Removal of mud components from reservoir sandstone rocks

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Lunch & learn

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Outline

› Background

› Water-based mud (WBM)

› Oil-based mud (OBM)

› Conclusions
Reservoir rock sampling

- **Pressure and temperature reduced**
  - Change of solubility (minerals and fluid components), adsorption, phase partitioning
  - Gas phase formed

- **Mud invasion can alter rock properties, e.g.**
  - Wettability alteration
  - Permeability reduction

Representative conditions in lab experiments

› If reference potential (e.g. water flooding) not correct, EOR-potential not correct

› Reservoir temperature and pressure

› Reservoir fluids
  • Formation water
  • Crude oil

› Injection fluid composition (e.g. water)

› Reservoir rock
  • Ideally no contaminations
## Water-based mud, example

<table>
<thead>
<tr>
<th>Component</th>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bentonite clay</td>
<td>Rheology and filtration control</td>
<td>Impure clay mostly montmorillonite</td>
</tr>
<tr>
<td>Barite</td>
<td>Weight material</td>
<td>BaSO$_4$</td>
</tr>
<tr>
<td>Fluid loss additives</td>
<td>Reduce fluid loss</td>
<td>Acid soluble particles</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Carbon-based particles</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Modified starch</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Polymers (e.g. polyanionic cellulose)</td>
</tr>
<tr>
<td>Xanthan</td>
<td>Rheology and suspension of particles</td>
<td>Biopolymer</td>
</tr>
<tr>
<td>Potassium chloride</td>
<td>Stabilize formation</td>
<td>KCl</td>
</tr>
<tr>
<td>pH, brine composition</td>
<td>Optimize properties of components, reduce corrosion</td>
<td>Lime, Ca(OH)$_2$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Soda ash, Na$_2$CO$_3$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sodium bicarbonate, NaHCO$_3$</td>
</tr>
<tr>
<td>Other</td>
<td>Inhibitors, shale, H$_2$S scavenger, biocide, defoamer, lubricant</td>
<td></td>
</tr>
</tbody>
</table>
KCl-mud / High permeability reservoir sandstone

- Cleaning
  - Synthetic formation water (SFW) flooding
  - Methanol/toluene flooding cycles until colourless effluent
  - SFW flooding
  - Effluent analysed for elements by Inductively Coupled Plasma (ICP)
- Cleaned reservoir rock
  - Wettability characterization by spontaneous imbibition + forced imbibition using synthetic oil
  - Crushed rock
    - Scanning Electron Microscopy (SEM)
    - Dichloromethane extracts analysed to characterize oil residue
KCl-mud / SFW before solvent cleaning

Effluent potassium (K) concentration
- K first much higher than in SFW

Effluent sodium (Na) concentration
- Na first much lower than in SFW
- Similar profiles Ca and Mg

Core plugs contaminated by KCl-mud

KCl-mud / SFW after solvent cleaning

Effluent K concentration

- K higher in beginning
- At the end Na, Ca and Mg also as in SFW

- Many PV of SFW required
- Usually not verified by analysis
- Change in brine composition can’t be detected by differential pressure

KCl-mud / SEM cleaned reservoir rock

- Invasion particles and polymers can reduce permeability
- Invasion particles, especially clay, will increase surface area and may affect established wettability

Element composition EDS-spectra

<table>
<thead>
<tr>
<th>Element</th>
<th>Inlet</th>
<th>Mid</th>
<th>Outlet</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>36.3</td>
<td>37.7</td>
<td>38.5</td>
</tr>
<tr>
<td>Na</td>
<td>1.2</td>
<td>0.6</td>
<td>0.4</td>
</tr>
<tr>
<td>Mg</td>
<td>0.1</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>Al</td>
<td>6.9</td>
<td>6.6</td>
<td>5.4</td>
</tr>
<tr>
<td>Si</td>
<td>45.5</td>
<td>43.6</td>
<td>45.2</td>
</tr>
<tr>
<td>S</td>
<td>1.0</td>
<td>0.9</td>
<td>1.0</td>
</tr>
<tr>
<td>K</td>
<td>3.8</td>
<td>5.3</td>
<td>4.0</td>
</tr>
<tr>
<td>Ba</td>
<td>3.7</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Fe</td>
<td>1.5</td>
<td>1.8</td>
<td>1.8</td>
</tr>
</tbody>
</table>

KCl-mud / After water flood - SEM

Barite and clay

Barite and clay

Clay minerals

Barite

Quartz grain

Clay minerals

KCl-mud / Oil residue

Core plug crushed and extracted

<table>
<thead>
<tr>
<th>Sample id</th>
<th>Extracted material (mg/kg Rock)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet</td>
<td>62</td>
</tr>
<tr>
<td>Mid</td>
<td>132</td>
</tr>
<tr>
<td>Outlet</td>
<td>604</td>
</tr>
</tbody>
</table>

All crude oil not removed

KCl mud / Wettability characterization

Cleaned core plugs prepared with Isopar H (synthetic oil)

- Water-wet rock
  - Spontaneous imbibition of SFW
    - Rather high and fast
  - Forced imbibition
    - No additional oil produced
    - No capillary end effects

- Invasion of particles may still affect wettability established during aging with crude oil

Oil adsorption lower for KCl than FW

Injection of STO to reservoir rock saturated with brine

KCl earlier breakthrough of polar oil components

Bentonite rather oil-wet

Wettability characterized by flotation (%oil-wet particles)


Invasion of bentonite can give too oil-wet rock
## Oil-based mud, example

<table>
<thead>
<tr>
<th>Component</th>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organoclay</td>
<td>Rheology together with water phase and emulsifiers</td>
<td>Modified bentonite, impure clay mostly montmorillonite</td>
</tr>
<tr>
<td>Barite</td>
<td>Weight material</td>
<td>BaSO₄</td>
</tr>
<tr>
<td>Emulsifiers (primary and secondary)</td>
<td>Emulsification and wetting agents</td>
<td>Fatty acid derivates, polyamide</td>
</tr>
<tr>
<td>Fluid loss additives (primary and secondary)</td>
<td>Polymer, resins and/or particles</td>
<td></td>
</tr>
<tr>
<td>CaCl₂</td>
<td>Water activity control</td>
<td></td>
</tr>
<tr>
<td>Lime</td>
<td>Activate emulsifiers, reduce corrosion</td>
<td>Ca(OH)₂</td>
</tr>
<tr>
<td>Base oil</td>
<td>Continuous phase</td>
<td>Petroleum distillate or synthetic oil</td>
</tr>
<tr>
<td>Water</td>
<td>Internal brine phase</td>
<td></td>
</tr>
</tbody>
</table>
Organoclay stabilized emulsion

Without organoclay

With organoclay

Interference contrast microscopy

OBM / STO injection

- Sandstone rock (100-200mD)
- STO aging at $S_{wi}$
- OBM filtrate aging
- STO injection until constant $\Delta P$
- Emulsifier production by interfacial tension (IFT)
- Wettability characterized by spontaneous imbibition of SFW
OBM STO injection / IFT

IFT between effluent samples and SFW

OBM / Capillary desaturation curve

Water-wet rock expected in project

Methanol cleaning: Unexpected CDC

Methanol/toluene, acetic acid and ethanol cleaning: As expected CDC

Rock composition probably altered by acetic acid

CDC Mixed-wet sandstones

› Today many sandstone rocks characterized as mixed-wet

› Atypical CDC wetting phase (Chukwudeme et al., 2014)

› Atypical CDC mixed-wet reservoir rock (Fjelde, Lohne and Abeysinghe, 2015)

Recommended to interpolate between $k_r(N_c)$-curves


Representative rock samples

› Ideally all mud components should be removed

› Differential pressure can’t confirm mud contaminations removed

› Effluent analyses
  • Colourless effluent can’t confirm all mud components removed
  • Challenge many components in muds
  • If mud components easiest to remove still present, rock probably not representative

› Cleaning efficiency
  • Additional plugs or after flooding experiments
Conclusions

› WBM contamination
  
  • High permeability sandstone reservoir rock
    
    – Mud contaminations can be difficult to remove, especially particles
    
    – Cleaned reservoir rock water-wet, but clay particle invasion may affect established wettability

› OBM contamination
  
  • Slow release of emulsifiers during STO injection, and core plugs exposed to OBM filtrate less water-wet
  
  • CDC measured for reservoir sandstone rock found to depend on cleaning procedure
Conclusions cont.

› Mud components with potential to affect flow conditions should be removed during cleaning of reservoir core plugs, otherwise, ideally, these core plugs should not be used

› Recommended to analyse effluent samples for mud components to confirm removal, at least the easiest removable components

› If not all mud contamination removed, recommended to investigate whether presence of mud components may have affected the results

› Method for determination of cleaning efficiency should be developed
Acknowledgements

› Lundin Norway for financing and supporting the work on water-based mud presented in this paper.

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