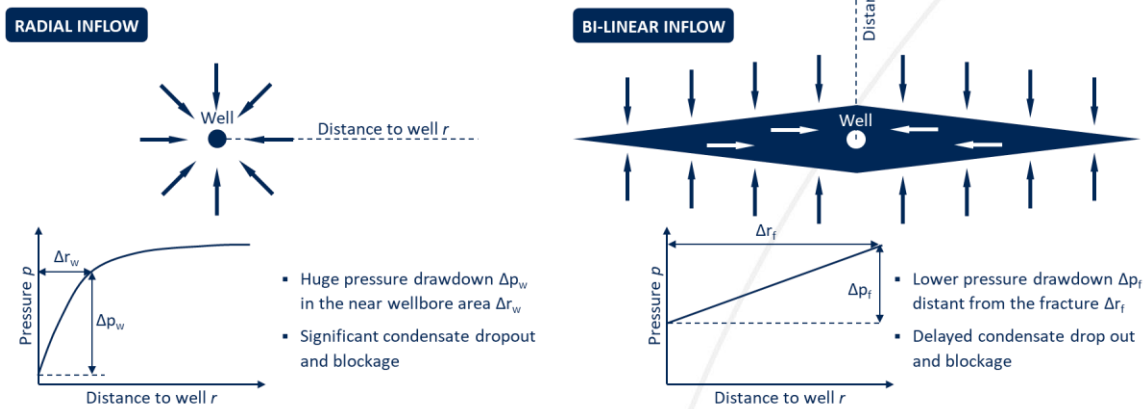
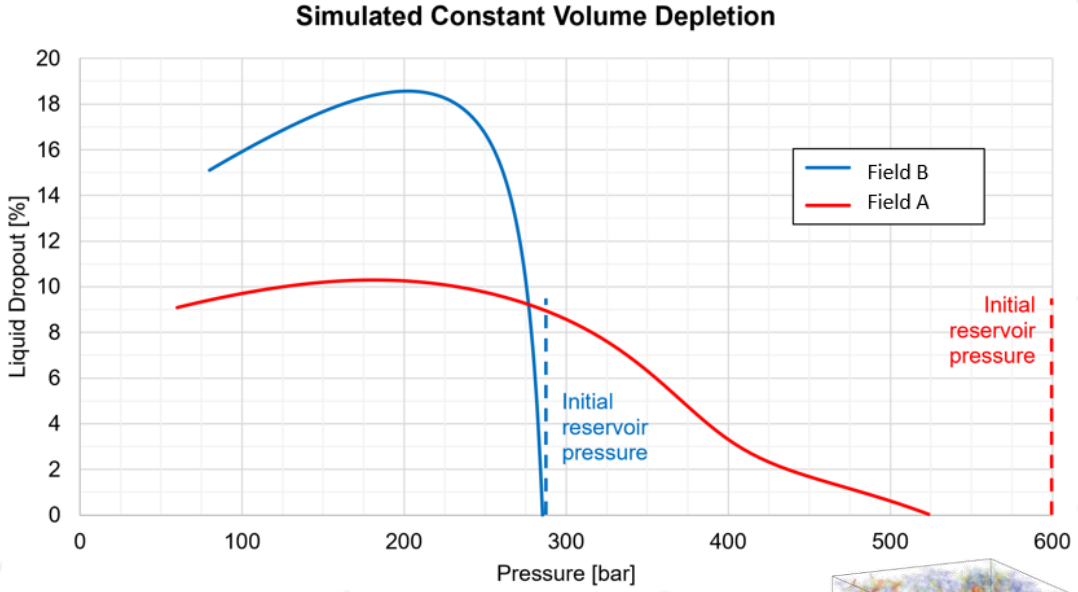
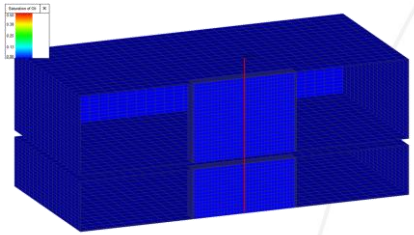
Field Candidates – Challenges



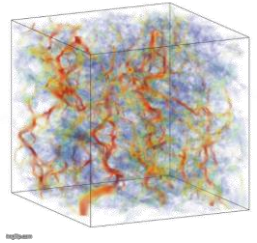


Field A



- Most wells hydraulically fractured
  → preventive measure for condensate blockage but proppant degradation over time unknown
- Coarse gridding and only implicit representation of fractures in full field model → potential underestimation of condensate blockage
- More than 100 wells → challenging screening for wells with high risk of condensate blockage

Field B



- Green field = not much data available
- No reliable SCAL results
  → Digital Rocks analysis necessary
- Dew point pressure close to initial reservoir pressure → condensate dropout and blockage expected from start of production
- Limited condensate handling capacity, operational rescoping currently ongoing
- EWT discarded due to environmental concerns

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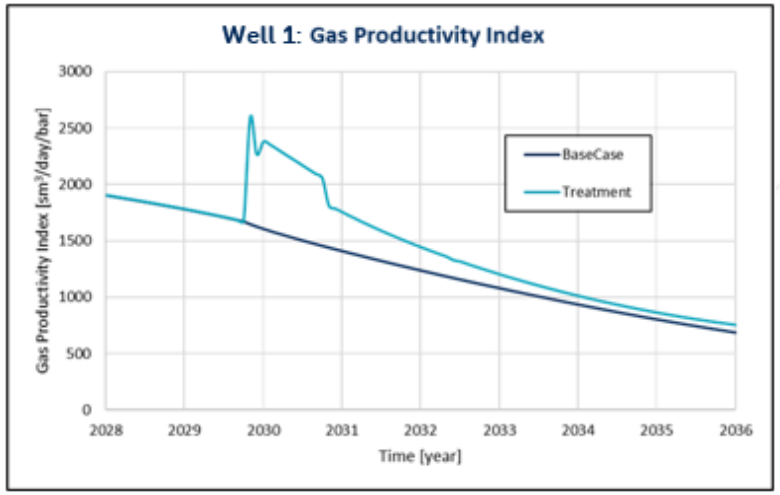
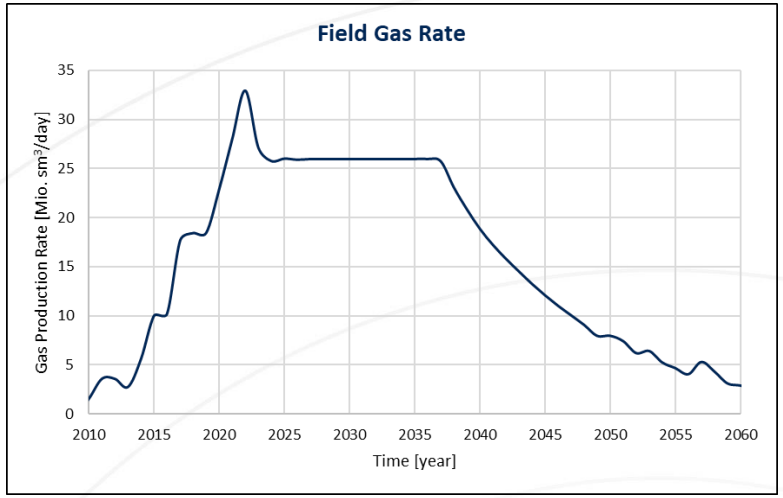
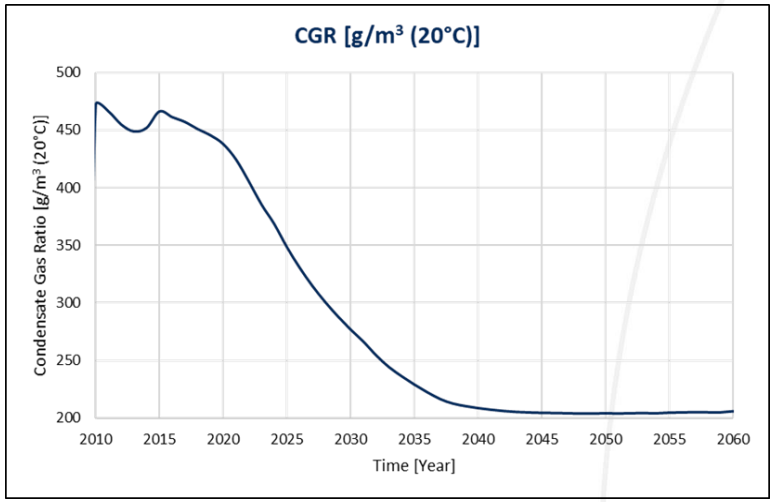
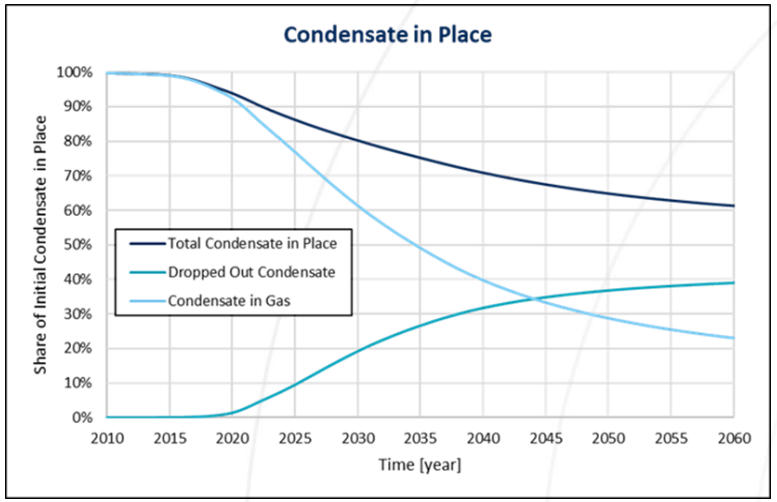
Field A – Solution Identification

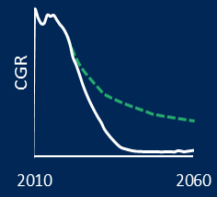
Provide a Solution to Restore Gas Productivity for Damaged Wells & Maintain Field Plateau Production











Provide a Solution to Enhance Condensate Production ASAP

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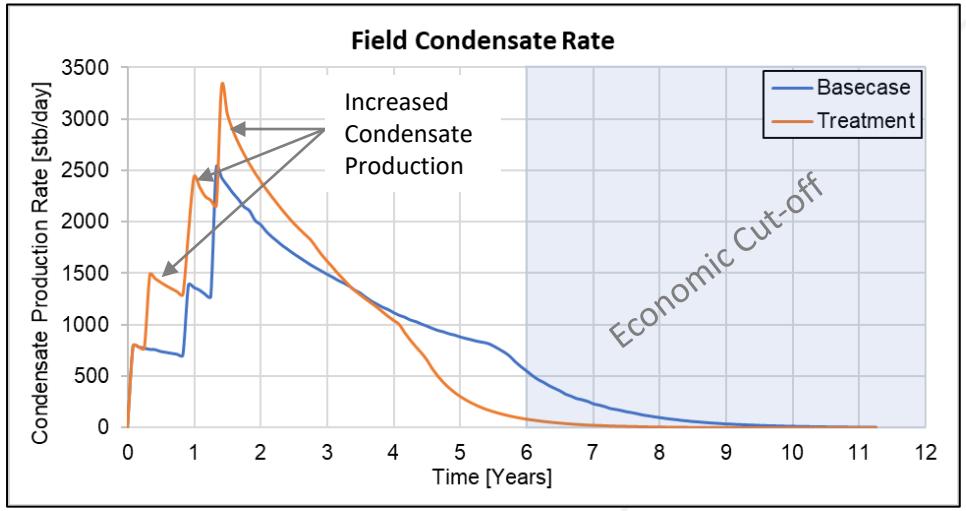
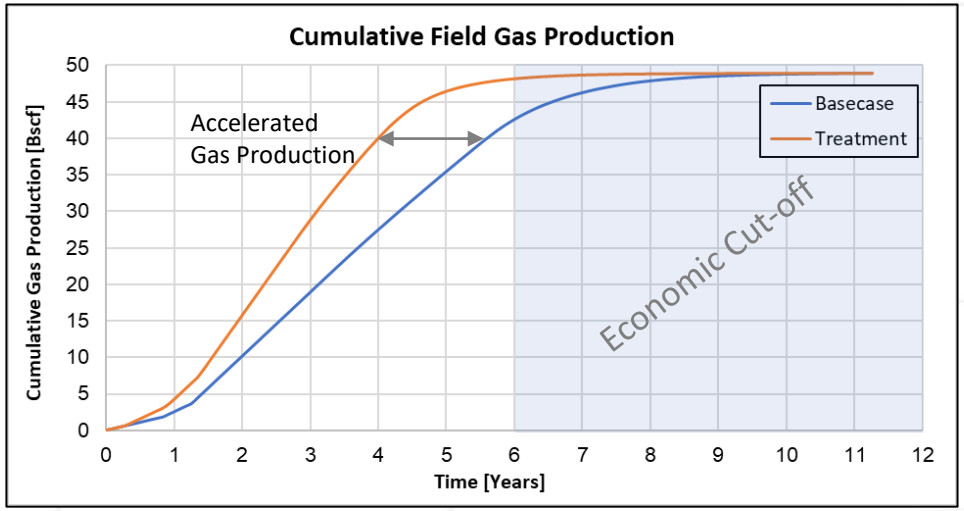
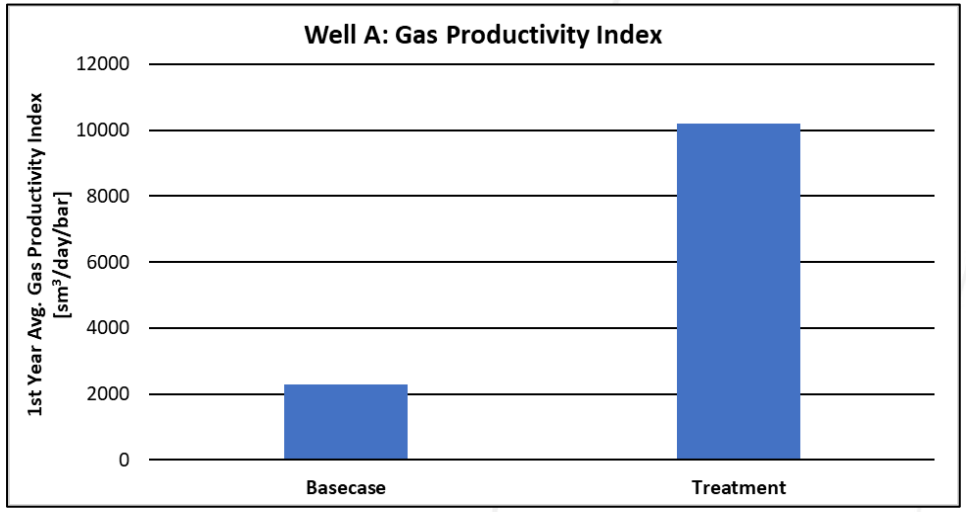
Field B – Preliminary Results







Field B

- Nanofluid treatment shows increased condensate production
- Accelerated gas production at constant drawdown after treatment
- 5-fold increase in gas well PI after treatment showing improvement potential

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Summary and Conclusions

- Options for gas condensate mitigation using pressure maintenance and relative permeability change using surfactants were deemed unsuccessful. Commercially available alternative surfactants *did not meet expectations*
- Successful screening of different nanofluid formulations led to the *identification of a suitable nanofluid system* for gas condensate mitigation of WD assets
- Proof of concept w.r.to the *'do-ability'* of the nanofluid was *successfully demonstrated* using digital rocks technology, HPHT flooding and standard corefloods. *Significant improvement* in condensate and gas relative permeabilities were observed
- The possibility of condensate dropout and blockage in ***'Field A'*** was *successfully evaluated and de-risked* by the EGCR team. Plateau gas production until 2036 was forecasted and possibility to enhance the field condensate production was initiated
- A feasibility study for field pilot implementation is currently in progress for ***'Field B'***. Preliminary simulation results obtained during the ongoing 'testing and validation' phase seem *promising* and *highlight the improvement potential* post treatment
- The next steps for pilot implementation w.r.to operational planning, monitoring and surveillance, procurement, logistics and HSEQ have already been initiated. The pilot is currently *envisaged to be implemented in the later half of 2023*
- Robust business cases validating *'cost effective'* treatment concept and *'short pay-out time'* for pilot implementation have been performed diligently

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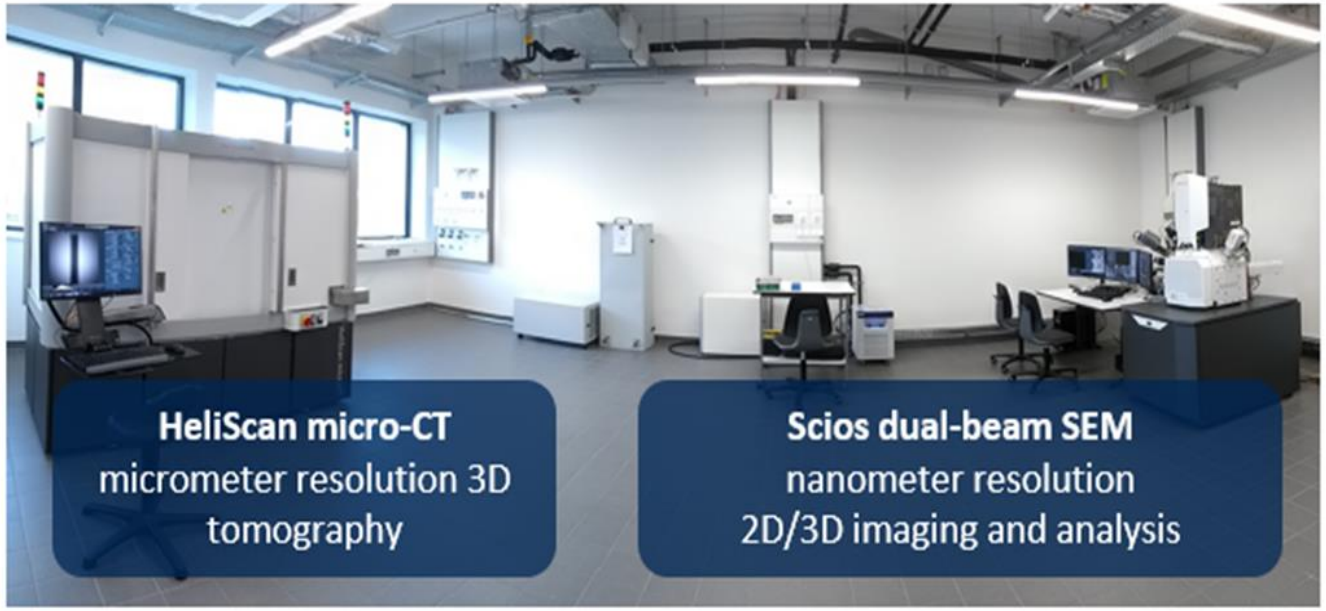
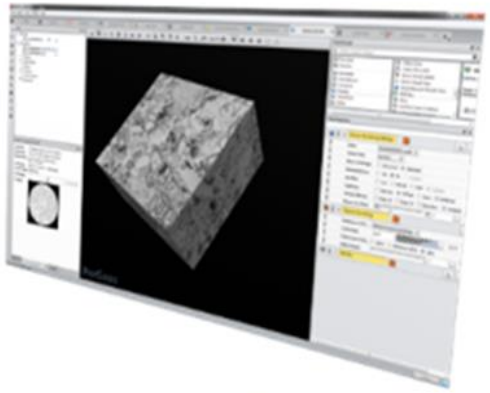
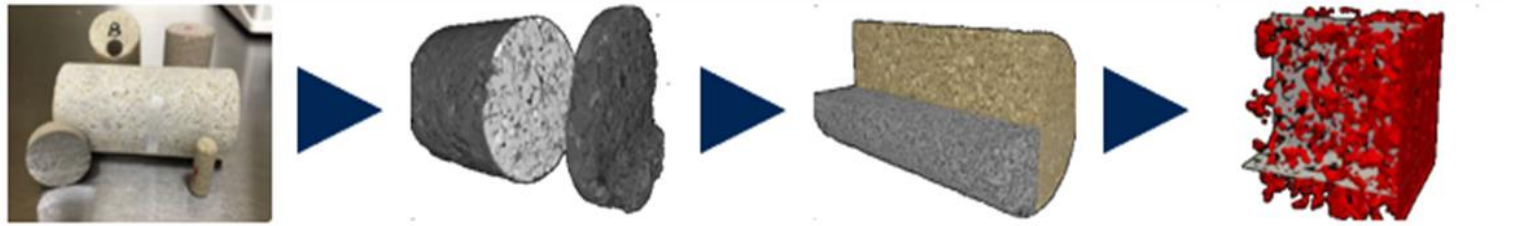
Digital Rocks Technology: Workflow





PerGeos/eCore
Data processing, visualization and analysis, digital RCA & SCAL



Maps Mineralogy (QEMSCAN)
automated spatial mineralogy

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Standard Corefloods – Impact of Influencing Parameters; S_{wi}