Case Study: Successful Installation of Frac Pack Across Target Interval Separated by 60ft of Shale

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# Agenda

## Discussion Topics
- Field overview
- Well completion types
- Well completion overview
- Well perforation selection strategy
- Well frac pack design
- Job Planning
- Well frac pack execution
- Result
- Lesson learned & best practices
- Conclusion

## Key Messages
- Completion philosophy
- Discuss challenges/assumptions in the job design
- Share experience during the main frac operation
- Discuss execution of the top off job to obtain good/effective annular pack
- Share lessons learned and best practices
Field Overview

- The field is a world class, billion barrel, prolific asset
- Located in Deepwater Offshore Nigeria (~4,800 ft water depth)
- Development Strategy involves Mid-Flank Oil Production, Crestal Gas Re-injection, and Peripheral Water Injection
- Phased field development from deepwater turbidite reservoirs
**Completion Types**

<table>
<thead>
<tr>
<th>Well Types</th>
<th>Lower Comp</th>
<th>Upper Comp</th>
<th>Production Tubing</th>
<th>Drilled &amp; Completed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1x zone Producer</td>
<td>CHFP</td>
<td>SCSSV</td>
<td>5-1/2”</td>
<td></td>
</tr>
<tr>
<td>2x zone producer</td>
<td>CHFP</td>
<td>SCSSV</td>
<td>5-1/2”</td>
<td>25</td>
</tr>
<tr>
<td>3x zone Producer</td>
<td>CHFP</td>
<td>SCSSV</td>
<td>5-1/2”</td>
<td></td>
</tr>
<tr>
<td>2x zone Water Injector</td>
<td>No</td>
<td>TRWIV</td>
<td>7” x 5-1/2”</td>
<td>10</td>
</tr>
<tr>
<td>2x zone Gas Injector</td>
<td>No</td>
<td>SCSSV</td>
<td>7” x 5-1/2”</td>
<td>5</td>
</tr>
</tbody>
</table>
Well Completion Overview

➢ **Objective**: Complete well as a single string oil producer to deliver expected rate – 18K BOPD

➢ **Water depth**: ~ 4675ft

➢ **Maximum Deviation**: ~55.3°

Lower Completion:
- Cased hole frac pack in deviated well
- Inclination at sandface: ~54.3° – **Highest in Field**
- 5.5”, 250 microns sand screen in 9-5/8” casing
- TCP: 7” 18-SPF HMX BH low debris charges

Upper Completion:
- Single string (5.5”) with HHC Packer
- Monitoring system (Flowmeter & Densitometer)
- 5.5 Chemical Injection & Gas Lift Mandrel
- Sub-Surface Safety Valve – 5.5 TRC-II SCSSV
Well Performance Update

Spud Date

- Spud / 4th Jun 2016
- Drilled By: 4th Gen DrillShip
- Installed XT / 29th Dec 2016

Execution

- LC: 25th Aug 2017
- UC: 3rd Oct 2017
- NPT: 5%

Job Debrief

- Achieved good annular pack
- Skin / PI Value: 6
- PI: 10 BOPD / PSI
Well Perforation Selection Strategy

A. Frac pack only 150’ section
   - 16,050’ to 16,200’ MD
     + Best chance for good annular pack throughout
       - Sacrifices lowest lobe in sand package

A3. Frac pack only 150’ section
   - 16,000’ to 16,150’ MD
     + Best chance for good annular pack throughout
       - Sacrifices lowest lobe in sand package

C. Gravel Pack Entire 285’ section
   - 15,990’ to 16,275’
     + Maximum net pay completed
       - Less penetration past near wellbore damage
Modelling of Well Perforation Interval

- Oil Rate & Cum
- Pressure
- Water Cut
- GOR
Well Frac Pac Design
Contractor Vs Chevron Design

- Contractor design is consistent with Chevron design
- Fracture expected to propagate only in the upper lobe
- Good annular pack is required for well reliability
Job Planning

Major Concerns

Drill Out Cement Plug

*Confirm PBTD

Run Clean Out Assy

*Wellbore Cleanliness

Run CBL

*Well deviation

Run Sump Packer

*BHI WL rig up

Run TCP Assy

~50’ Shale section b/w sands

Run Frac Pack Assy

Run screen to depth

Perform Frac Pack

~285’ of pay separated in 2 lobes by ~50’ of shale

1. Limited interval to 150ft
2. Increased acid treatment to 100gal/ft
3. Planned to frac upper lobe only
4. Generated robust shunt activation sequence to achieve good annular pack

1. Shock/surge pro analysis
2. Perforated shale section

1. Upgraded thread of BHA
2. Performed hydraulic analysis to establish circulation rate
3. Achieved desired NPT with brine before pumping downhole
4. Cleaned tanks
Planned Vs Actual Operation

Max Deviation 55.3 deg

Deviation @ Reservoir 54.6 deg

TD 16,355 MD

Drill Out Cement Plug

Run Clean Out Assy

Run CBL

Run Sump Packer

Run TCP Assy

Run Frac Pack Assy

Perform Frac Pack

Drill Out Cement

Run Clean Out Assy

Run CBL

Run Sump Packer

Perforate Liner

Run Frac Assy

Perform frac pack

Top Off Job
Frac Operations Time Map

14th Sep 2017
Thursday

09:00 Set Packer
20:30 Pickle Acid

15th Sep 2017
Friday

08:00 Data Frac
17:00 Start Main Fac

16th Sep 2017
Saturday

00:30 Re Stress
12:30 Circulation test
01:30 Suspend Ops
00:30 Dump Seal

17th Sep 2017
Sunday

15:30 POOH & Lay down tools
03:00 Test FS2 ball
20:00 Reversed out Proppants

ETC

40.5 hrs
28.5 hrs
11 hrs

56.5 hrs
Mini Frac & Step Rate Test

A - Spotting DataFRAC fluid while displacing surface lines overboard
B - Resume spotting DataFRAC fluid into the workstring with ST in Reverse
C - Shutdown to shift Service Tool to Set Down Circulation position
D - Resume pumping DataFRAC into the formation at 30 bpm
E - Hard shutdown and observing pressure decline
F - Step Rate Test performed from 1 to 20 bpm
G - Formation equilibrium test @ 4 bpm
H - Hard shutdown and observing pressure decline
# Main Frac Pump Schedule & Contingency Stages

## STIMPAC Pump Schedule

<table>
<thead>
<tr>
<th>Fluid Type</th>
<th>Proppant Type</th>
<th>Injection Rate (bpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>YF130 ReFlex</td>
<td>16/20 Carboprop</td>
<td>30</td>
</tr>
</tbody>
</table>

### Initial design

- **Adjustment after mini frac**
- **Initial design**

### Slow down contingency options

<table>
<thead>
<tr>
<th>Step Name</th>
<th>Pump Rate (bbl/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pad</td>
<td>30.0</td>
</tr>
<tr>
<td>1.0 PPA</td>
<td>30.0</td>
</tr>
<tr>
<td>2.0 PPA</td>
<td>30.0</td>
</tr>
<tr>
<td>3.0 PPA</td>
<td>30.0</td>
</tr>
<tr>
<td>4.0 PPA</td>
<td>30.0</td>
</tr>
<tr>
<td>5.0 PPA</td>
<td>30.0</td>
</tr>
<tr>
<td>6.0 PPA</td>
<td>30.0</td>
</tr>
<tr>
<td>7.0 PPA</td>
<td>30.0</td>
</tr>
<tr>
<td>Contingency</td>
<td>30.0</td>
</tr>
<tr>
<td>Flash</td>
<td>30.0</td>
</tr>
</tbody>
</table>

### Slow down Schedule

<table>
<thead>
<tr>
<th>Go to</th>
<th>Slurry Vol Left</th>
<th>Flash Volume Pumped</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 bpm</td>
<td>117</td>
<td>285</td>
<td>1</td>
</tr>
<tr>
<td>20 bpm</td>
<td>92</td>
<td>310</td>
<td>1</td>
</tr>
<tr>
<td>10 bpm</td>
<td>72</td>
<td>330</td>
<td>0.7</td>
</tr>
<tr>
<td>8 bpm &amp; 2 bpm returns</td>
<td>65</td>
<td>337</td>
<td>5</td>
</tr>
<tr>
<td>2 bpm &amp; 2 bpm returns</td>
<td>40</td>
<td>362</td>
<td>5</td>
</tr>
<tr>
<td>Shut down</td>
<td>28</td>
<td>373</td>
<td>2</td>
</tr>
<tr>
<td>Restart 2pm, 2bpm returns</td>
<td>28</td>
<td>373</td>
<td>5</td>
</tr>
<tr>
<td>Shut down</td>
<td>18</td>
<td>383</td>
<td>Start Reverse out Procedure</td>
</tr>
</tbody>
</table>

Shutdown to Shift Tool from REVERSE to W/D Circulating position (Live Annulus). Hydril Closed.
Well Main Frac Execution

1. Start slowdown
2. Open backside and pump while taking returns
3. 1st 2min shut down
4. Pump at 2bpm w/ backside open (lost returns)
5. 2nd 2min shut down
6. Pump at 2bpm, end job, go to reverse. No screen out.

- TSO achieved
- Job screen out not achieved:
  - Aggressive slowdown schedule to induce SO
  - Pumped for 30min taking 2bpm returns, no SO
  - ~350bph losses after frac
# Top-Off Pump Schedule

**Revision 0**

**Top-Off Pump Schedule (After 1st circulation test)**

<table>
<thead>
<tr>
<th>Fluid Type</th>
<th>Proppant Type</th>
<th>Injection Rate (bpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WF130</td>
<td>16/20 Carboprop</td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stg Nb</th>
<th>Stage Name</th>
<th>Pump Rate (bpm)</th>
<th>Proppant Concentration</th>
<th>Stage Proppant (lbs)</th>
<th>Cum Proppant (lbs)</th>
<th>Stg Slurry Volume (bbls)</th>
<th>Stage Starts</th>
<th>Stage Ends</th>
<th>Stage at Perfs</th>
<th>Stg Clean Fluid (gal)</th>
<th>Stg Clean Fluid (bbl)</th>
<th>Stage Pump Time (min)</th>
<th>Cum Pump Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pad</td>
<td>15</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>50</td>
<td>0</td>
<td>50</td>
<td>0</td>
<td>406.1</td>
<td>2,100</td>
<td>50.0</td>
<td>3.3</td>
</tr>
<tr>
<td>2</td>
<td>2 PPA</td>
<td>15</td>
<td>2</td>
<td>15,000</td>
<td>15,000</td>
<td>101.7</td>
<td>50.0</td>
<td>241.7</td>
<td>455.1</td>
<td>7,500</td>
<td>178.6</td>
<td>12.8</td>
<td>16.1</td>
</tr>
<tr>
<td>3</td>
<td>DISPLACEMENT</td>
<td>15</td>
<td>0</td>
<td>0</td>
<td>15,000</td>
<td>123.3</td>
<td>241.7</td>
<td>365.0</td>
<td>650.8</td>
<td>5,180</td>
<td>123.3</td>
<td>8.2</td>
<td>24.3</td>
</tr>
</tbody>
</table>

 Shutdown to Shift Tool from REVERSE to W/D Circulating position (Live Annulus), Hydrid Closed, SLB Choke Open

**Revision 1**

**Top-Off Pump Schedule (After 2nd circulation test)**

<table>
<thead>
<tr>
<th>Fluid Type</th>
<th>Proppant Type</th>
<th>Injection Rate (bpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WF139</td>
<td>16/20 Carboprop</td>
<td>8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stg Nb</th>
<th>Stage Name</th>
<th>Pump Rate (bpm)</th>
<th>Proppant Concentration</th>
<th>Stage Proppant (lbs)</th>
<th>Cum Proppant (lbs)</th>
<th>Stg Slurry Volume (bbls)</th>
<th>Stage Starts</th>
<th>Stage Ends</th>
<th>Stage at Perfs</th>
<th>Stg Clean Fluid (gal)</th>
<th>Stg Clean Fluid (bbl)</th>
<th>Stage Pump Time (min)</th>
<th>Cum Pump Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pad</td>
<td>15</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>50</td>
<td>0</td>
<td>50</td>
<td>0</td>
<td>408.1</td>
<td>2,100</td>
<td>50.0</td>
<td>3.3</td>
</tr>
<tr>
<td>2</td>
<td>2 PPA</td>
<td>15</td>
<td>2</td>
<td>15,000</td>
<td>15,000</td>
<td>191.7</td>
<td>50.0</td>
<td>241.7</td>
<td>455.1</td>
<td>7,500</td>
<td>178.6</td>
<td>12.8</td>
<td>16.1</td>
</tr>
<tr>
<td>3</td>
<td>DISPLACEMENT</td>
<td>15</td>
<td>0</td>
<td>0</td>
<td>15,000</td>
<td>123.3</td>
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<td>5,180</td>
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<td>24.3</td>
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 Shutdown to Shift Tool from REVERSE to W/D Circulating position (Live Annulus), Hydrid Closed, SLB Choke Open

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Well Top Off Job Execution

Inject PAD below the X/O Cover screen and start blank coverage

Lost annulus pressure

~2,300lbs proppant placed during top off job

Go to reverse

Started 30bbl brine followed by 50bbl linear gel at 8bpm. ~4min after starting injection observed ~2bpm returns and the annulus pressure started increasing
Well Frac Pack Diagnostics Summary
Evaluate Frac Coverage & Effectiveness of Annular Pack

1) Effective frac coverage of perforated sand body.

2) Ample proppant reserve above top of screen.

3) Effective top off operation
## Lesson Learned & Best Practices

### Run Clean Assy
- Achieved NTU of 7
- Hydraulic analysis done to establish circulation rate
- Upgraded BHA thread to X57

### Run CBL Sump Packer
- Use of 50’ bail to rig up WL

### Perforate Liner
- MPA tool released with overpull
- Plan not to perforate shale interval but gun housing only

### Run Frac Assy, Acid, Cir Test, Mini Frac
- Plan to pump HCL ahead of Xylene to place HCL in front of perforations

### Perform frac pack
- Presence of perforated shale is the likely cause of not screen out
- Do not perforate b/w shale & sand interface to assist in limiting height growth

### Top Off Job
- RMA formation min stress in the shale may have been overestimate. Based on the processed data, intermediate shale was not supposed to have broken down.

1. Casing & liner logged in a single run
2. Defined log objectives upfront

1. Retained 100% crew
2. Adopted re-design output of 1000 ibs/ft
3. Strong collaboration b/w Chevron & Service Partner

1. Achieved up to 8 bpm during acid injection
2. Pumped ~100gpf instead of 50gpf
3. Decision to exercise stop work after 40.5 hrs

1. Installed NRD densitometer
2. Achieved good annular pack
3. Plan not to perforate shale interval but gun housing only

1. Retained 100% crew
2. Achieved 2 min reverse out drill
3. Hydrualic analysis done to establish circulation rate

1. Plan to pump HCL ahead of Xylene to place HCL in front of perforations
2. Presence of perforated shale is the likely cause of not screen out
3. Strong collaboration b/w Chevron & Service Partner
## Well Completion Highlights

<table>
<thead>
<tr>
<th>#</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Successful installation of first phase 4 completion ahead of target at record NPT with new rig that has been out of operations for 18 months.</td>
</tr>
<tr>
<td>2</td>
<td>Overall the frac pack achieved TSO (Tip Screen Out) and WSO (Wellbore Screen Out)</td>
</tr>
<tr>
<td>3</td>
<td>The operations to confirm the presence or not of the annular pack were carefully planned and executed, allowing to perform the annular top off remediation job</td>
</tr>
<tr>
<td>4</td>
<td>The top off remediation job was executed successfully; the tracer log providing the necessary information regarding the quality of the proppant placement.</td>
</tr>
<tr>
<td>5</td>
<td>Achieving an unprecedented NTU of 4 may have contributed to the skin value of 6.5</td>
</tr>
</tbody>
</table>
Questions
<table>
<thead>
<tr>
<th>ACRONYM</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCSSV</td>
<td>SURFACE CONTROLLED SUB-SURFACE SAFETY VALVE</td>
</tr>
<tr>
<td>CHFP</td>
<td>CASED HOLE FRAC PACK</td>
</tr>
<tr>
<td>TRWIV</td>
<td>TUBING RETRIEVABLE WATER INJECTOR VALVE</td>
</tr>
<tr>
<td>SCITT</td>
<td>SURFACE CONTROLLED INTERVENTION TEST TREE</td>
</tr>
<tr>
<td>IWC</td>
<td>INTELLIGENT WELL CONTROL</td>
</tr>
<tr>
<td>ICV</td>
<td>INTERVAL CONTROL VALVE</td>
</tr>
<tr>
<td>GLM</td>
<td>GAS LIFT MANDREL</td>
</tr>
<tr>
<td>DCIN</td>
<td>DOWNHOLE CHEMICAL INJECTION</td>
</tr>
<tr>
<td>XT / TH</td>
<td>CHRISTMAS TREE / TUBING HANGER</td>
</tr>
<tr>
<td>BOP</td>
<td>BLOW OUT PREVENTER</td>
</tr>
<tr>
<td>TOL</td>
<td>TOP OF LINER</td>
</tr>
<tr>
<td>TCP</td>
<td>TUBING CONVEYED PERFORATION</td>
</tr>
<tr>
<td>CBL</td>
<td>CEMENT BOND LOG</td>
</tr>
<tr>
<td>WBCO / NTU</td>
<td>WELLBORE CLEAN OUT / NEPHELOMETRIC TURBIDITY UNIT</td>
</tr>
<tr>
<td>SP</td>
<td>SUMP PACKER</td>
</tr>
<tr>
<td>UC</td>
<td>UPPER COMPLETION</td>
</tr>
<tr>
<td>IWOCS</td>
<td>INSTALLATION/WORKOVER CONTROL SYSTEM</td>
</tr>
<tr>
<td>FH / CTLF</td>
<td>FLOW HEAD / COIL TUBING LIFT FRAME</td>
</tr>
<tr>
<td>TD / PBTD</td>
<td>TOTAL DEPTH / PLUG BACK TOTAL DEPTH</td>
</tr>
<tr>
<td>TSO / SO / WSO/GOR</td>
<td>TIP SCREEN OUT / SCREEN OUT / WELLBORE SCREEN OUT / GAS OIL RATIO</td>
</tr>
<tr>
<td>RMA</td>
<td>ROCK MECHNICS ALGORITHM</td>
</tr>
<tr>
<td>NRD</td>
<td>NON RADIOACTIVE DENSITOMETER</td>
</tr>
<tr>
<td>WL / NPT</td>
<td>WIRELINE / NON PRODUCTIVE TIME</td>
</tr>
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</table>