Deepwater Nigeria Acid Stimulation Case Study

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Presentation Outline

• Executive summary
• Intelligent well completion configuration
• Well surveillance & candidate selection process.
• Well damage mechanism.
• MPV vs Rig deployed acid stimulation.
• Case histories.
• Conclusion & key learnings
Executive Summary

Discussion Topics

- Well completion damage mechanism.
- Acid stimulation candidate selection.
- Acid stimulation case histories
- Best practices & challenges.

Key Messages

- Declining oil rates have been observed in a number of wells due to Large and Increasing skin.
- Increasing skin values have been as a result of fines migration during production.
- Skin damage has been successfully treated in 11 producers, helping to restore ~ 71 MBOPD of incremental production.
- Fourteen (14) of the acid stimulation jobs were conducted utilizing a rigless acid stimulation system, while one job was performed from a drill ship.
- Compared to the rig option, the rigless system provides $7MM – $8MM/ job savings and much lower deferred production from shut-ins.
- Detailed design of acid recipe and flowbacks ensured no adverse impact to topside process equipment and acid stimulations Ops can be safely performed.

Desired Outcomes

- Share the successes of acid stimulation campaigns in the deep water field offshore west Africa using a Multi-Purpose Vessel [MPV] & the tremendous execution efficiencies & cost saving advantages over a conventional rig.
- Demonstrate the value of diligent data gathering and provide insights into a systematic, data driven candidate selection process.
- Share lessons & best practices & demonstrate how diligent application of look backs & lessons learned resulted in outstanding results.
Intelligent Well Completion Configuration

- Allows real-time pressure, temperature, density and flowrate measurements.
  - Enables effective well performance modeling & monitoring.
- Provides downhole/Sand-face Shut-in capability via ICV’s
  - Zonal production optimization
  - Facilitates accurate data capture for PBU analysis.
- Configured to take advantage of opportunistic shut-ins to obtain build-up data for analysis.

All Wells (Producers & Injectors) are equipped with intelligent completions
Data Gathering & Pressure Build-up Analysis

- Planned Pressure Build-up tests & pressure data from ESD’s provide multiple data points for well performance analysis.

- High skin wells & zones are identified from PBU data & a preliminary list of candidates is generated.

- Candidates are monitored & the list is kept evergreen. As skin increases, wells are choked back to honor the flux constraint and prevent completion failures.

- Candidate wells & zones are further evaluated based on expected rates.
Why So much Skin?

Rock Mineralogy
- Reservoir is composed primarily of quartz, with smaller amounts of feldspar and clay.
- Approximately 50% of the clay is kaolinite, which has the potential to migrate during high rate flow.

Surge & Compaction
- Multistage Surge Tests reveal that:
  - Emergency shutdowns (ESDs) & rapid well restarts cause grain fracturing in the near wellbore area.
  - Permeability decrease in the range of 14-18% was observed on cores samples.

Sand Mineralogy

Quartz
Feldspar
Kaolinite
Other Clays

Crushed/Broken Grains
Migratory Clays
Multistage Surge Tests

Fines Migration
Acid Sensitivity Test

• Two acid systems were identified & tested for use:

1. **OneSTEP Acid**
   – Core sample showed slightly improved permeability after treatment.
   – If the expected cause of damage is crushed, fractured grains or fines migration, the OneStep System is recommended.

2. **Organic Mud/Clay Acid**
   – Higher Strength.
   – Core sample showed significant permeability increase after treatment.
   – Recommended if damage from crushed, fractured grains & fines migration is excessive.

• **Both acid systems showed no signs of emulsion or incompatibility with crude & formation brine**
Acid Stimulation Candidate Selection Criteria

Three questions to answer when planning an acid campaign:

Which well or zone to acidize?
- High Skin: >20 & history of increasing over time.
- Low Oil rate wells.
- Low GOR & BS&W
- Sufficient Riser Capacity: (bottlenecked system).
- Well bore concerns. (EV, Completion integrity, etc.)

When to perform the acid job?
- Field Below Capacity
- No new wells/production coming on.
- Host Facility Readiness to receive flowback.
- Reservoir Mgmt. considerations – Voidage etc.

What type of acid to use?
- Pump mildest acid that will successfully treat the skin.
- Utilize Core tests results.
- Historical performance of each acid recipe on individual wells.
- Work vessel capacity (deck space, tank capacity, etc.).
Configuration of Rigless (MPV) Acid Stimulation

- 70m RELIEF WIRE IS INSTALLED

75m GOLDEN EAGLE

COIL TUBING

CLUMP WEIGHT

TRIPPLE J CONNECTOR

EMERGENCY QUICK DISCONNECT

70m RELIEF WIRE

GAS LIFT CONNECTOR

CHECK VALVE

PRODUCTION TREE
Acid Stimulation: Multi-Purpose Vessel vs. Rig

### MPV Time Benefits:
- Fewer runs.
- No need to pull crown plugs.
- Well access is through Gas Lift Connector (GLC) on Xmas Tree.
- BOP Run/Hook-up/Testing much faster. (<1 day vs. 2-3 days from rig).
- Lower execution days (3 days vs 7 days from rig).

### Cost Comparison

<table>
<thead>
<tr>
<th></th>
<th>RIG</th>
<th>RIGLESS</th>
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<tbody>
<tr>
<td>Cost</td>
<td>$1 MM/DAY</td>
<td>$0.1 MM/DAY</td>
</tr>
<tr>
<td>Days (Well Shut-in)</td>
<td>6-7</td>
<td>1-2</td>
</tr>
<tr>
<td>Deferred Production</td>
<td>BIG</td>
<td>SMALL</td>
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specific acid stimulation cases
**Acid Stimulation Case 1**

**Discussion**
- The well started production in Aug 12 & the UZ tested ~8,000 bopd with a PI of 7.6 stb/day and skin of 29,
- 6 months later the oil rate had halved while the skin had doubled with the PI @ 4 bbls/day/psi.
- Analysis revealed SKIN damage was due to fines migration.
- A rig-less acid stim intervention from a MPV using One Step acid was conducted.

**Results**
- Safely executed – no incidents
- 4300 BOPD increase (+90%)
- Skin decreased from 59 to 14
- LPO – 1 day <7,000 BO
- Successfully flowed back to FPSO
- Economic Payout - < 1 month

EXCELLENT RESULTS!!!
Acid Stimulation Case 2

Well 2B Discussion

- Well 2B started production in 2010 at ~16 MBOPD & peaked @ ~19 MBOPD in 2012
- 2012: Skin had increased from 18 to > 70
- Oil rate declined to 7.5 MBOPD.

Acid Stim -1 (2014)

- One-Step mixture deployed.
- Not successful: Skin increased to 95
  - suspect acid mixture was weakened due to delay in pumping acid after mixing.

Acid Stim -2 (2015)

- One-Step mixture pumped
- Following 'lessons' learned from first attempt, acid was pumped immediately after mixing.
- Not Successful – Commissioned core analysis.
- OMA/OCA was recommended for this well.

Acid Stim -3 (2016)

- Rate = 1,100 BOPD, skin >100 & PI ~0.5bopd/psi
- OMA/OCA/Acetic cocktail deployed.
- No Delays between mixing & pumping.
- Post acid rate = 18,300 BOPD
- Skin Dropped from 110 to 24

EXCELLENT RESULTS!!!

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<tr>
<th>Pre-Acid</th>
<th>Post-Acid</th>
<th>Actual Incremental</th>
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<tbody>
<tr>
<td>BOPD</td>
<td>Skin</td>
<td>PI (b/d/psi)</td>
</tr>
<tr>
<td>1077</td>
<td>110</td>
<td>0.4</td>
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</table>

Well 2B Production Profile

Finally! After 2 unsuccessful attempts
**Acid Stimulation Case 3**

**Discussion**
- Well completion damaged from LCM pumped to control fluid losses during completion operations.
- Rig attempted to deploy acid after completion but aborted due to failure to pump into well.
- Well started up & the LZ Cleaned up but UZ High skin (207) & Low rate 1,460.
- A rig-less acid stim intervention from a MPV using Acetic/OMA/OCA cocktail was conducted.

**Results**
- 13,079 BOPD Increase (+900%)
- PI increased from 3.5 to 15.8 BOPD/PSI
- <1 day of actual pumping operation
- LPO: 1/2 day – 3,800 BO (LZ SI)
- Successfully flowed back to FPSO
- Economic Payout - < 1 month

**EXCELLENT RESULTS!!!**
## Process improvement from application of Lessons

<table>
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<tr>
<th>Campaign</th>
<th>Lesson</th>
<th>Action</th>
<th>Results</th>
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| 3        | Increase in well skin after application of One-Step. | Conducted core Studies & selected Appropriate acids. | • Significant skin reduction.  
• > 1000% increase in oil rate |
| 4        | Inadvertent Flowback of unspent acid despite sufficient soak time. | HBSW zones opened & their flow rate increased during flowback | • Preserved riser and topside equipment. |
| 2        | Acids got spent on deck before pumping leading to poor results. | Doubled work crews – added a night crew. | • Improvement in efficiency & prep time reduction by 50%.  
• Mitigated risk of deploying spent acids. |
| 1        | Initial campaigns utilized Anti-foaming & Increased Emulsions Breaker injection to mitigate topside issues. | Conducted fluid compatibility tests which eliminated the need for anti-foam. | • Reduced costs from chemical application. |
Key Lessons

Well Selection:
• Properly identifying and quantifying well damage requires data & analysis from pressure build up (PBU) well tests & analysis.
• High Skin & Low rates wells are not always the best candidates. The impact on the entire field production has to be considered as well as possible impact of increased Gas & water.
• A structured Multidisciplinary approach is critical in candidate selection, planning & execution.
• Proper analysis of core is required to understand the damage mechanism.

Acid Selection:
• Understanding damage mechanism will enhance the right selection of acid for the stimulation job. Core studies and acid compatibility tests are crucial to a successful cocktail selection. One size does not fit all!

Acid Deployment:
• Ensure sufficient over-flush of acid into formation to minimize live-acid contact with completion jewelry & prevent damage.
• Develop contingencies in the event the formation is unable to take the acid. Consider pumping acid into other zones.
• Top sides should be prepared to receive live acids. – increase corrosion inhibitors dosage etc.
• Design a topsides flowback path that minimizes contact with process equipment.
• Ensure acid compatibility with produced fluids & ensure issues such as foaming etc. are identified & mitigated adequately.
The End

Thank You!