Engineered Perforating Charges Designed for Proppant Frac Stimulation

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Contents

1. Justification
2. Design Parameters
3. Opportunities to Optimize
4. Conclusions
Background (Ghawar Gas Field)

Depth increases going to the North (reduction in CGR)
Temperature increases going to the North (BHT = 340 deg F)
Stress increases going to the flanks/North (1.1 psi/ft)
Background (Ghawar Pre-Khuff)

- Sandstone formations at 15,000 ft
- CO2 = 4% (Pre-Khuff gas Wells)
- Static BHT = 330 deg F
- SIWHP ranges from 6,500 to 7,100 psig
- Pickup tension from 2,100 to 3,200 lbs
- 20 to 40 ft guns – tool weight = 450 to 600 lbs
- S shape well profiles – requires use of ART
- 3.688” restrictive nipple
- H2S = average of 5% (Khuff gas wells)
- Limitations of oriented perforating in S shape wells
Justification

- **K2 Gas Well - Saudi Aramco standard in 2005**

- Main disadvantages - restrictive tubing condition and limited 2-7/8” charge penetration (into 7” liner)
New 4 ½” Monobore Approach (2009)

- 4 ½”, 13.5 ppf, high collapse connection (3.688” nipple)
- 4 1/2” monobore completion - 5 to 25 MMSCFD
  (Saudi Aramco Operative Conditions)
Pre-Khuff Development (past 3 years)

- Increasing temp with depth
  - 1.65 deg F/100 ft
- Increased rock stress
- New Pre-Khuff development in Lower Jauf, Sarah, Tawil, Qusaiba Formations
Main Challenge (Increase Gun Size)

• OD changes considering maximum swell
  • max swell - 3.219”, avg 3.19” (hydrostatic pressure > 4500 psi)
  • minimum well restrictions (3.688” nipple profile)

• Increased tool weight
  • wireline strength to move tools at working depth
  • margin for over pull if tools become stuck

• Increased shock via higher weight charges with larger gun
  • maximum gun length
  • successfully used 30 ft guns with 7/32’s and 5/16’s corrosive resistant cables
Main Challenge (New Stress)

Increased Rock Stress after strike new Pre-Khuff Reservoirs (Tawil, Qusaiba, Sarah)
Additional Implications

- 1. Hydraulic grease injection
- 2. Cable selection (4800# at 50%)
- 3. Grease selection (winter and summer)
- 4. ART (release tool) – S shape wellbore
- 5. Well modeling (Cerberus)
- 6. Methanol use (hydrates)
- 7. Charges design (for prop frac)
- 8. Stimulation design (rate and pressure)
- 9. Sand control (oriented perforating)
Cable Head Test

Expected Pull out @ 3757 lbs (10 x 442 x 0.85)

Actual Pullout 4259 lbs, 502 lbs (13.4%) above expected. Cone & Washer were used, but the Rope socket was very well done.

If we count the inners as reported in the 20Apr09 Cable Head report, @ 60% of the BS, new expected weak point would be 4208 lbs,

\[\left(10 \times 442\right) + \left(2 \times 442 \times 0.60\right) \times 0.85 = 4208 \text{ lbs}\]
Increased Margin with 5/16” Cable

* Job not possible with 7/32’s cable
Increased Margin with Release Tool

* Job Performed with 5/16 1N32PTZ-S77 and Addressable Release Tool
Decision Made for 3 1/8” Engineered Charge

1. Retrievable in 4 1/2” tubing and 3.688 R nipple
2. Targeting increased entrance hole size and reduced perforation friction
3. Targeting reduction of breakdown pressure and increased rate
4. Minimize early screen-out
5. Maximize fluid and proppant distribution
Frac Orientation Benefit

How a Frac Charge works.

\[ \sigma_1 = T_{fail} \]

\[ \sigma_1 = Kp \quad p_{bd} = T_{fail}/K \]

- Larger casing-hole diameter reduces breakdown pressure
- Ensures larger hole-size is in contact with preferred fracture plane
- Contact with fracture plane minimizes near-wellbore tortuosity

SPE 159085
Benefits (SRT and SDT – reach 40 BPM)

Before – 24 BPM

After – reach 40 BPM

Total Fric = 5,189 psi.
Perf Fric = 3,037 psi.
NW Fric = 559 psi
Case Study (Pre-Khuff Evaluation)

Stresses Distribution Grid

Frac Charge - 14,830-14,840 ft  6 spf 60 holes

Case 1 - 15,250-15,270 ft  6 spf 120 holes

Deep Sandstone Formation High Stresses Tight Gas
First Interval perforated with a 3 3/8” Deep Penetration
Second Interval perforated with the Engineered Charge
Comparing Results – Proppant Frac
Comparing Results – Frac Placement

Case 2: 135,000 lbs of proppant

Case 1: 54,000 lbs of proppant

4 1/2" Liner 15.20# Q12
7" Liner 35.0 # Q12
Conclusions

1. Successful implementation for 3 1/8” Engineered Charge for consistent entry hole approach with 4 ½” monobore

2. Reduction of treating pressures ranging from 800 to 1,100 psig

3. Increased injection rate – avg 6 BPM, 36 BPM (normalized 30 ft)

4. Average NWB friction values are lower than other perforating methods resulting in reduced likelihood of early screen-out

5. No operational issue while deploying/retrieving 3 1/8” spent gun
Thank You