Energize the CEE Region
Focusing Reliable Energy Security

Workshop

16-17 November 2023, Visegrád

Society of Petroleum Engineers

Energize the CEE Region
Focusing Reliable Energy Security
Workshop
16-17 November 2023, Visegrád

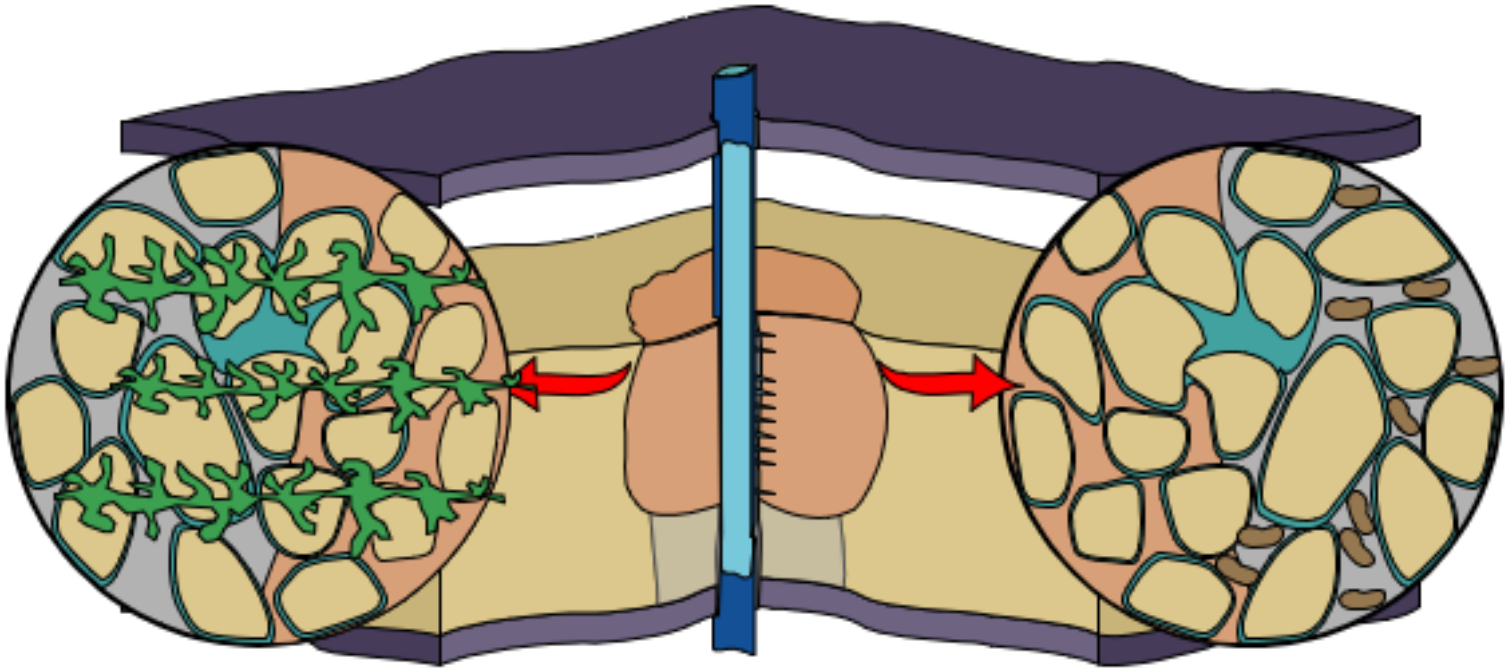
Review of modern Techniques in Carbonate and Sandstone Acid Stimulation

Edmund Eswein
Stimulation Domain Champion Europe

Agenda

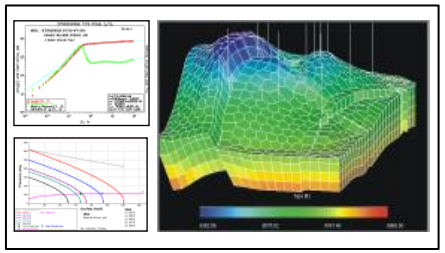
- Matrix Stimulation Application Areas
- Carbonate Acidizing Case Study
  - Workflow Case Study
    - Well Performance Analysis & Creation of a Reservoir Model
    - Fluid Selection
    - Calibration of Acid-Rock Interaction & Advanced Acid Treatment Modelling
    - Implementation and Evaluation
  - Results
- Sandstone Acidizing
- Diversion Technologies

Carbonate vs. Sandstone Matrix Treatment



ACID STIMULATION - INTEGRATED WORKFLOW

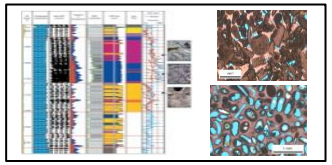
Candidate Selection



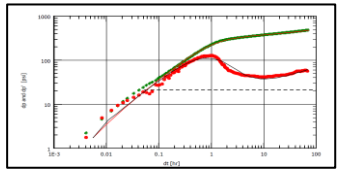
Well candidate selection for stimulation (field analysis)

Reservoir and Rock Characterization

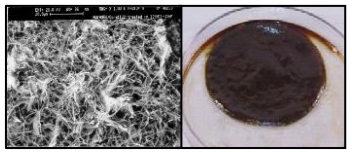
1. *Formation Characterization*



2. *Damage Quantification*

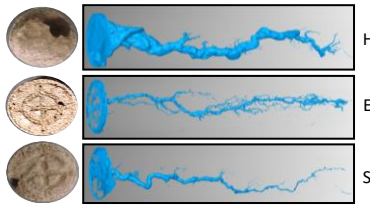


3. *Damage Characterization*



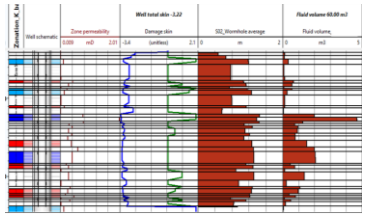
Treatment Design & Optimization

1. *Optimize Volumes, Rates, Fluid Type*



2. *Optimize Placement (Diverters, Flow Path)*

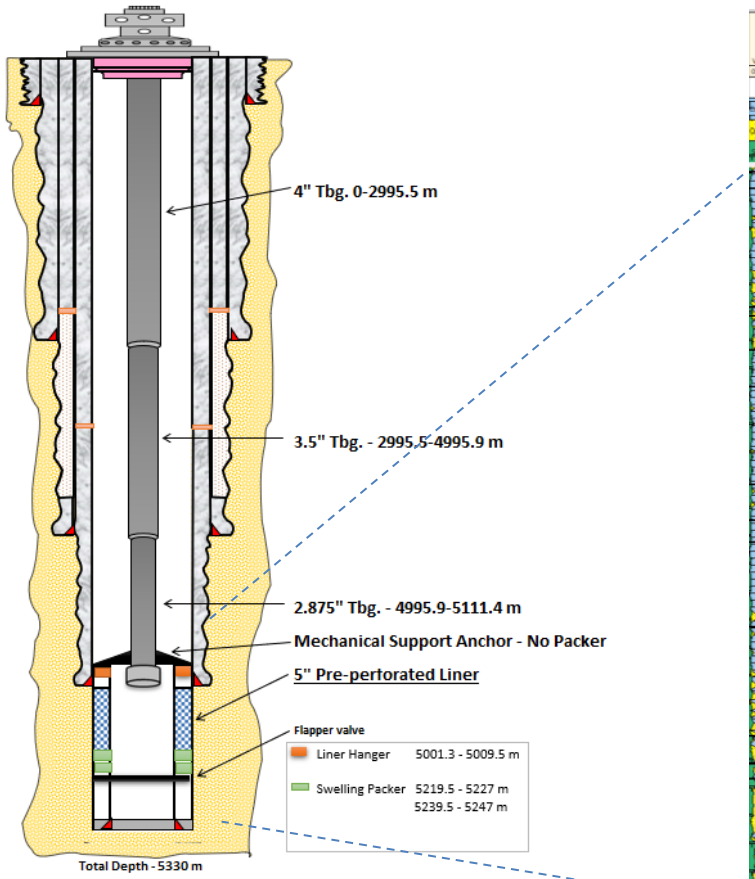
3. *Optimize Treatment (Software Simulation)*

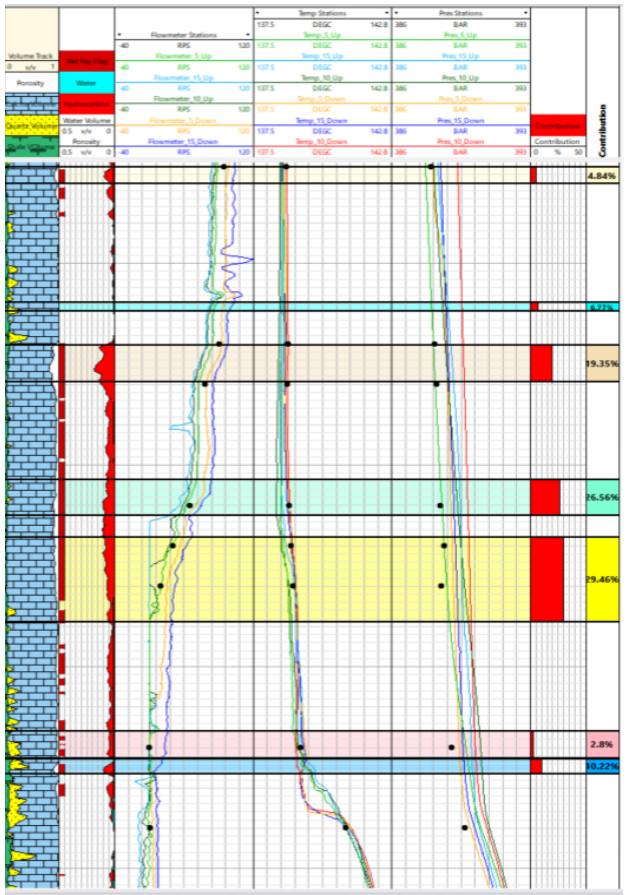


Job Execution and Evaluation

Real-time job monitoring and evaluation

Carbonate Stimulation Candidate





Well Characteristics

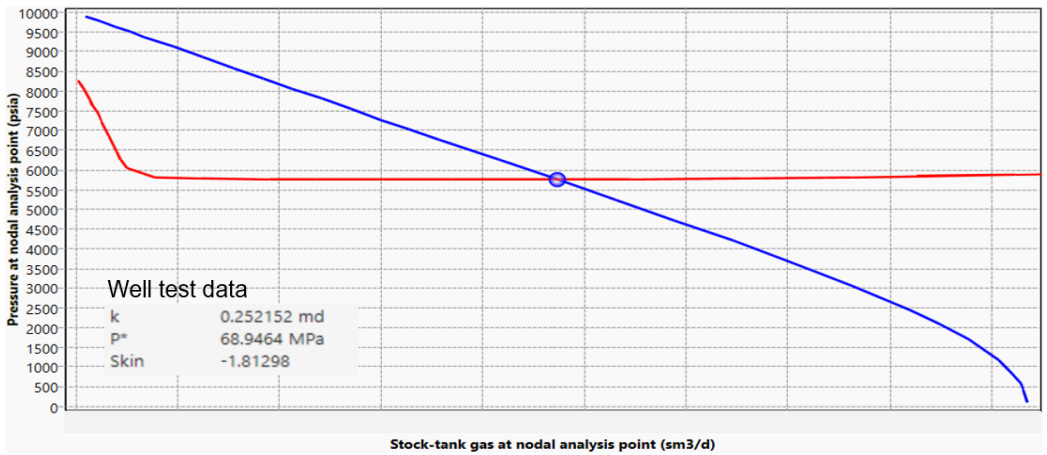
- Vertical, openhole completed with preperforated Liner
- Losses of heavy weight OBM (Barite)
- PLT identified poor contributing zones despite good Reservoir Quality

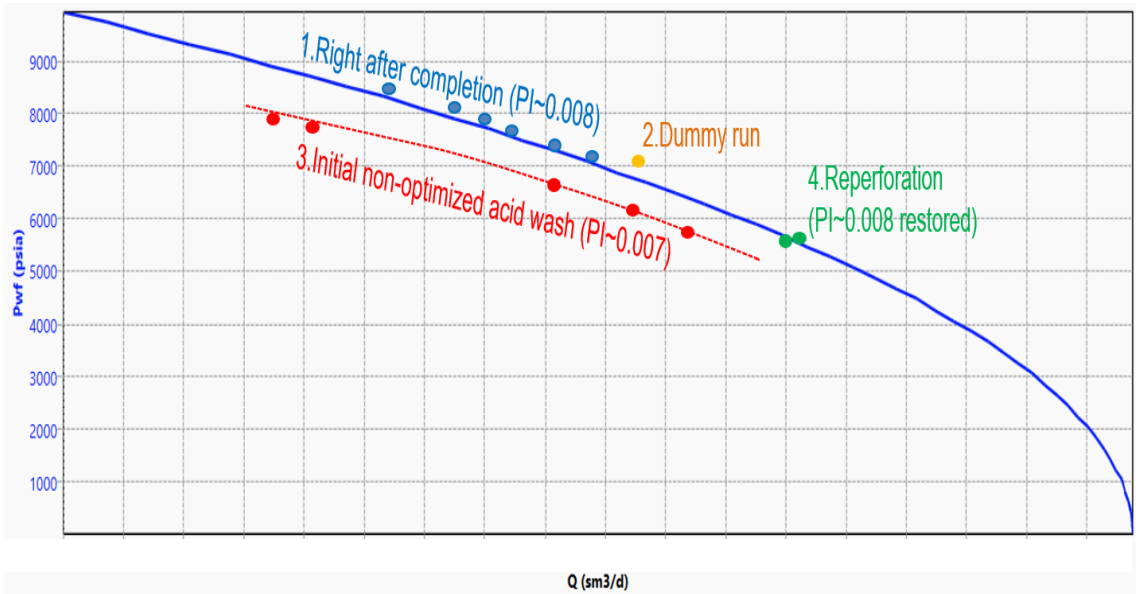
Depth	>5000 m TVD
Lithology	Limestone
Hgross /net (m)	~ 50 m
K (mD)	avg. 0.25 mD
Pres i/cur (bar)	700 / 406
Skin (recent WT)	- 1.8
BHST (°C)	**150°C**

Well Performance Analysis

- Nodal Analysis Well Model based on Well Test & known reservoir parameters / petrophysics / PLT
- Analysis of historical operating points after each intervention to evaluate well‘s response to interventions / stimulation attempts

➢ Valid Model for Production Prediction

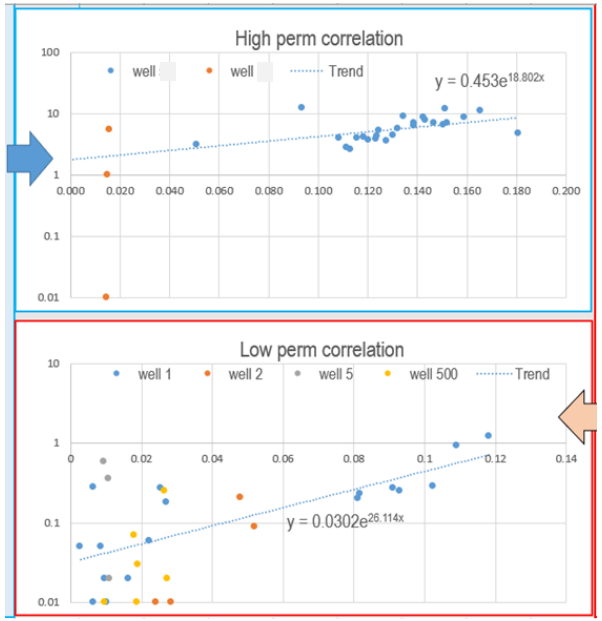




Building a Reservoir Model

Core-based Poro-Perm Correlation

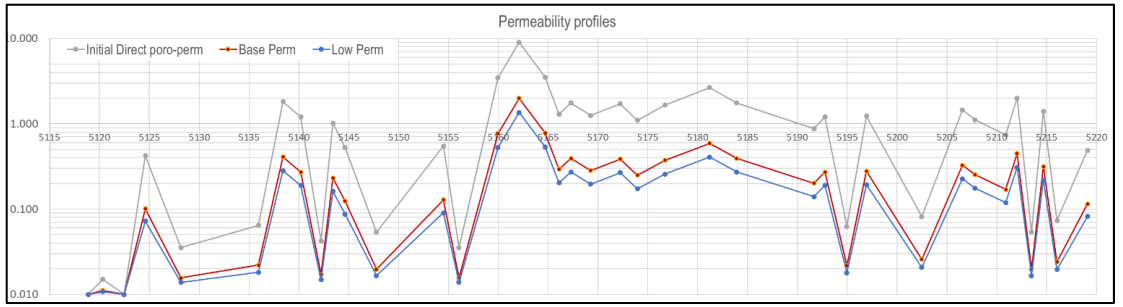
- High and low Permeability correlation derived based on core data from 2 wells,
- Different correlations below and above ~4% porosity

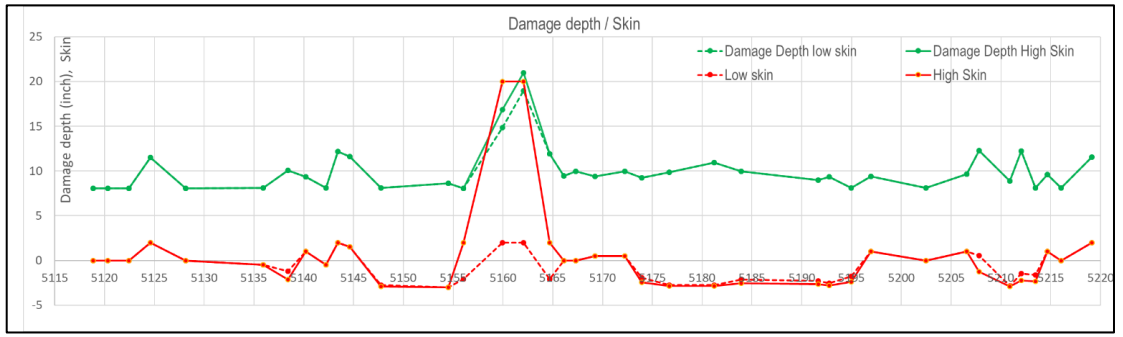


Permeability & Skin Profiles

$$k_{avrg} = \frac{\sum k_i \cdot h_i}{\sum h_i} = k_{well\ test}$$

- Poro-Perm derived profile is iteratively changed to match the average permeability from Well Test
- Skin & Damage Depth Allocation considering PLT & Petrophysics while honoring average skin from Well Test





Fluid Selection

Clean Up Fluids

Requirements:

- Breaking & Dissolution of OBM Filtercake
- Suspension and Transport of Remaining Mud Material

Selection:

- Oil-based mud cleaning fluid blend
- Mud & Silt Removing Acid System



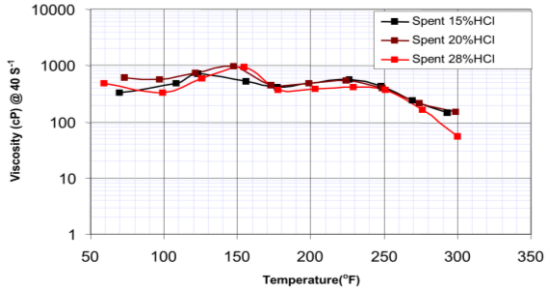
Diversion Technology

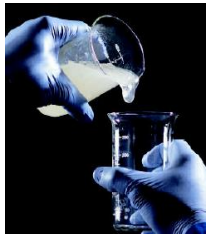
Requirements:

- Minimum Damage
- Diversion Efficiency in High Permeability Contrast

Selection:

- Viscoelastic polymer-free Diverting Acid
- Solvent Pre-& Post-Flush



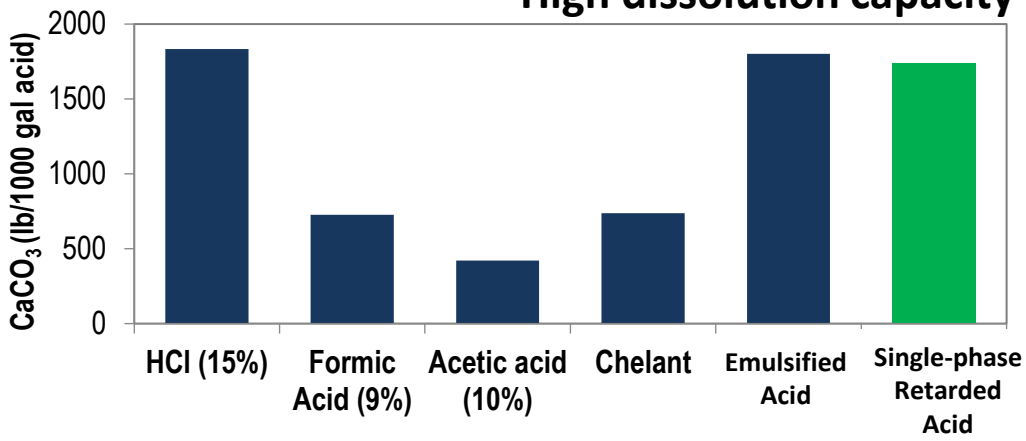



Fluid Selection –> High Temperature Carbonate

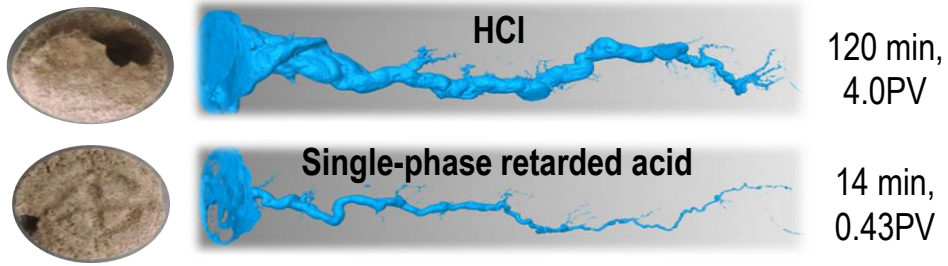
Single-Phase Retarded Acid (SPRA)

Property / Acid Type	HCl	Organic Acids	Chelants	Emulsified acid	Single-phase retarded acid
Dissolution					
Retardation					
Friction Pressure					
Environmental					
Ease of use					

High dissolution capacity

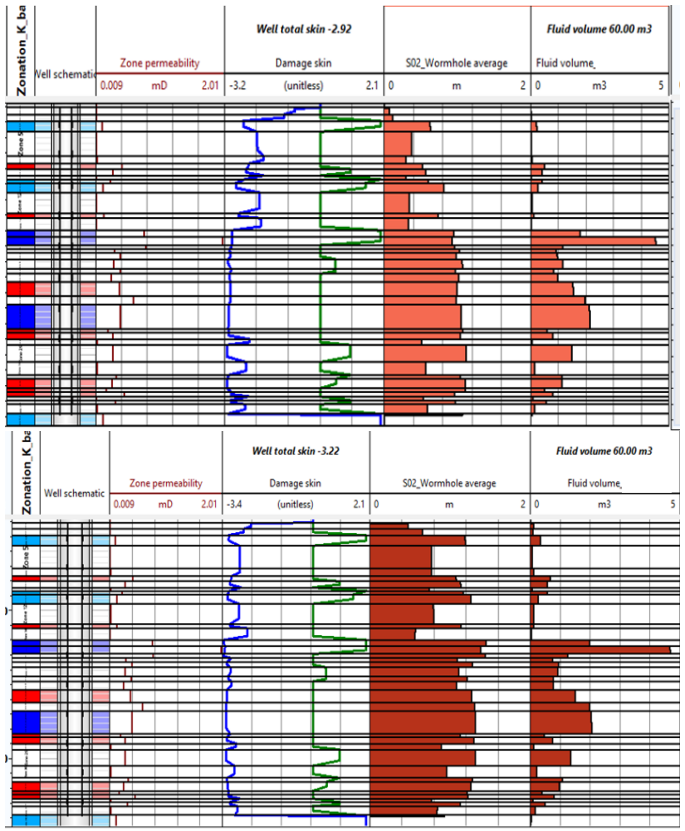


Deep Penetration



Advanced Acid Treatment Modelling and Optimization

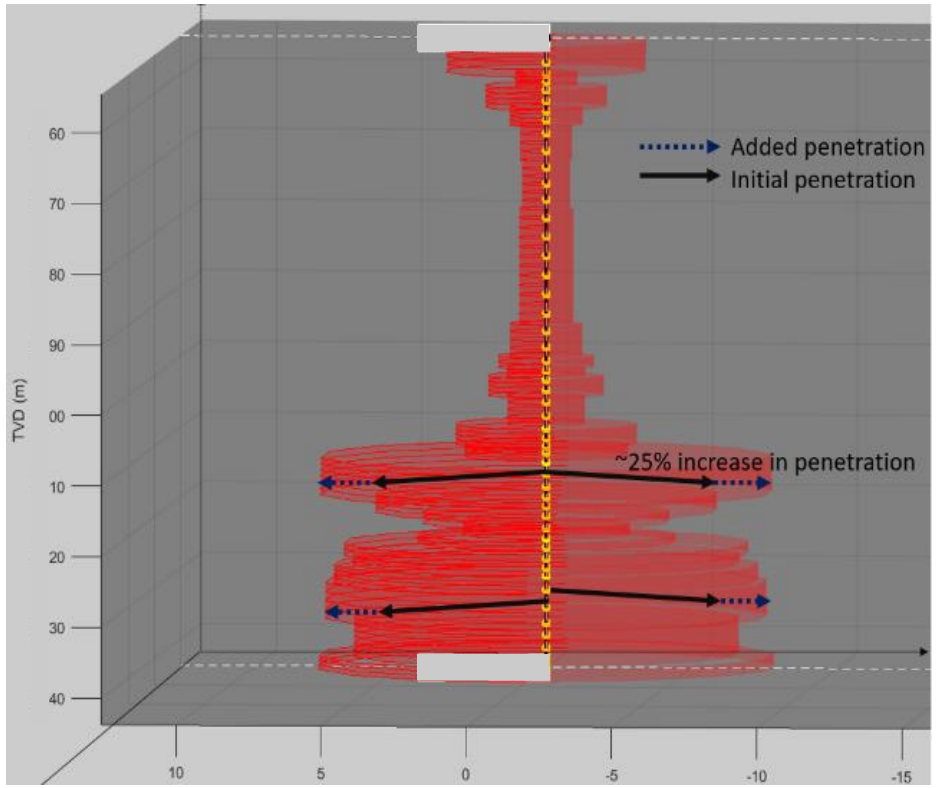
Chelant vs. Single-Phase Retarded Acid Comparison



Chelant Fluid
Volume: 60 m3
Skin: **-2.92**

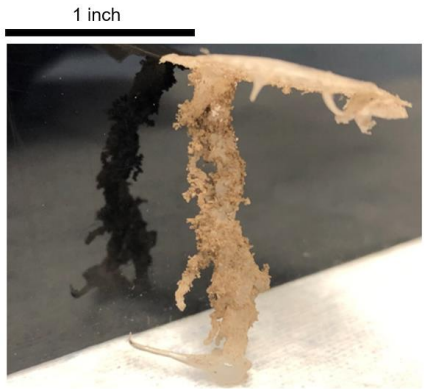
Single-Phase Retarded Acid
Volume: 60 m3
Skin: **-3.22**
Longer Wormholes in upper part of the reservoir

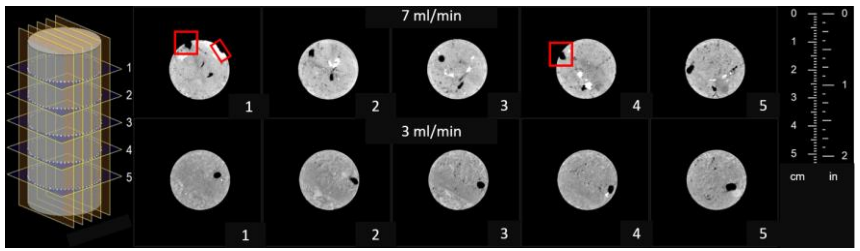
Bullheading vs. CT + Bullheading

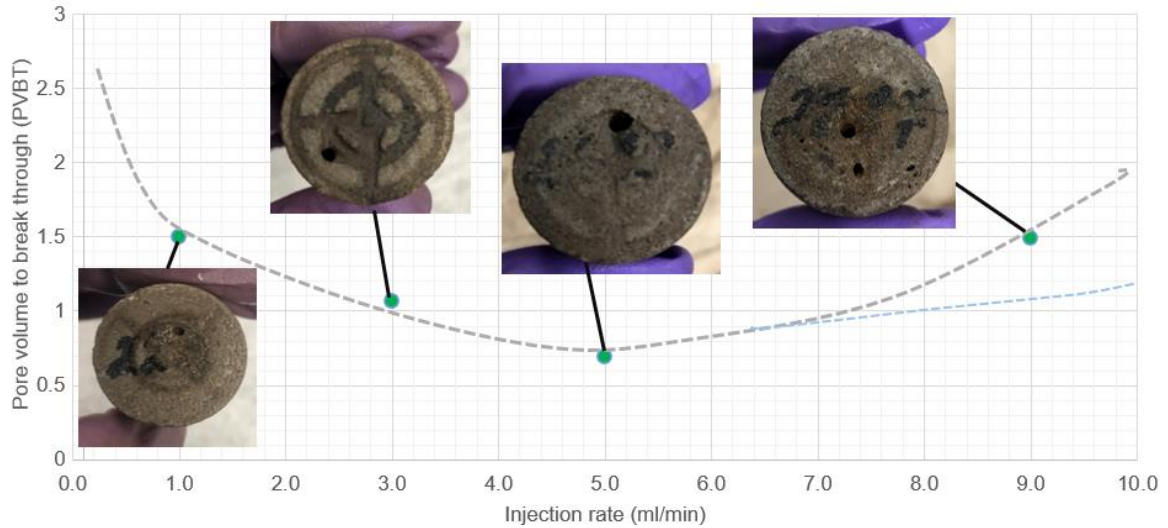


Acid-Rock Interaction Calibration

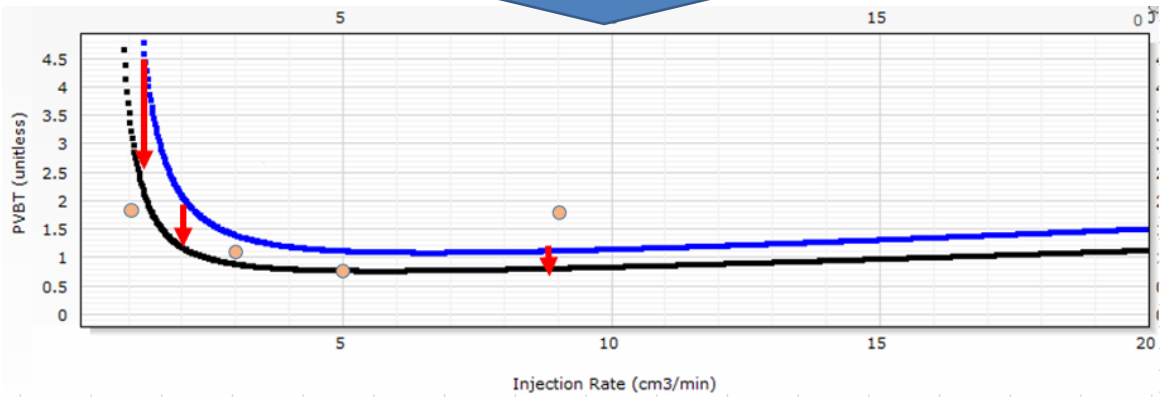
- XRD Test to understand Rock Mineralogy (>95% LS)
- Core Flow Tests to obtain specific PVBT values
- Verification of PVBT results through 3D Visualization of Wormholes





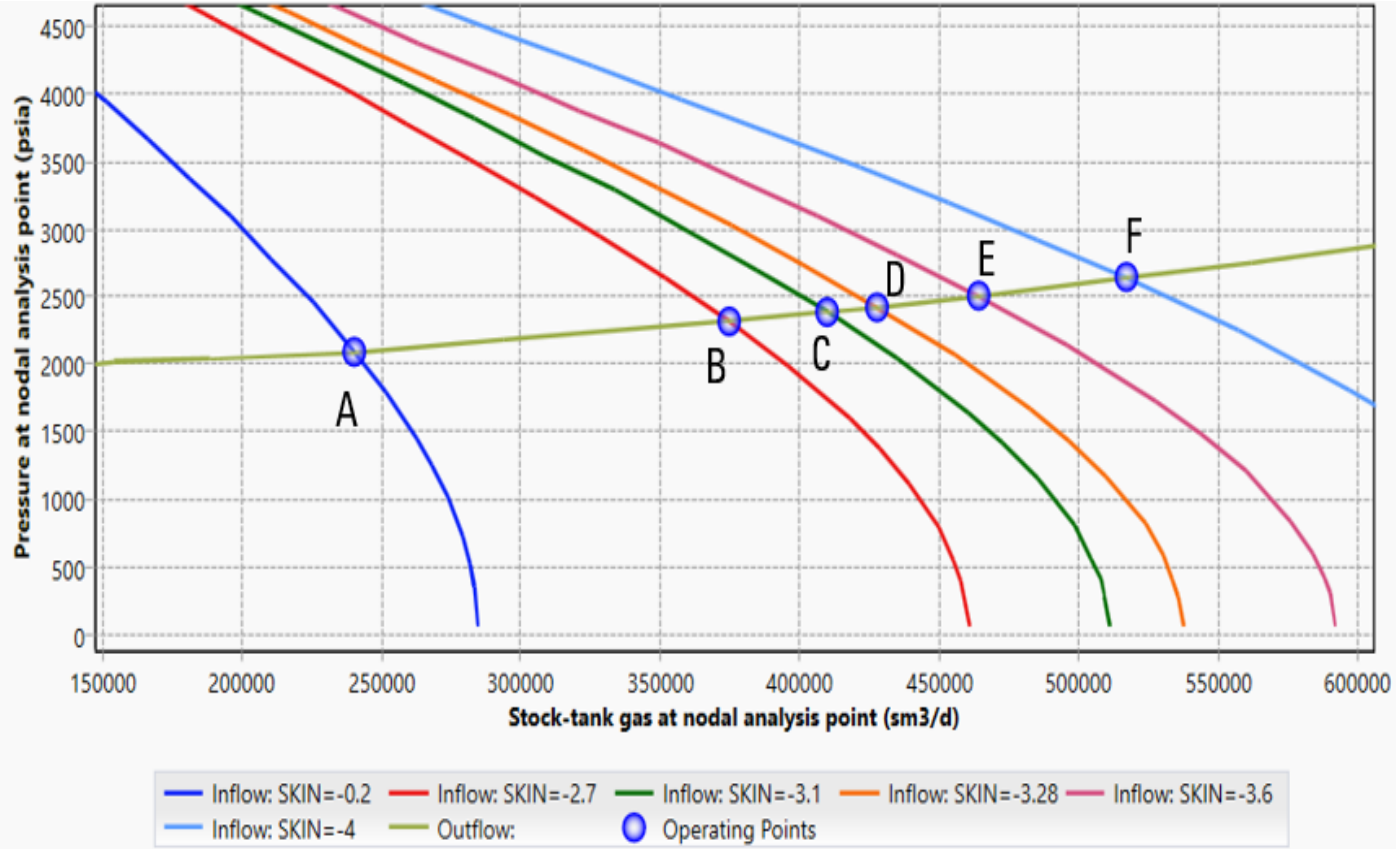


Calibration of Simulator Library Data



Production Forecast for different Stimulation Approaches

Case	Fluid	Deployment	Injection Mode	Skin
A	-	-	-	- 0.2
B	Chelant	CT + Bullheading	Matrix	- 2.7
C	SPRA	CT + Bullheading	Matrix	- 3.1
D	SPRA + Diverter	CT + Bullheading	Matrix	- 3.28
E	SPRA + Diverter	CT + Bullheading	Frac + Matrix	- 3.6
F	SPRA	CT + Bullheading	Large Acid Frac	-4



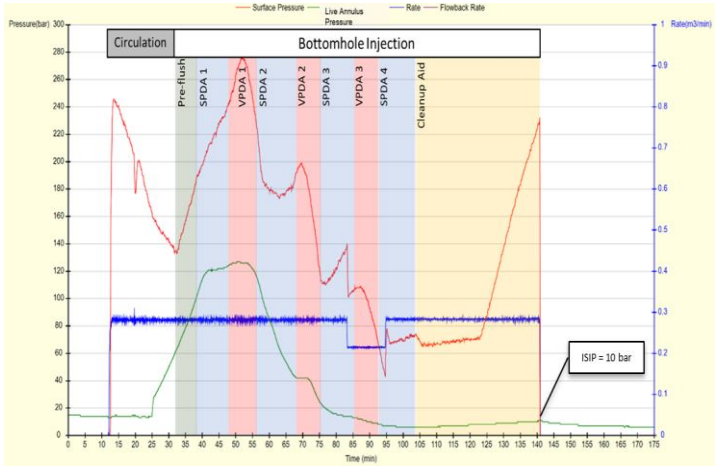
Implemented Operation

Nitrified CT CleanOut

- Clean annulus between openhole and slotted liner with minimum losses into formation
- Break and remove any residues to precondition the well for acid stimulation

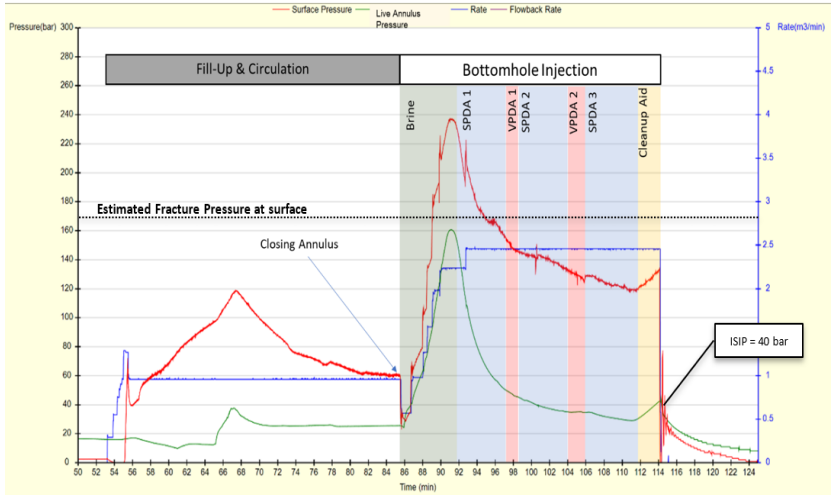
CT Acid Matrix Treatment

- Targetted Acid & Diverter place-ment to access underperforming zones
- Alter injection profile favoring the main treatment efficiency and increase radial Acid Penetration (+25%)

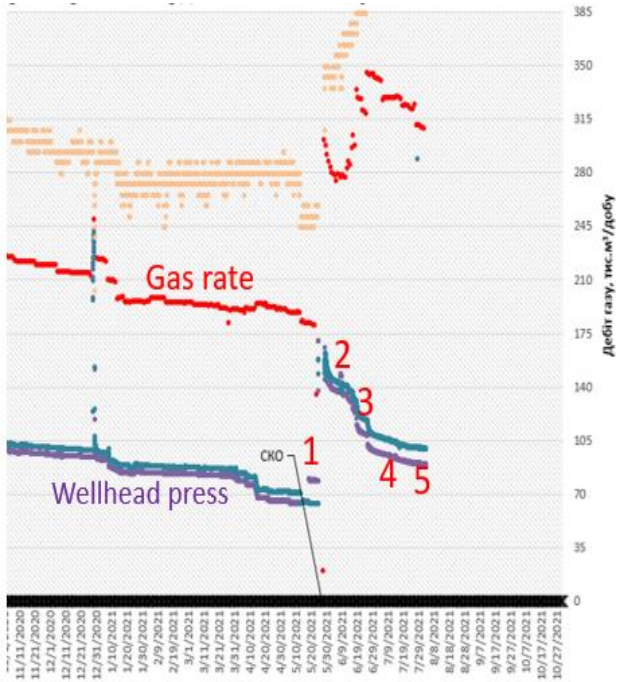


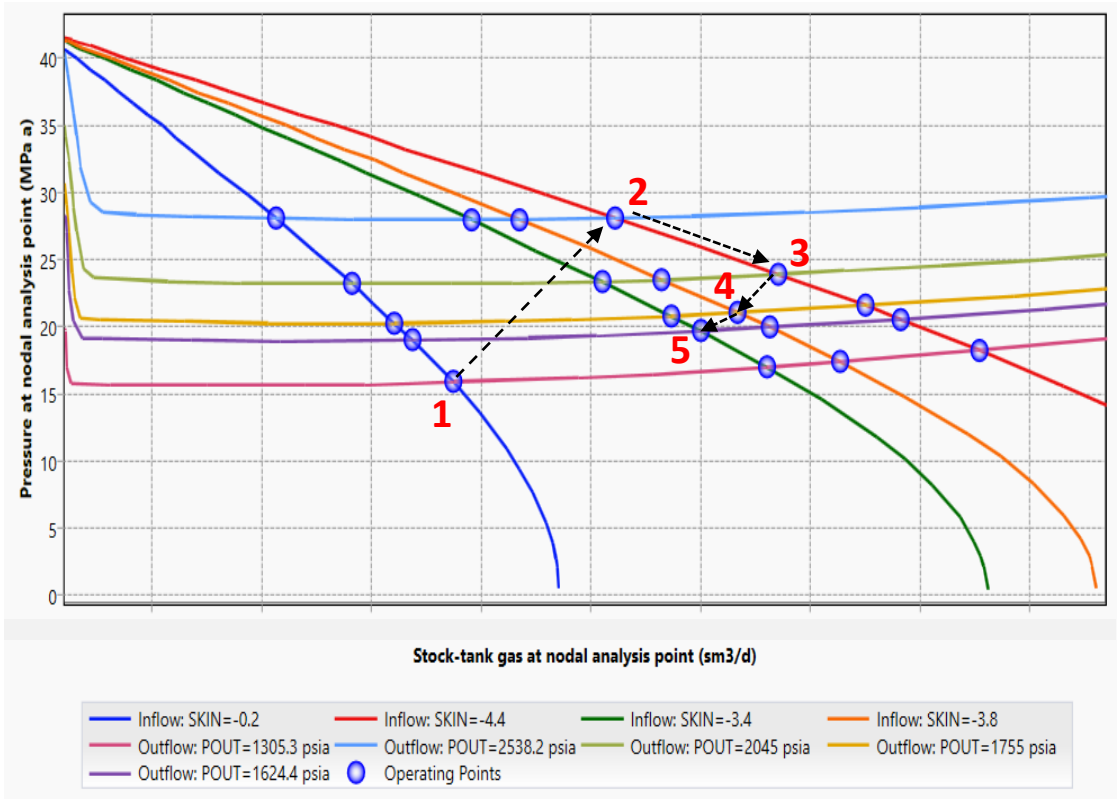
Acid Bullheading

- Main Stimulation Treatment including Diverter to maximize Wellbore coverage and Acid Penetration
- Injection initially in Frac Mode, transitioning into Matrix Mode



Well performance before and after stimulation





Operating Point	Timing	Skin
1	Pre-Stim	-0.2
2	Post-Stim	-4.4
3	Post-Stim	-4.4
4	Post-Stim	-3.8
5	**Post-Stim**	**-3.4**

Stimulation Campaign Results

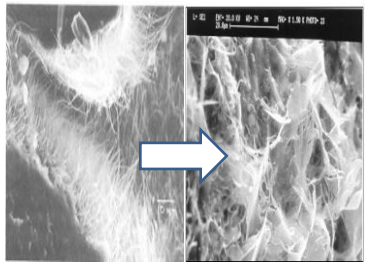
Parameter	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6
Total volume of acids pumped*, m^3 (bbl)	70.4 (442.8)	85.6 (538.4)	105.8 (665.5)	101.5 (638.4)	105.0 (660.4)	122.5 (770.5)
Target interval length, m (ft)	98.9 (324.5)	136 (446.2)	120 (393.7)	90 (295.3)	92 (301.8)	202 (662.7)
Maximum pumping rate, m3/min (bbl/min)	2.46 (15.5)	3.07 (19.3)	2.96 (18.6)	3.54 (22.2)	2.98 (18.7)	3.2 (20)
PI FOI	**4.3**	**3.21**	**2.42**	**2.1**	**2.42**	**2.18**

*Normalized for 15% HCl acid strength

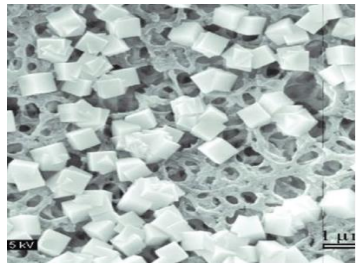
SANDSTONE ACIDIZING – CHALLENGES & REASONS FOR FAILURE

- Inadequate damage characterization and fluid selection e.g. acid sensitive clays
- Complex secondary and tertiary chemical reactions
- Ineffective reservoir coverage, insufficient volume and lack of diversion
- Human error during the complex design and execution process

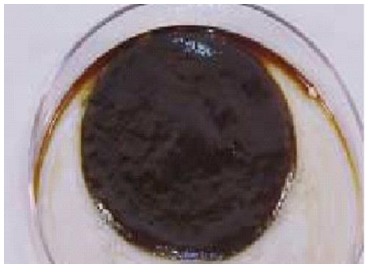
Clay Swelling/Pore blockage

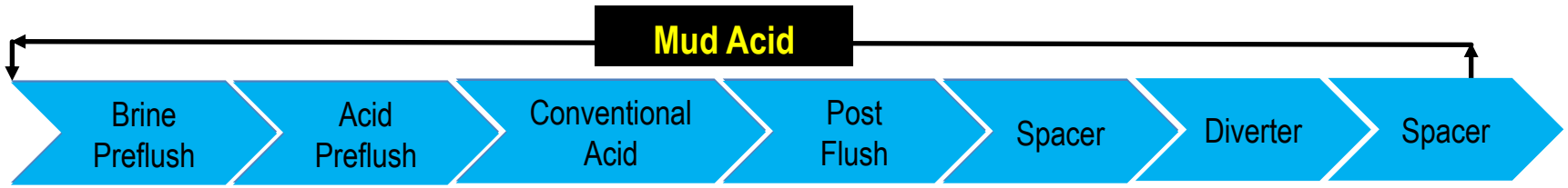


Insoluble Precipitates



Sludge and Emulsion

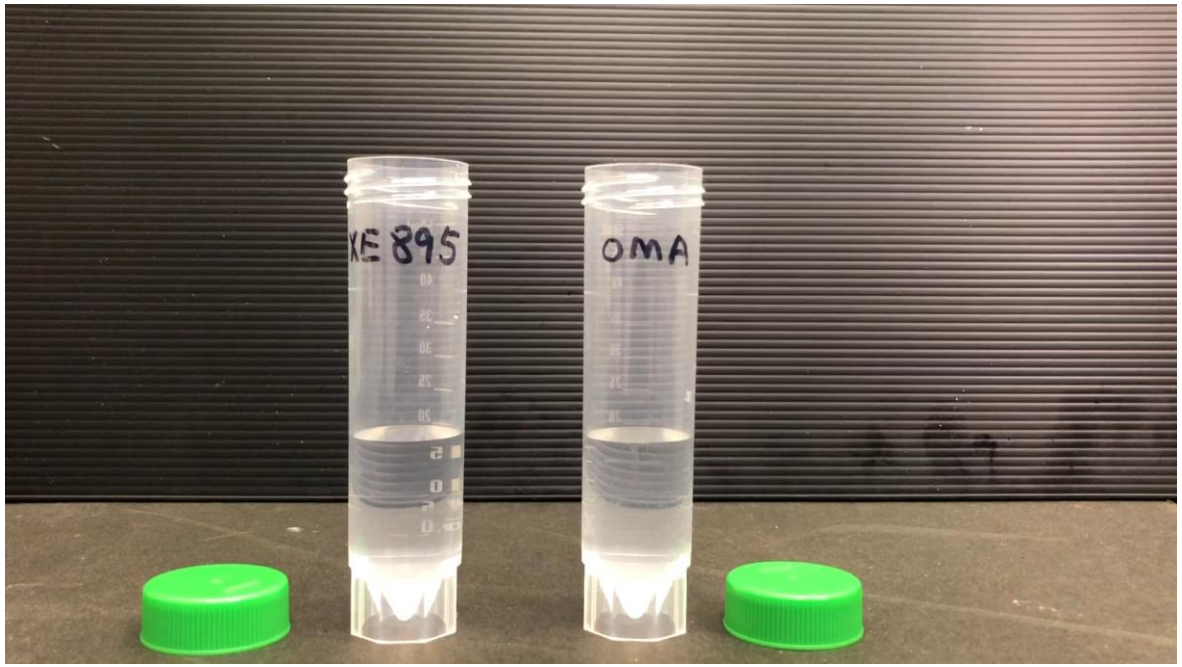




SINGLE STAGE SANDSTONE ACIDIZING FLUID

- Fluid system enables Single Step Operation
  - Lower Volume / Pumping Time / Resources
  - Low Precipitation Risk –> Low Risk of Failure

- Temperature range of 54-177 degC



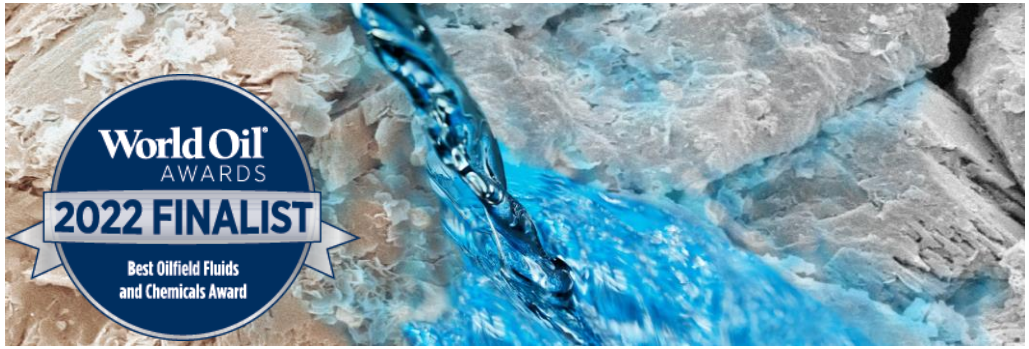
Mud Acid

Brine Preflush → Acid Preflush → Conventional Acid → Post Flush → Spacer → Diverter → Spacer

Single Stage Sandstone Acid

Lower Vol Preflush → SSSAF → Diverter → Spacer

Single Stage Sandstone Acid Treatment reduces Treatment Volume up to 50%

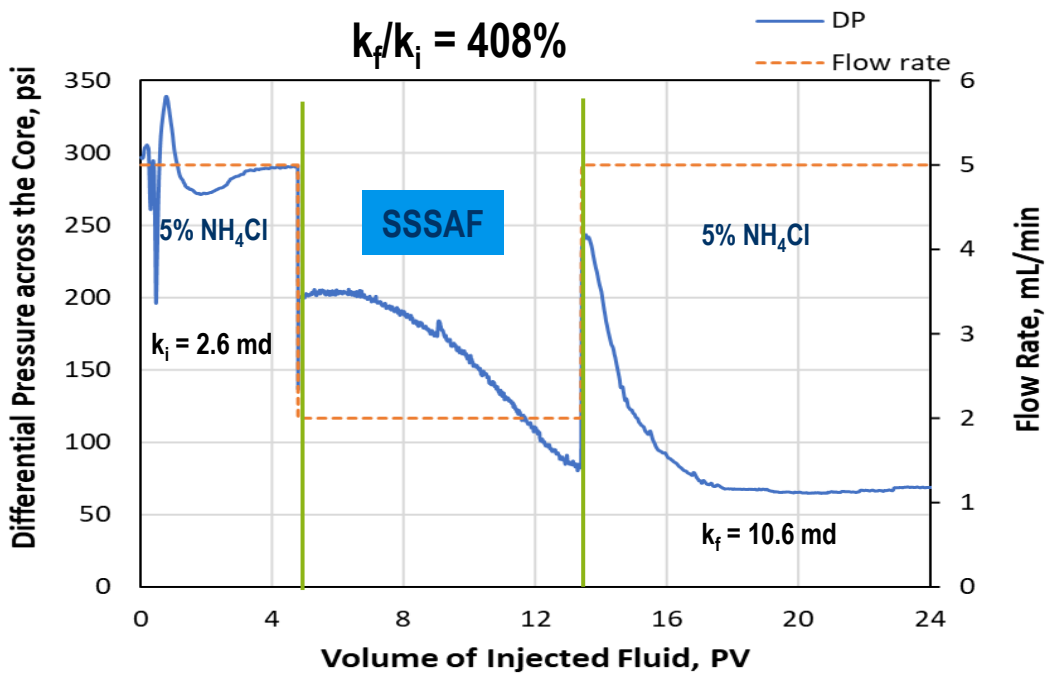


Energize the CEE Region
Focusing Reliable Energy Security
Workshop
16-17 November 2023, Visegrád

SPE International
Hungarian Section

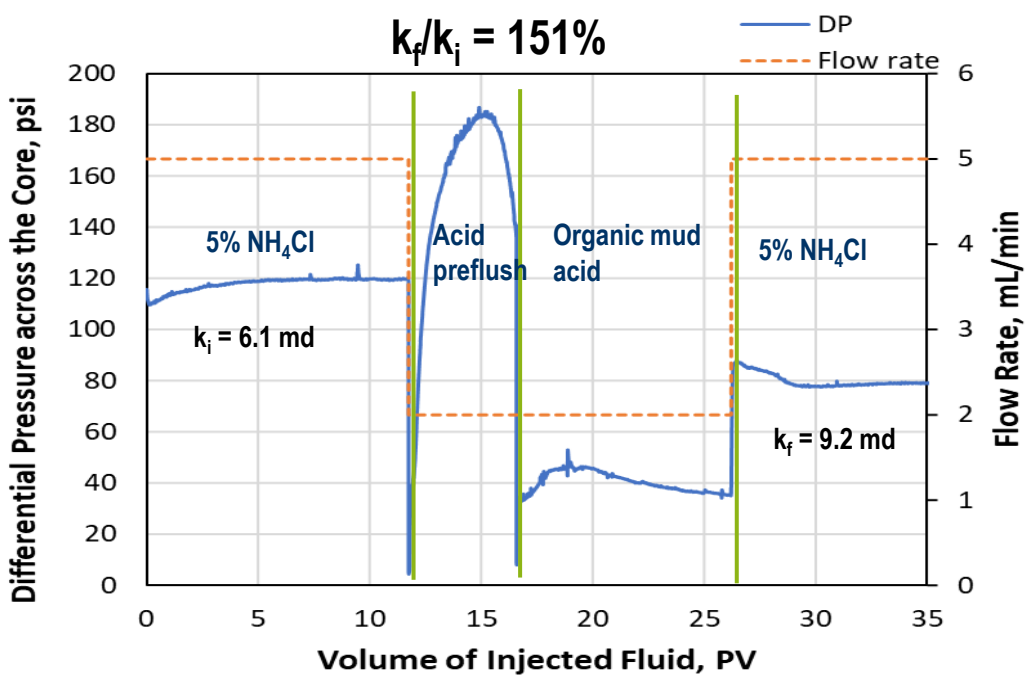
FLUID PERFORMANCE AT HIGH TEMPERATURE

Single Stage Sandstone Acid



Bandera gray core, 300°F, 10 PV main acid
back pressure: 500 psi ; confining pressure: 2000 psi

Organic mud acid + acid pre-flush



Preflush: 10% formic acid, **5 PV**
Organic Mud acid: 9/1 formic acid/HF, **10 PV**

CASE STUDY – NORTH AFRICA

Challenge

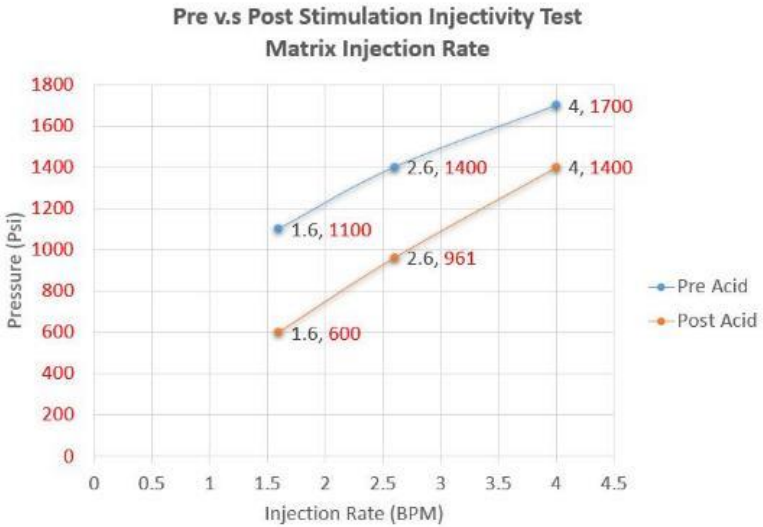
- Boost Production from older well re-entry.
- Produced ~ 100 bopd before decline and shut in in 2000
- Quartzitic Sandstone with acid sensitive clays
- Unsuccessful mud acid treatments

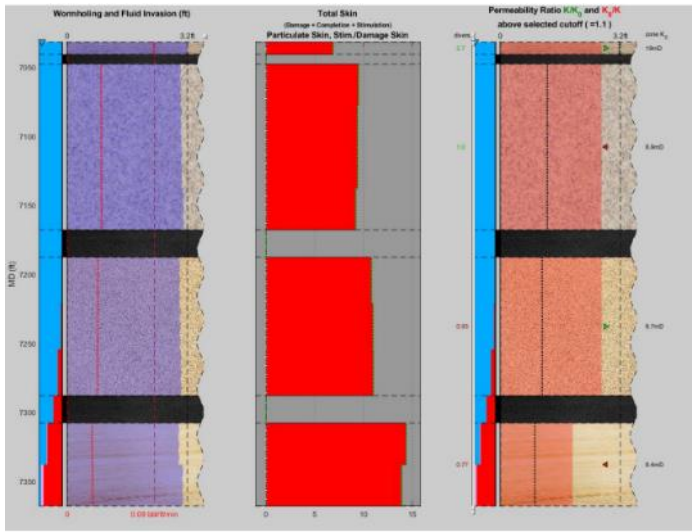
Solution

- Low risk, high efficiency Single Stage Sandstone Acid
- Stimulation modeling using Kinetix Matrix

Results

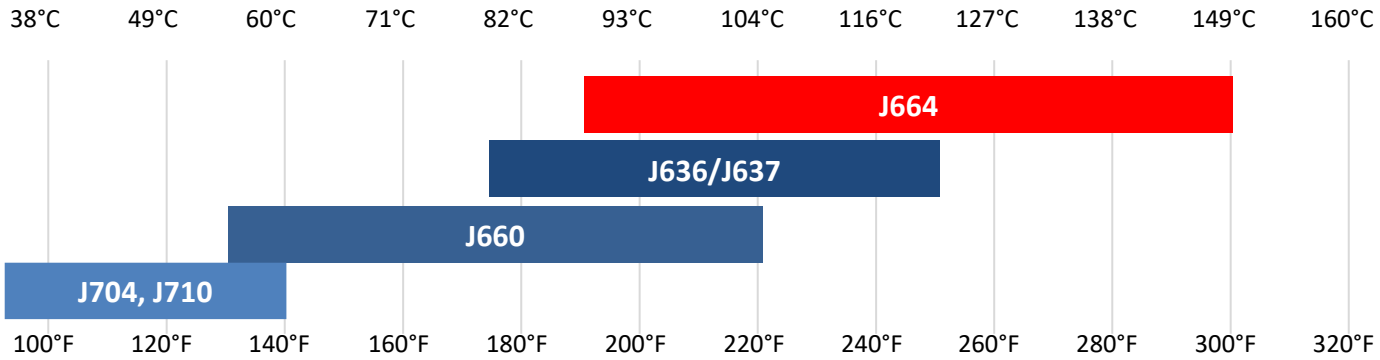
- Significantly increased injectivity post to pre acid stimulation
- Early Production results show restoration of production to 170-180 bopd. Full production results pending (Update as of Feb 2023)
- Client is planning a larger campaign for the year



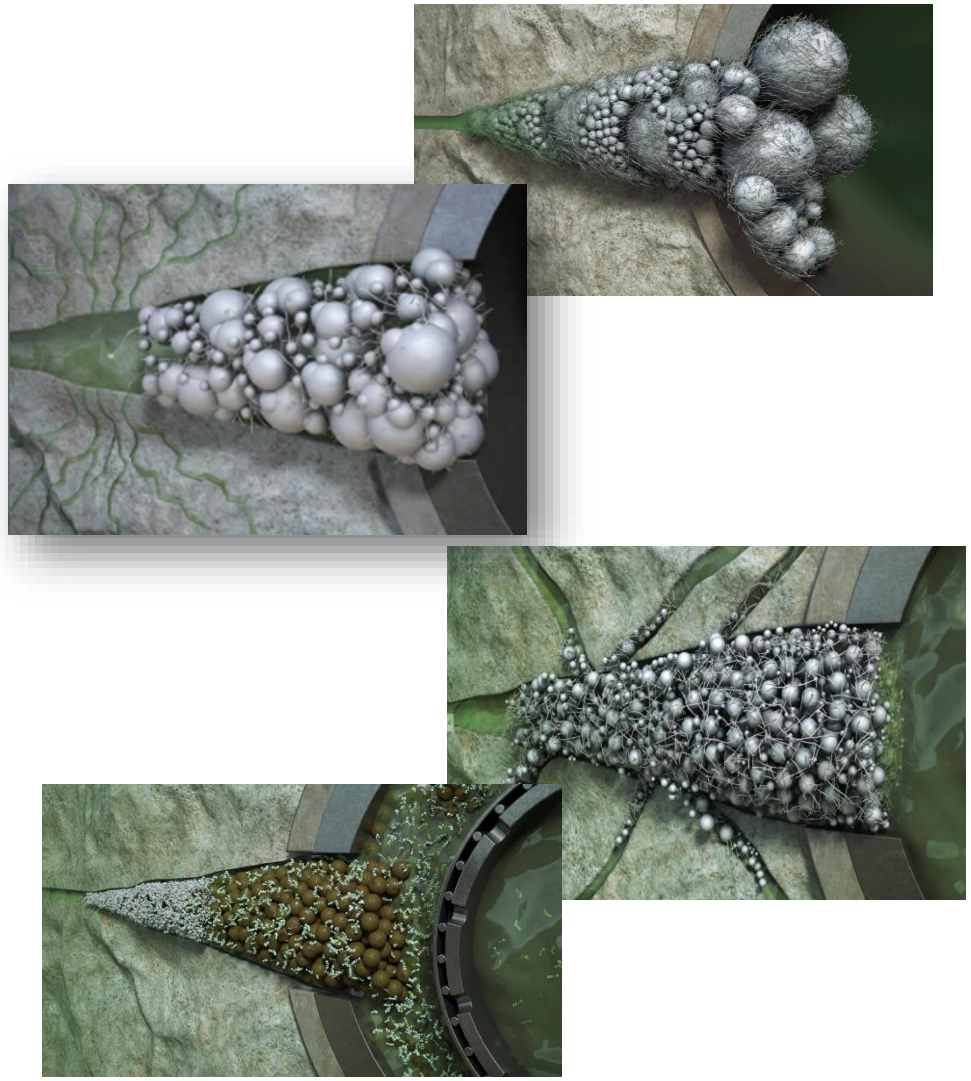


Degradable Particulate Diversion Materials

- Combination of degradable fibers and multi-modal particles
- Effective diversion for acid fracturing or matrix stimulations
- 4 different materials for BHT range is 130 to 350˚F (54 to 177˚C)

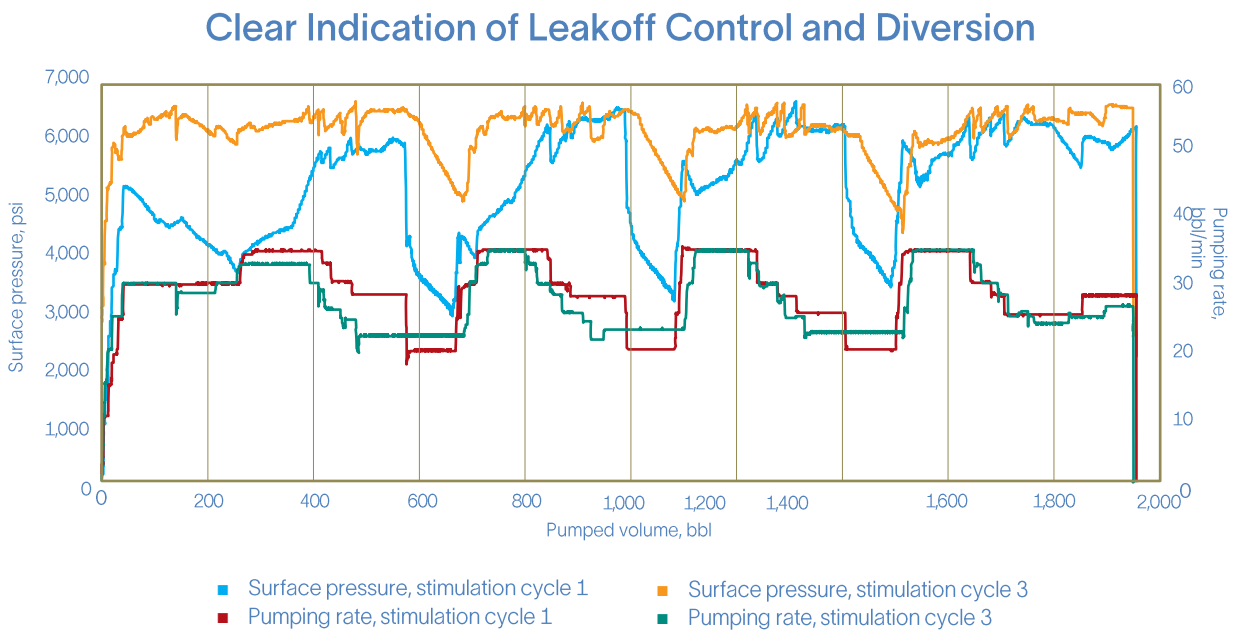


Degradation of J636 (mass loss)



CASE STUDY – ACID FRACTURING

- Challenge
  - Economically stimulate oil production from an offshore horizontal well through a hot carbonate formation
- Solution
  - OpenPath Sequence service with two diversion stages
- Results
  - Increased productivity index by >300%
  - Boosted oil production by 243%



Fluid Flow Distribution, % of volume injected			
	Prejob Test	After First Diversion Stage	After Second Diversion Stage
Upper interval 1	41	16	15
Upper interval 2	5	3	22
Upper interval 3	25	10	13
Upper interval 4	6	7	2
Upper interval 5	23	64	35
Lower interval	0	0	13
Total	100	100	100

Thank you!