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High-Salinity Water Based Muds as Oil-Based Mud Alternatives for Optimized Shale Drilling

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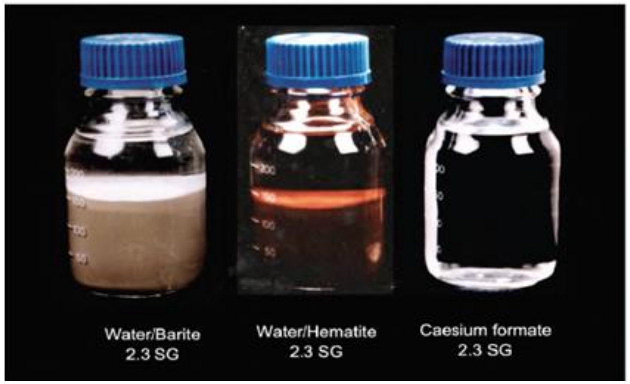
Presentation Overview

- Background
  - Overcoming negatives of OBM/SBM
  - Borehole stability essentials
- Pressure Transmission
  - OBM/SBM vs. formate mud behavior
- Shale Stabilization & ROP Enhancement by Formates
- Field Experience – Shale Drilling with Formates
- Conclusions & Acknowledgment



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Overcoming Negatives of OBM/SBM

Advantages of OBM/SBM

- High ROP, reduced bit-balling
- Excellent shale inhibition
- Excellent wellbore stability / gauge hole
- Thermal stability
- High lubricity, lower torque
- Low fluid loss
- Reduced differential sticking
- High solids tolerance
- Good coring / salt drilling fluid
- Low corrosion

Disadvantages of OBM/SBM

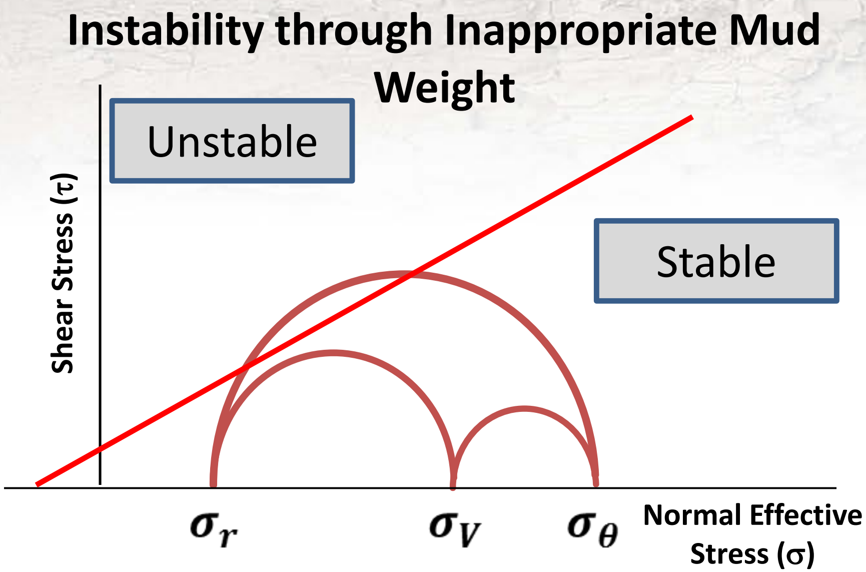
- High cost (direct & waste)
- Electrical / resistivity log difficulties
- Oil emulsion blocks in gas sands, production impairment
- Prone to severe ballooning & lost circulation
- Poor cement bonds possible
- Gas kick detection more difficult
- Difficulty fingerprinting HC's
- Messy work environment
- Waste disposal logistics
- Fumes / fire hazard

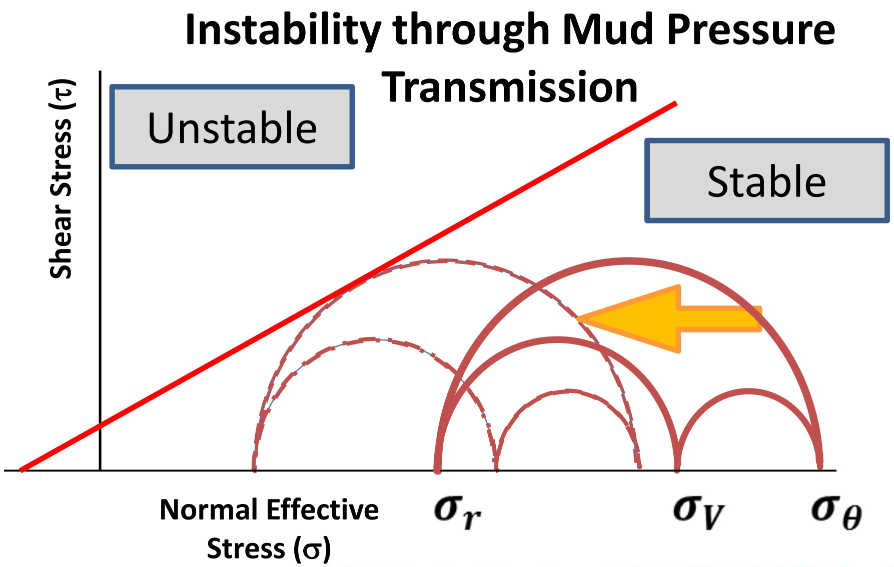
Shale Drilling

- Underbalanced drilling is possible in some shales
  - Determined entirely by shale strength in relation to in-situ rock stress / pore pressure
  - Preferred when possible, leading to high ROP
  - Beware of gas kicks in fractured / faulted zones
- Stuck pipe / casing often not because of shale instability
  - Due to difficult deviated/horizontal hole cleaning, poor wellbore quality/high tortuosity & stiff drilling assemblies
- Focus on shale instability when drilling overbalanced
  - OBM/SBM often not the best choice

Shale Borehole Stability

- Leading cause of shale borehole instability is **inappropriate mud pressure**, causing immediate wellbore cavings & failures
- Time-delayed shale borehole instability is caused by **mud pressure transmission**, increasing pore pressure, reducing effective stresses





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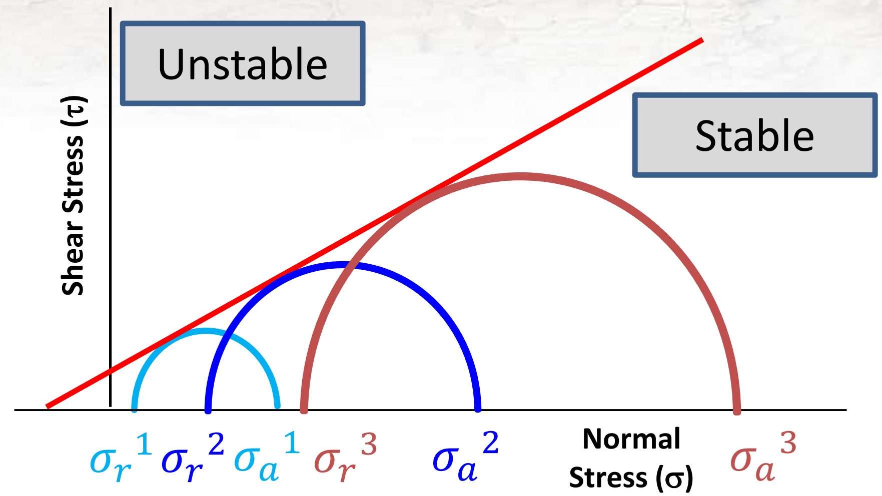
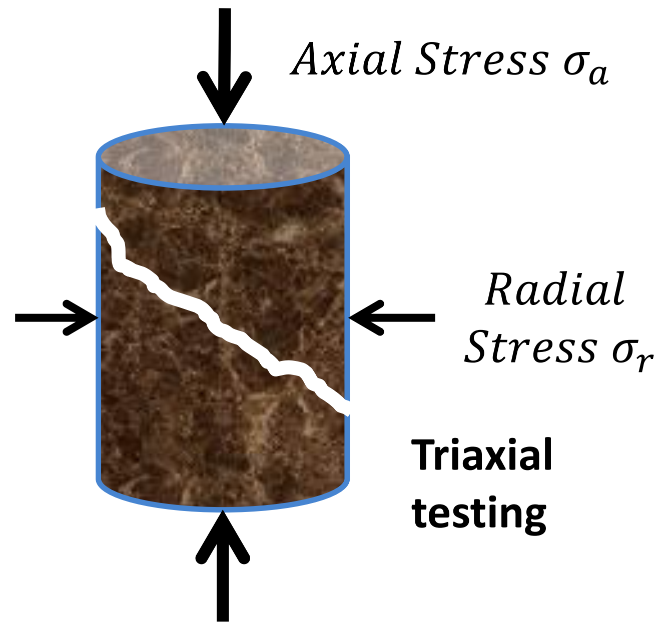
Instability Due to Mud Weight / Pressure

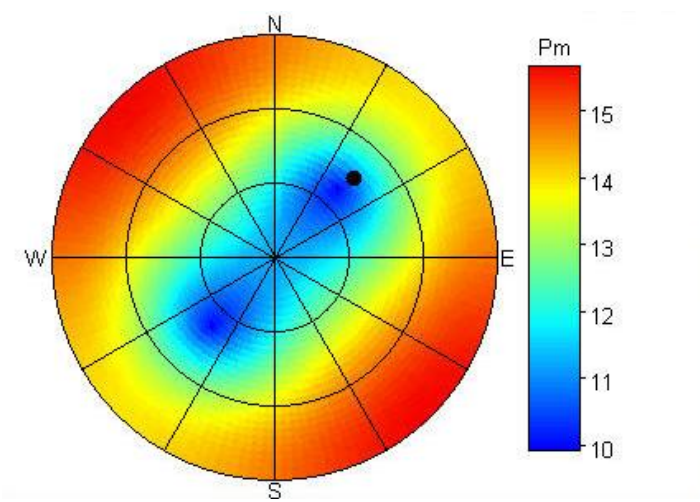
- Failure is immediate (immediate caving), irrespective of mud type
- Optimum mud weight can be determined using triaxial failure testing on core & modeling
- Optimum mud pressure needs to be managed in the field (managing annular pressure fluctuations, swab & surge etc.)

Mapping the shale failure envelope



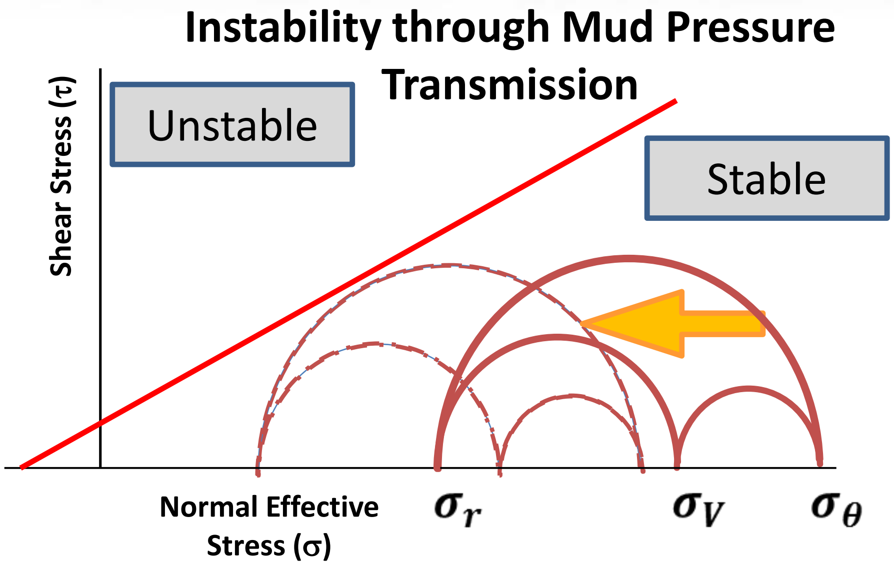


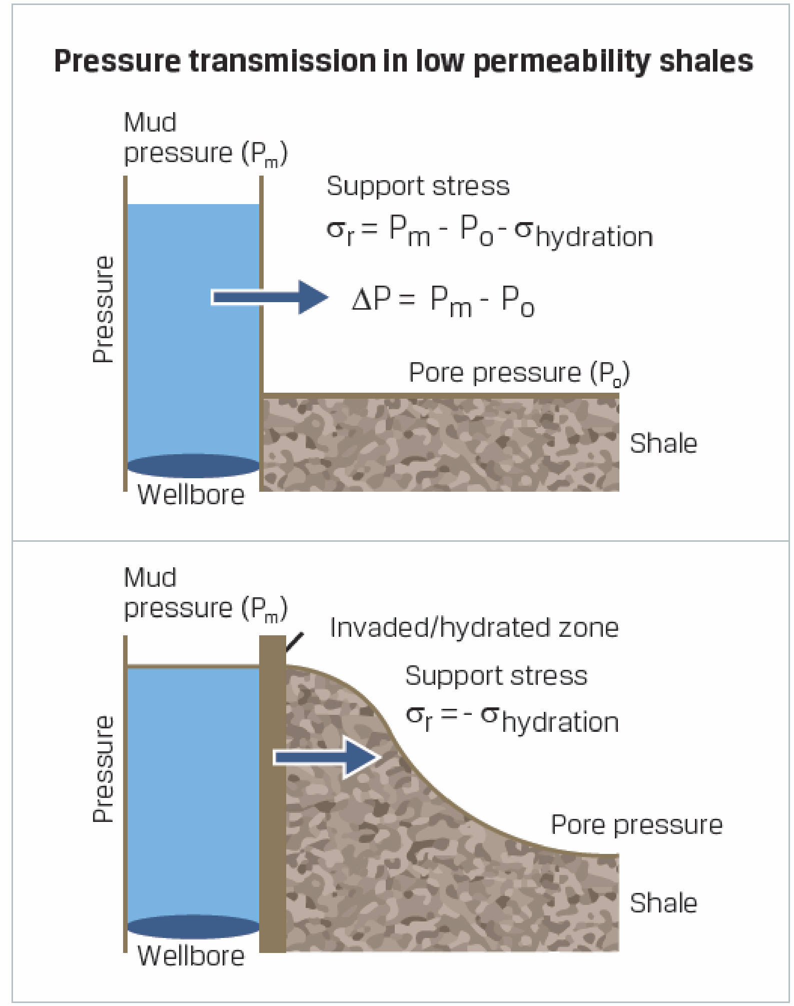
Triaxial testing



Mud Weight as a function of deviation and azimuth

Instability Due to Pressure Transmission





- Failure is not immediate, but delayed in time
- Cavings on shakers become progressively worse
- Few problems while drilling / with ECD on the well, but “tight hole” when static and while tripping (swabbing) / backreaming

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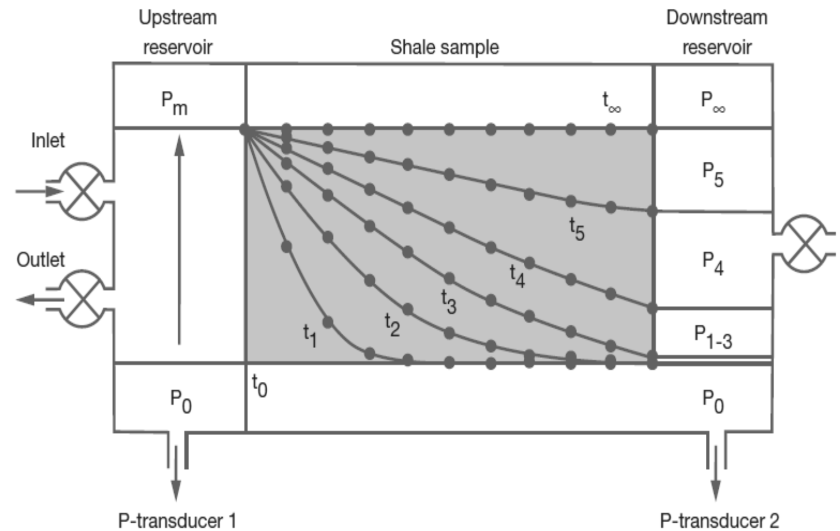
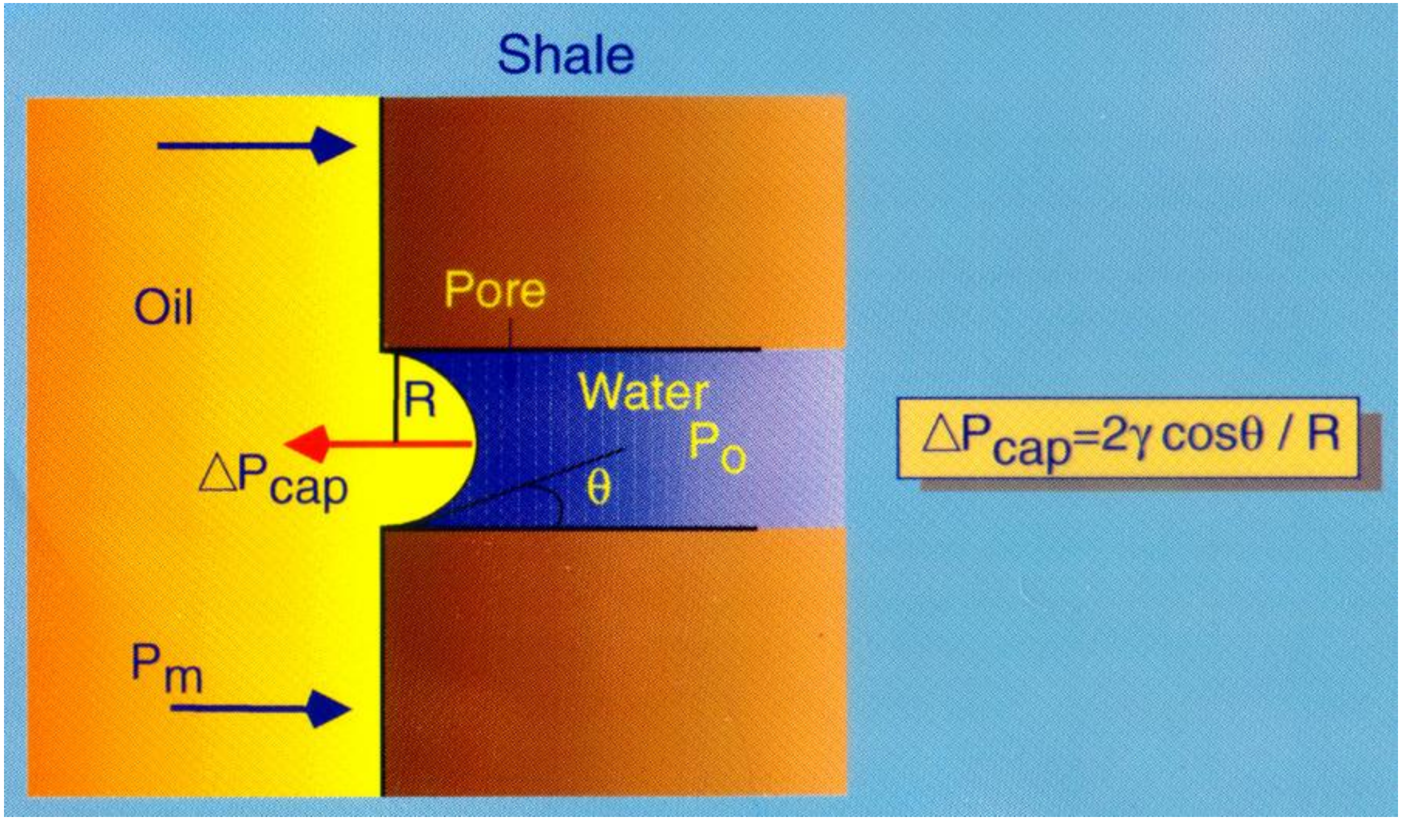
Pressure Transmission Measurements

PT test apparatus



- Pressure pulse decay experiments of saturated shale samples exposed to different mud systems show significantly variation in invasion behavior, particularly when comparing WBM and OBM systems

OBM/SBM Shale Stabilization: Capillary Forces



OBM/SBMs give rise to capillary entry pressures when contacting water-wet shales that are intact, **but not when shales are oil-wet, (micro-)fractured or simply have large pore throats**

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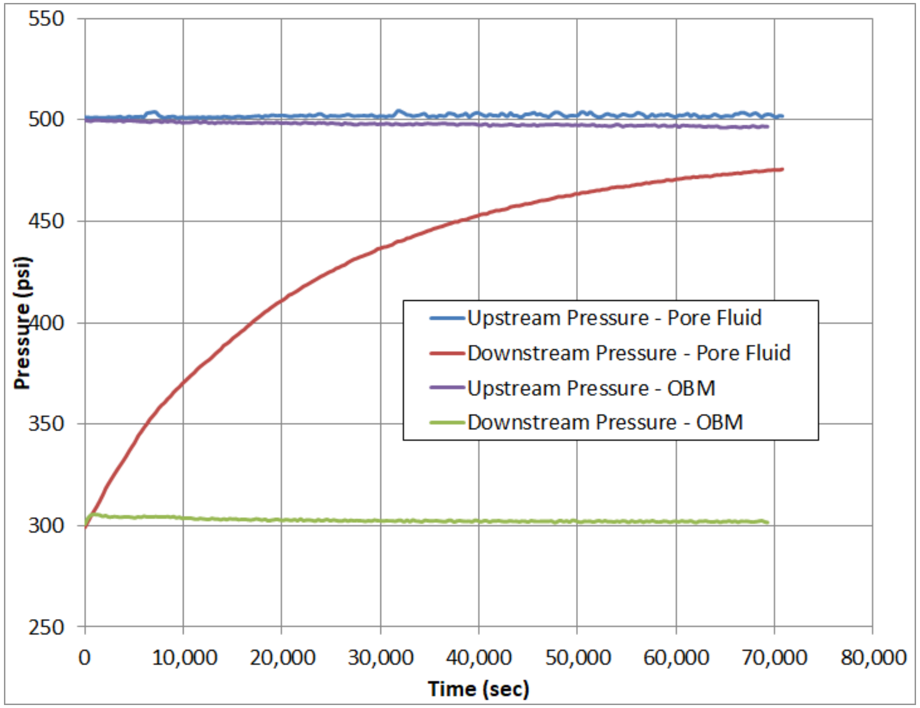
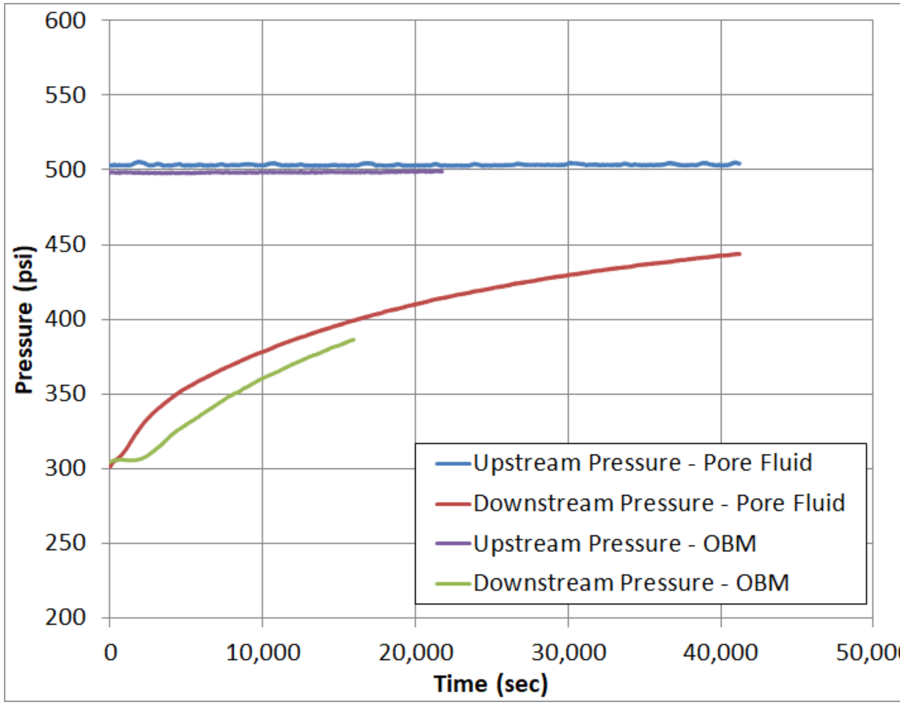
OBM/SBM Behavior on Different Shales

Intact, Water-Wet Shale



Oil-Wet Shale, Micro-Fractured Shale, Shale with Large Pore Throats



(van Oort, SPE 189633, 2018)

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Delaying Fluid Invasion into Shales

1. Reduce shale permeability

Hydraulic Gradient

Osmotic Gradient

3. Counterbalance hydraulic flow into the shale with stimulated osmotic flow out of the shale

$$q = \frac{k}{\mu}(\nabla P - \sigma \nabla \pi)$$

2. Increase mud filtrate viscosity

Membrane efficiency σ is highly shale-dependent determined by pore space diameter

σ = 0 for (micro-) fractured shales and shales with large pore diameters

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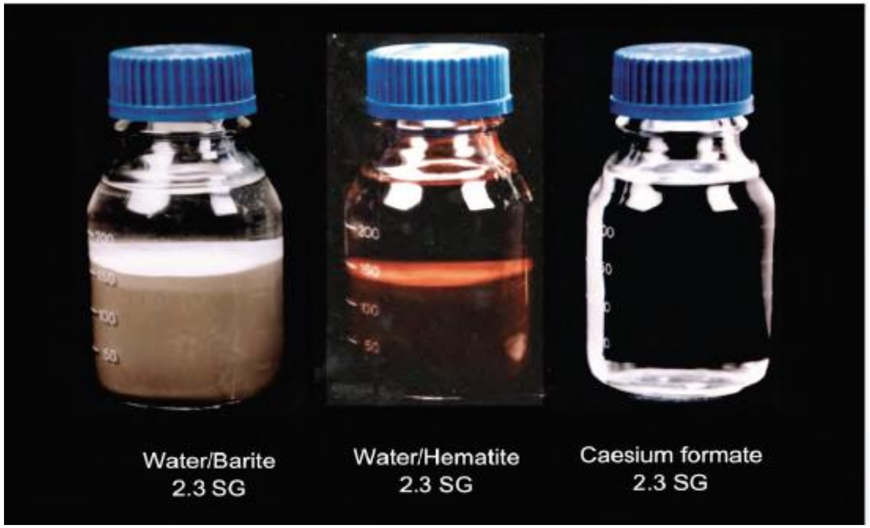
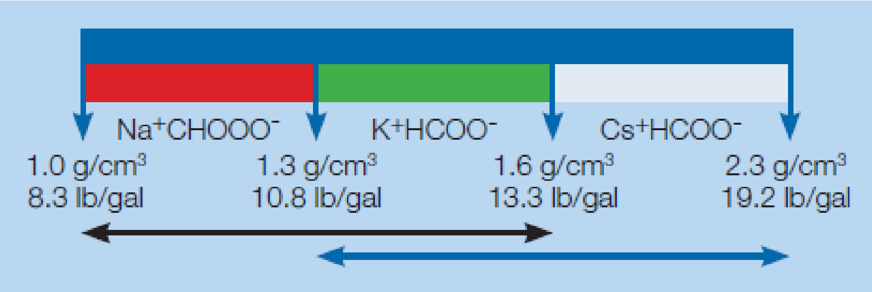
Introduction to Formate Brines & Muds



Sodium formate	$H-C(=O)O^{-}Na^{+}$
Potassium formate	$H-C(=O)O^{-}K^{+}$
Cesium formate	$H-C(=O)O^{-}Cs^{+}$



Component	Function	Concentration
Formate brine Shale Stability	Density Lubricity Polymer protection Biocide	1 bbl
Xanthan	Viscosity Fluid loss control	0.75 - 1 ppb
Ultralow vis PAC and modified starch	Fluid loss control	3 or 4 ppb of each
Sized calcium carbonate	Filter cake agent	20 ppb
$K_2CO_3/KHCO_3$	Buffer Acid gas corrosion control	0 – 6 ppb

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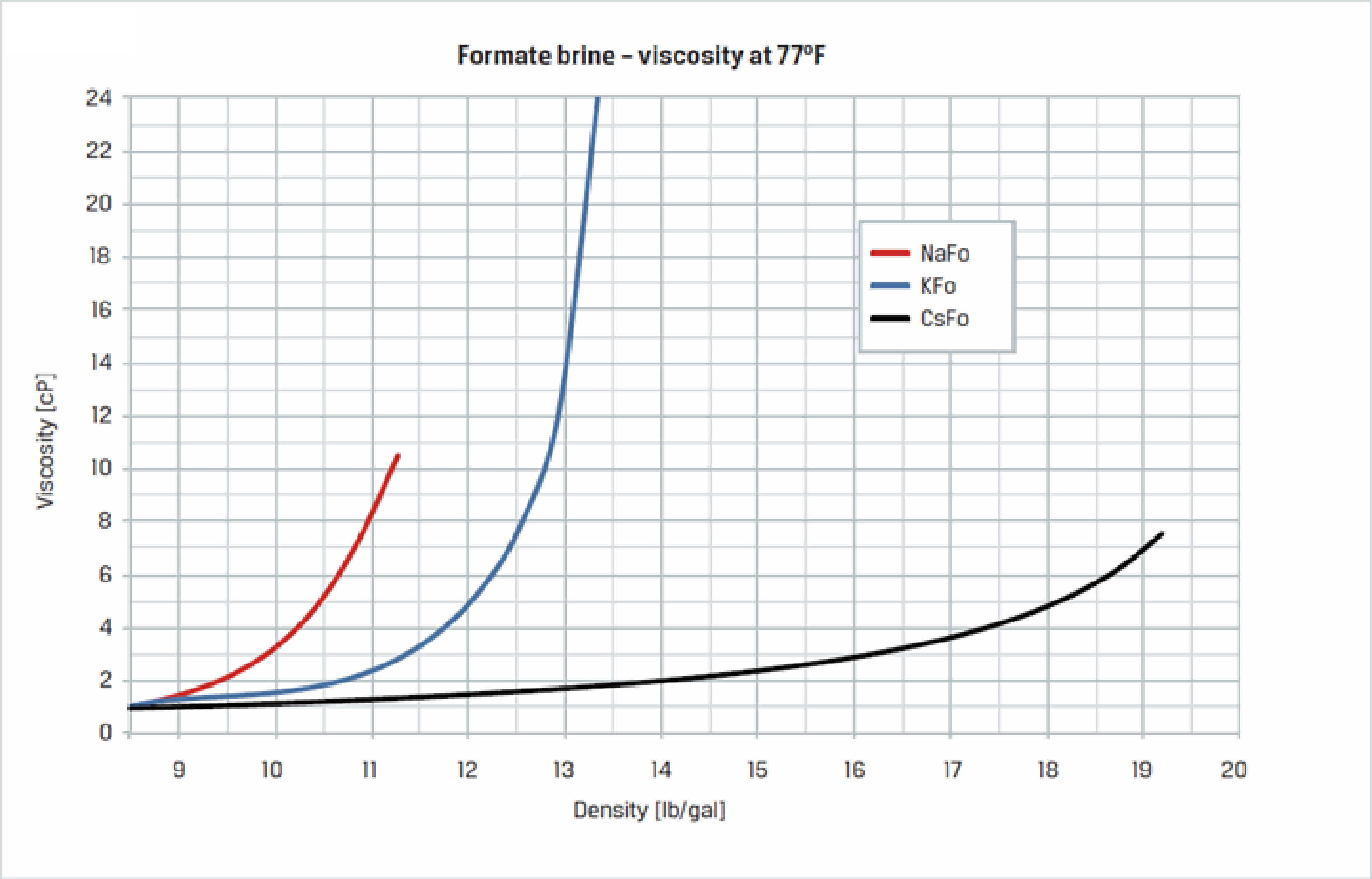
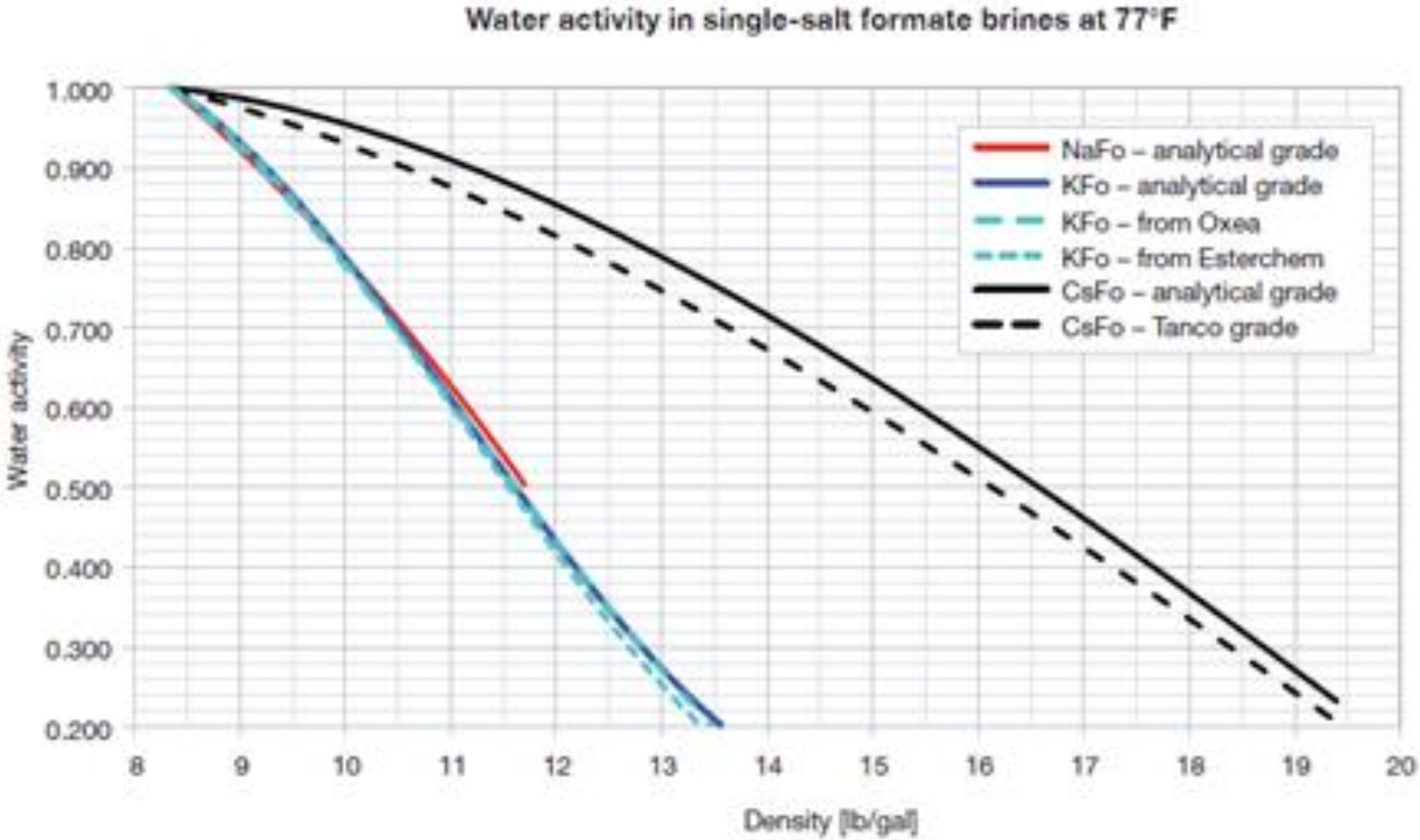
Mechanism 2 – Formate Brine Viscosity



Mechanism 3 – Water Activity Reduction



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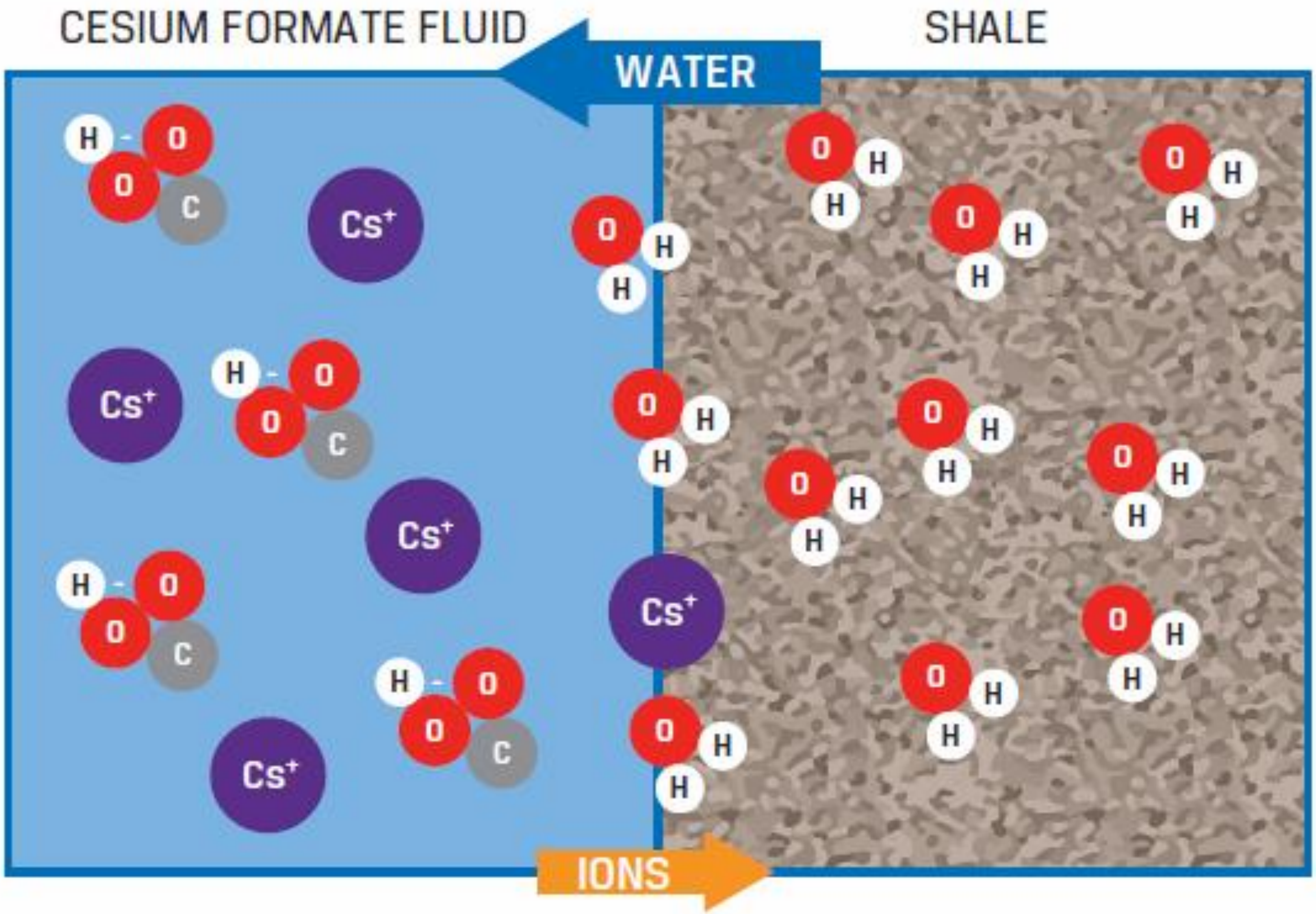
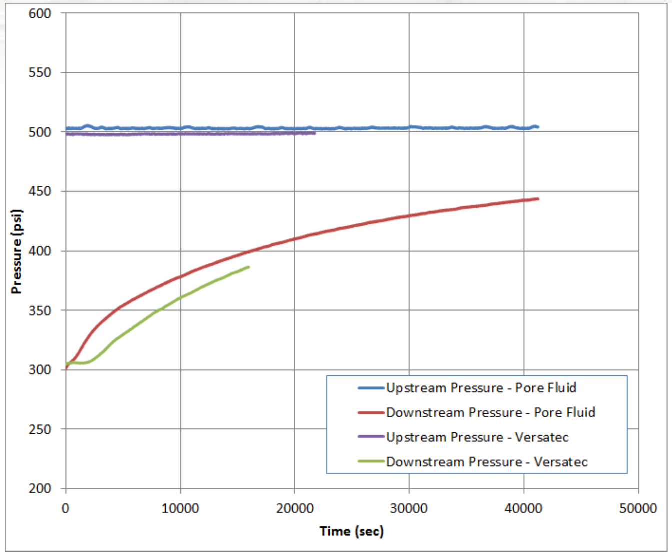
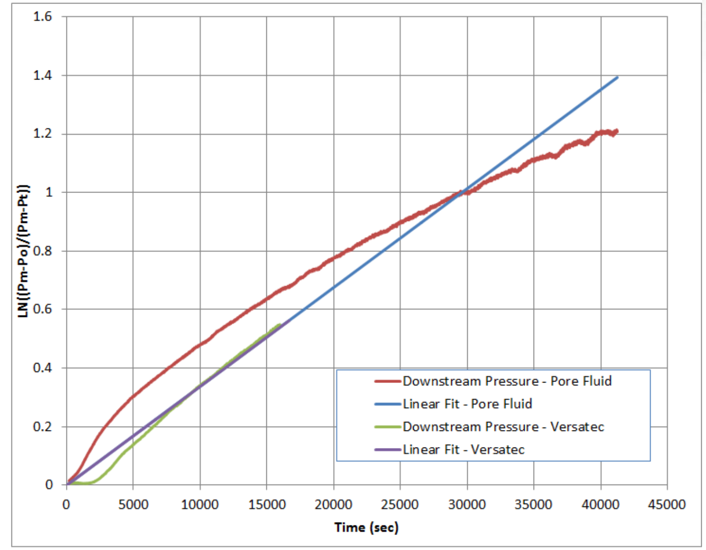
Leaky Formate-Shale Membranes



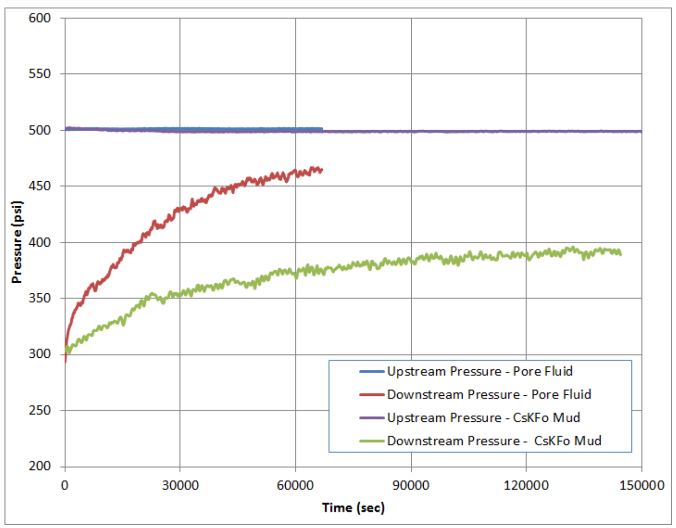
OBM/HP-WBM Pressure Transmission

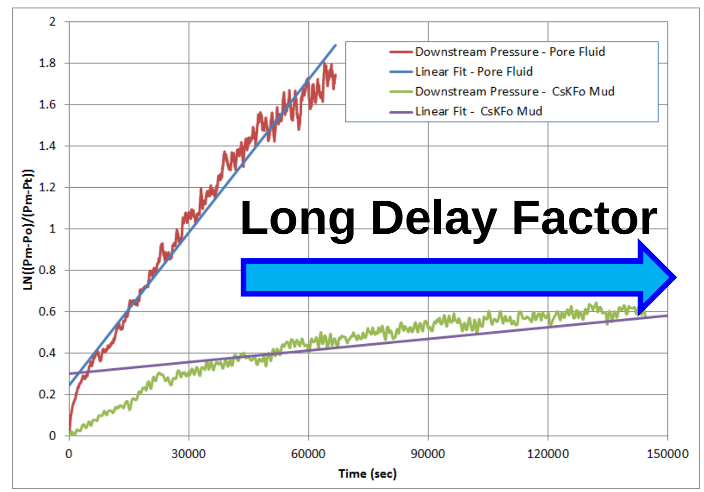
OBM





Formate Mud





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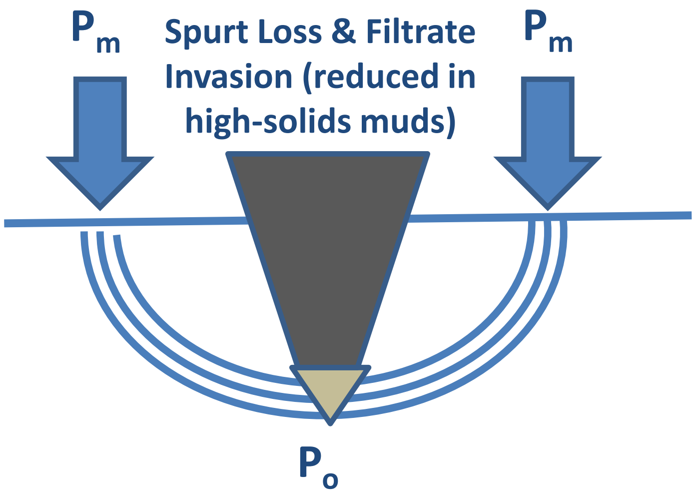
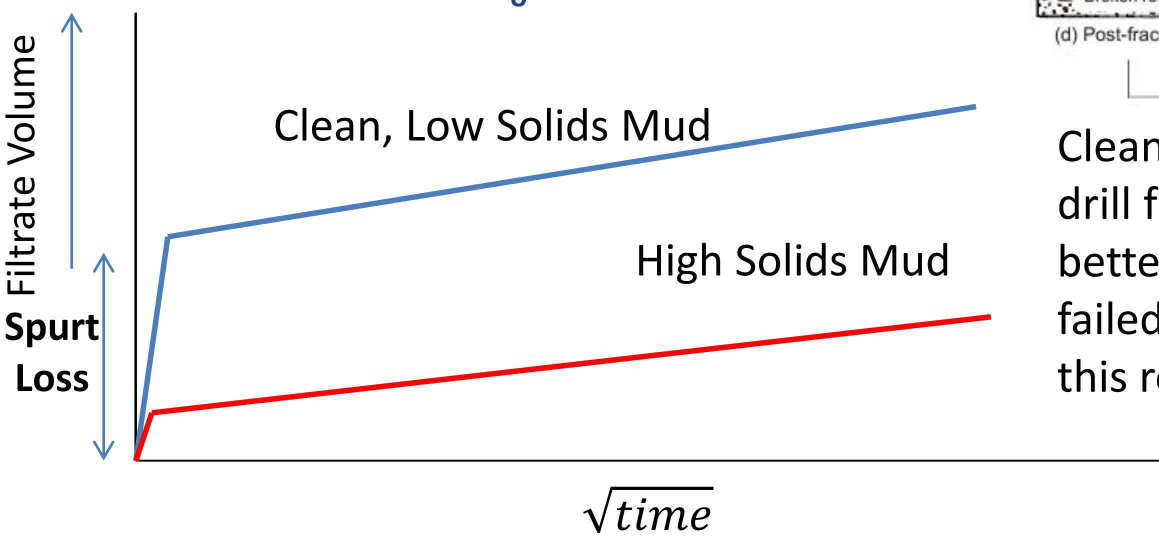
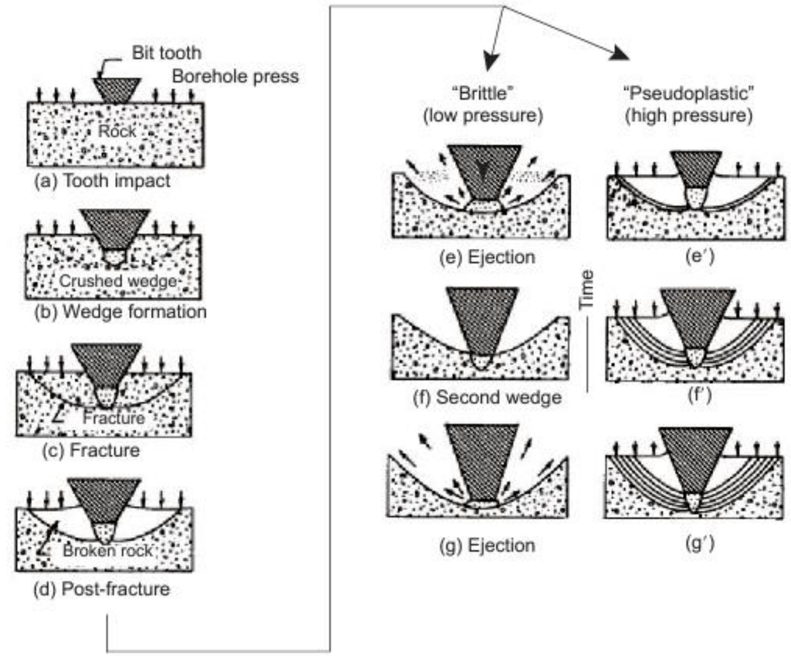
Faster Shale Drilling with Formates: Clean Fluids & Chip Hold-Down Effect







Clean, unweighted drilling fluids generally drill faster by having higher spurt loss, better pressure invasion in fractured / failed rock, causing better evacuation of this rock from the bit tool face

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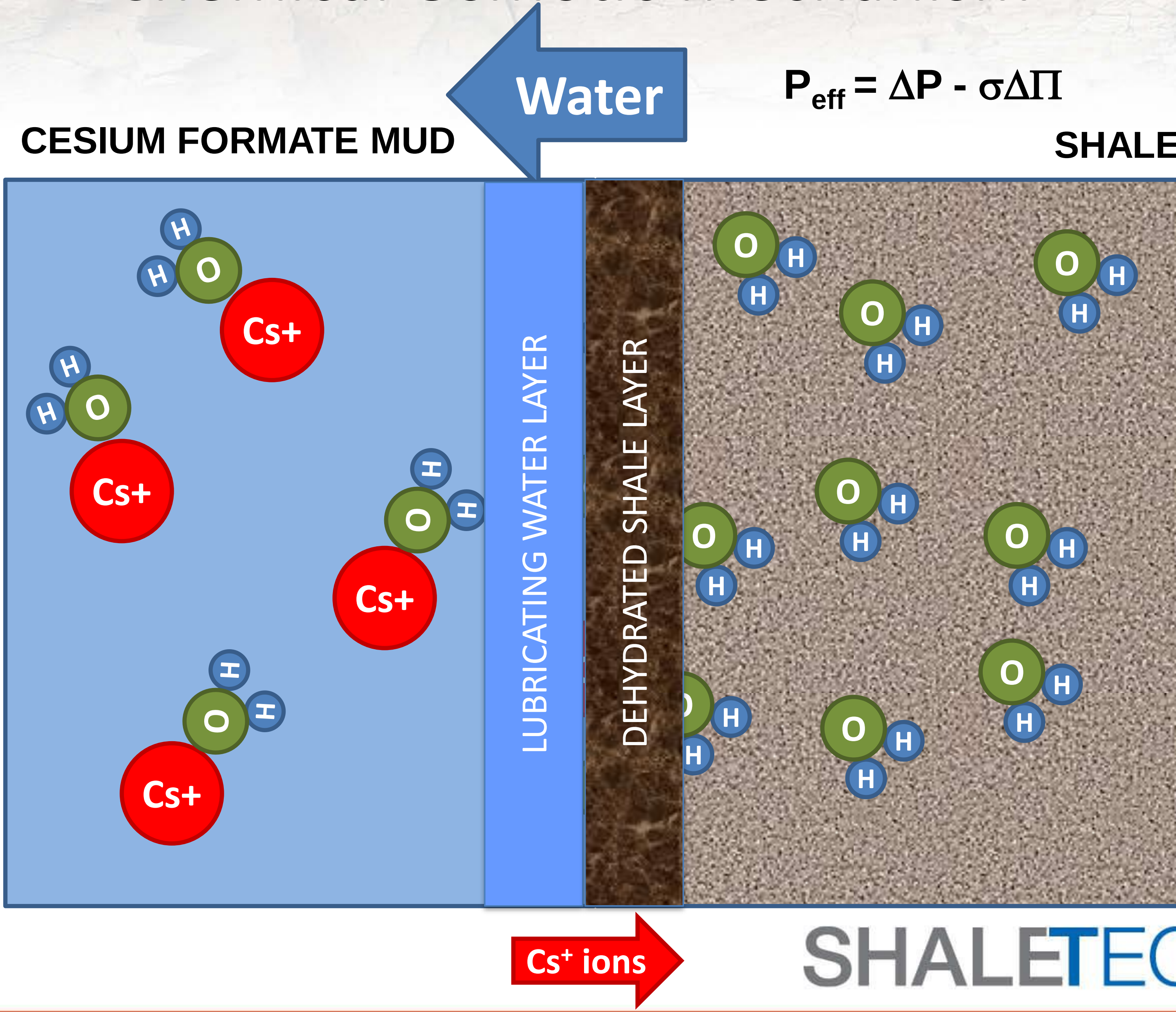
Chemical Osmotic Mechanism

$$P_{eff} = \Delta P - \sigma\Delta\Pi$$



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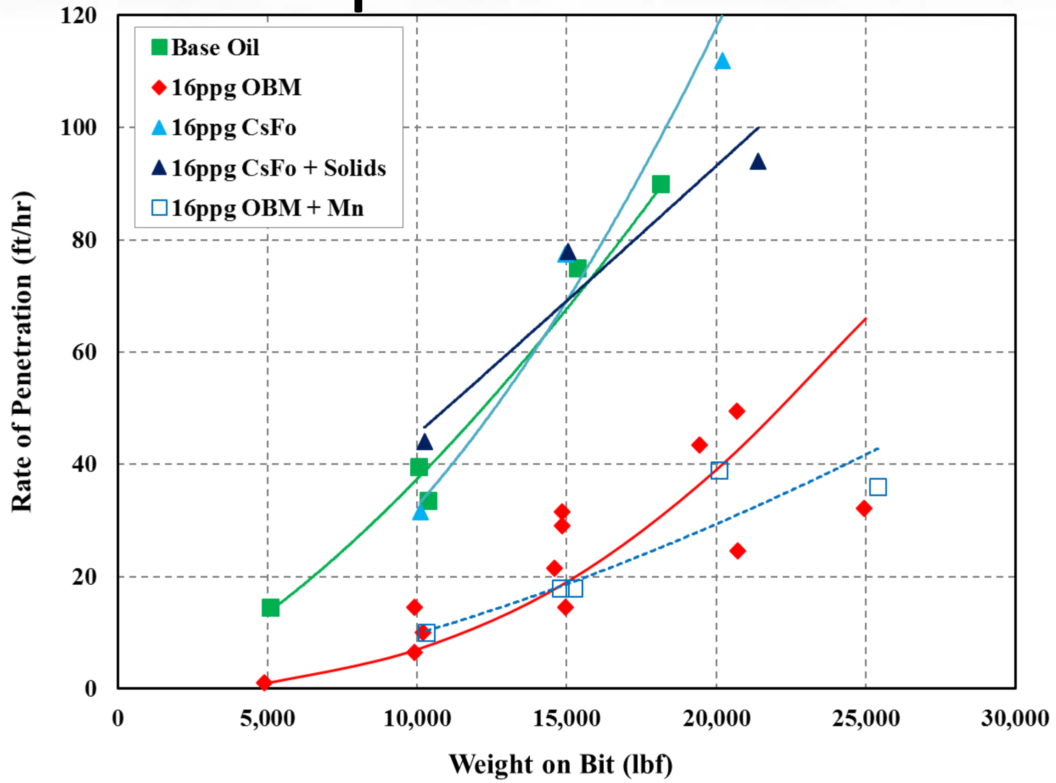
Faster Shale Drilling with Formates: Deeptrek Results



Deeptrek (SPE 112731) misinterpreted the ROP results for CsFormate as being due to “clear fluid behavior”: note that the ROP results for Cesium Formate (CsFo) with and without solids are very similar. Faster drilling in shale (and other formations?) -> lower formation exposure times

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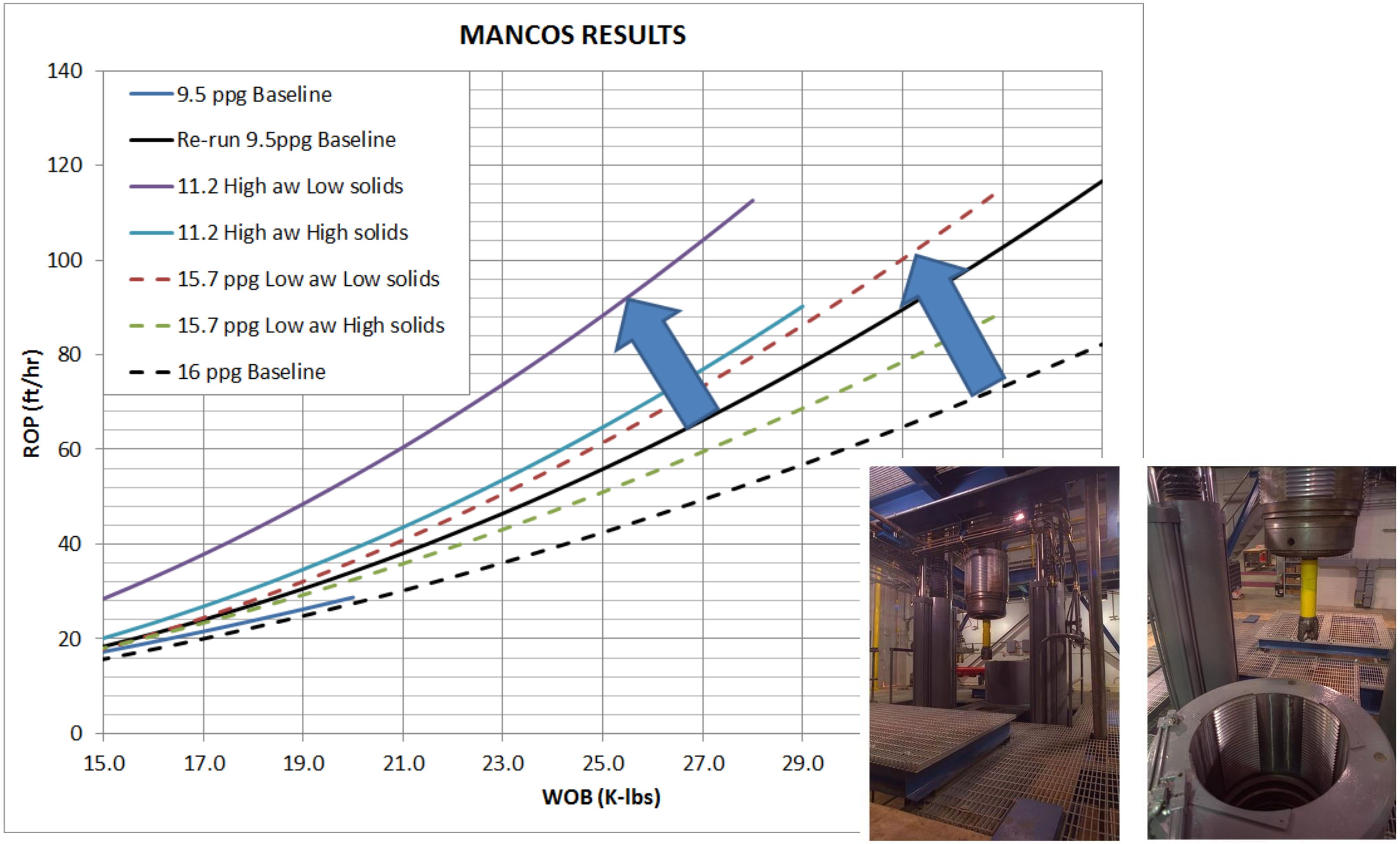
Faster Shale Drilling with Formates: Effect of Formates



(van Oort et al., SPE 173138, 2015)

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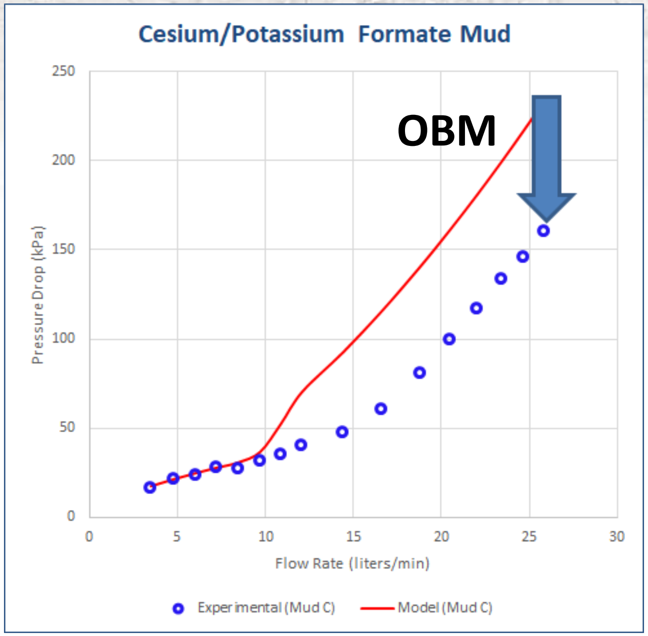
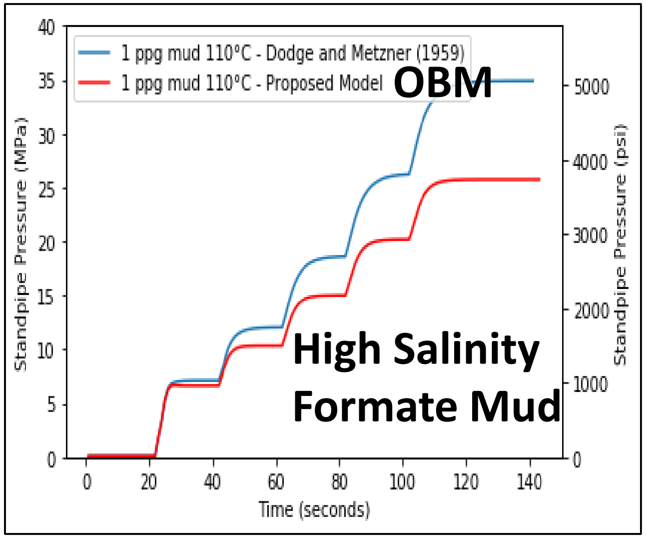
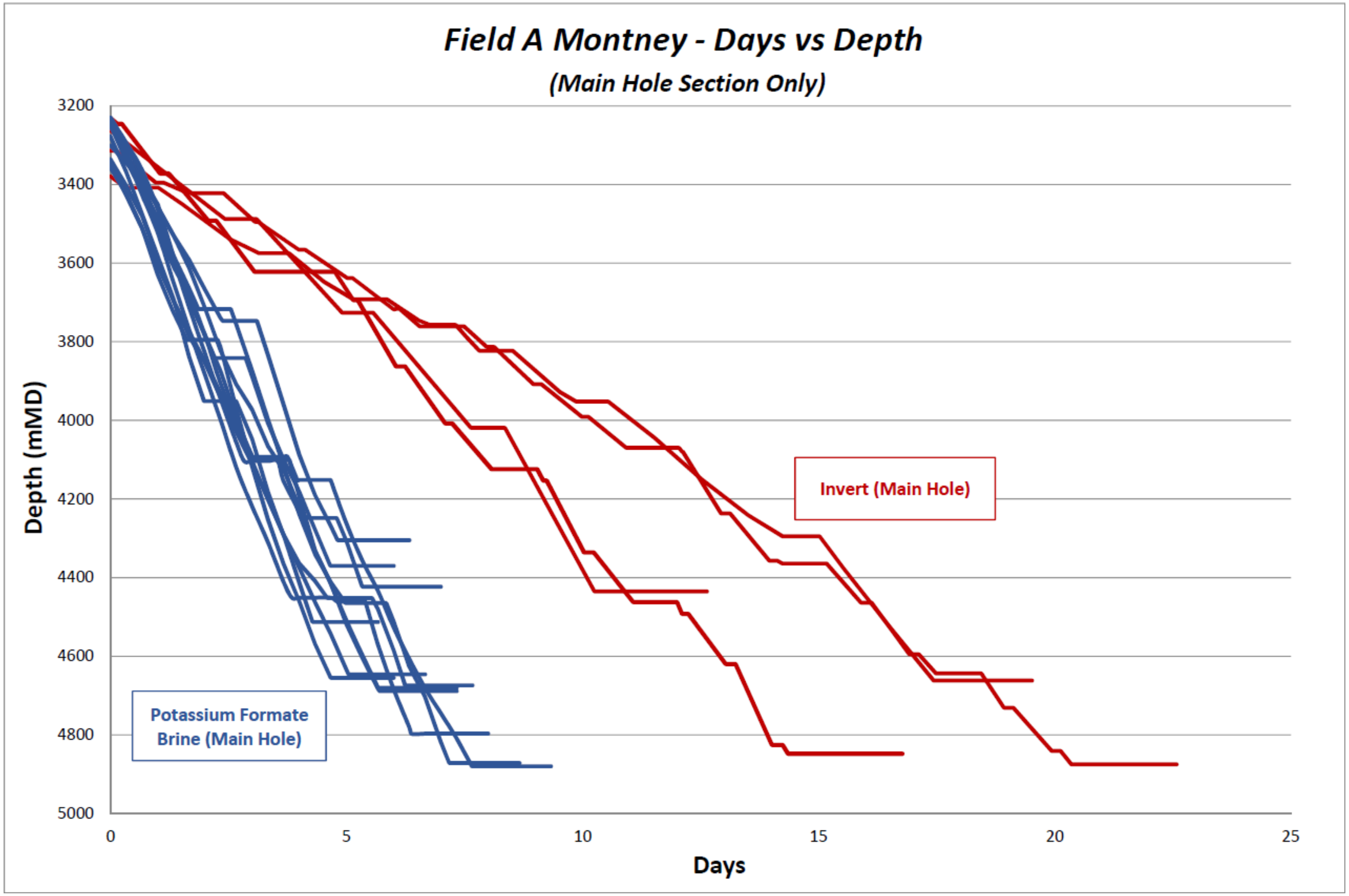
Improved Hydraulics for Improved ROP

- Many shale drilling operations use hydraulically underpowered bits / too low HSI
  - Bit balling becomes a drilling / ROP limiter
- Formate mud use viscosifying polymers (XC) that can reduce hydraulic friction
  - Delay onset of turbulence
  - Reduce pump pressure and ECD
  - Improve bit hydraulics





Faster Shale Drilling with Formates: Canada Shale Drilling Performance - I



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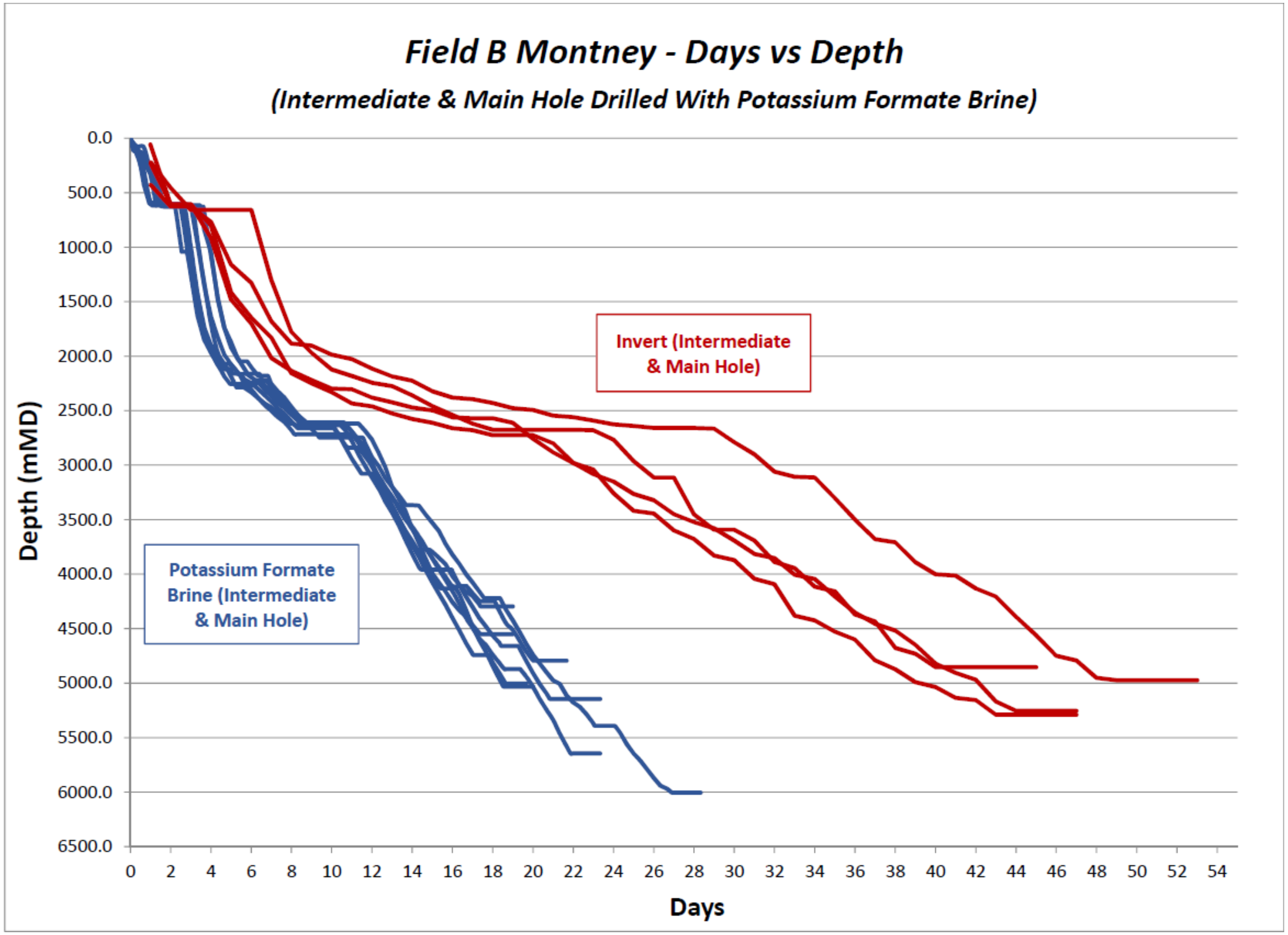
Faster Shale Drilling with Formates: Canada Shale Drilling Performance - II



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Faster Shale Drilling with Formates: Chevron-Encana Experience

- The success of the use of formate fluids on Canadian shale wells has been reported by Chevron - Encana (Siemens and Meyer, 2014).
- Noted various benefits of use of formate muds
  - Elevated, no-solids brine density,
  - Low corrosion tendency,
  - High lubricity,
  - Formation compatibility,
  - Etc.
- 30-40% avg. savings in drilling time
- 17-27% fluid cost savings
- 27% total drilling well cost savings

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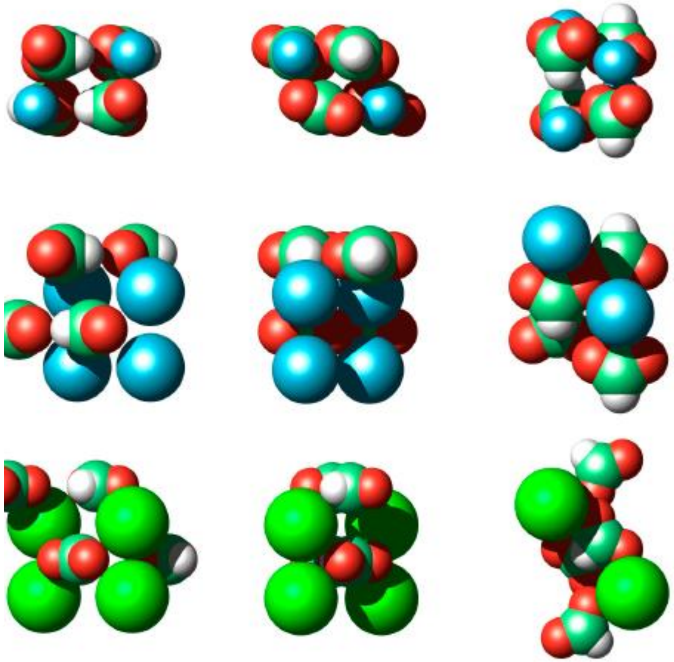
Conclusions & Recommendations

- Formate muds should be seriously considered as drilling fluids that can outperform OBM / SBM in land and offshore shale drilling operations
- Superior shale stabilization, particularly in oil-wet / micro-fractured / high porosity shale
- ROP improvement from formates originates from:
  - Clean, low-solids formulations (reduced chip hold-down)
  - Chemical osmotic effects
  - Secondary benefits:
    - Excellent lubricity, contact friction with steel and formation (for low-solids formulations)
    - Rheology, frictional pressure loss benefits that improve ECD
    - Improved waste management
    - Excellent electrical/resistivity logs

Sodium Formate

Potassium Formate

Cesium Formate



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Acknowledgments

- Siv Howard – Cabot Specialty Fluids
- RAPID Consortium @ UT Austin

RAPID RIG AUTOMATION
Performance Improvement in Drilling

ExxonMobil ConocoPhillips NOV OXY GE BAKER HUGHES PIONEER NATURAL RESOURCES woodside HESS Apache STAGE 3 SEPARATION Shell Anadarko Petroleum Corporation cenovus ENERGY TERADATA ارامكو السعودية Saudi Aramco

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