Perforating Carbonates

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MENAPS 13-02
Perforating Carbonates

- Carbonate Completion
- Sandstones vs Carbonates
- Case Studies (depending on time!)
Carbonates Completion
Carbonate Complexity—Porosity

Porosity in Carbonates: inter- or intra-particle (left); inter-crystalline Dolomite (centre); moldic or secondary porosity Oolitic Limestone (right)

Porosity in Sandstones: always inter-particle
Carbonate Complexity—Production

- Large heterogeneities—even for similar strength rocks
- Natural fractures and type of fracture network are important
- Often production from Carbonates requires matrix acid treatments or acid fracs or propped fracs
- Completion strategy often determined by stimulation technique
- Perforating Carbonates has to take above into account and is therefore part of the stimulation strategy
- Several service providers are involved in implementing the strategy
Combined Approach—Synergy

- Data input provided by Wireline or LWD measurements, and from core analysis
- Pumping and Chemistry to design acid and frac treatments
- Data-Enabled CT to deliver guns and acid at the right depth
- Data-Enabled CT for real-time data acquisition such as P, T
- Tubing Conveyed Perforating to deliver guns and acid at the right depth
- Wireline Perforating to deliver guns at the right depth
Completion Strategy—Some Options

- Open hole or cased hole
- Matrix acidizing
  - Mechanical diversion
  - Chemical diversion
  - Limited entry
- Hydraulic Fracturing
  - Acid frac
  - Propped frac
- Perforated
  - O/B, U/B, DUB
  - Oriented
  - Propellant stimulation
- Combinations of above
Differences Between Sandstone & Carbonates From Perforating View
Geometry Differences

- Penetration is slightly shorter in similar strength Carbonates
- Tunnel diameter is significantly smaller
Rock Strength & Stress

- Shaped charge penetration is dependent on rock strength (UCS)
- It is also dependent on pore pressure and confining stress
- We combine the two in a term called Ballistic Indicator Function or $F_{BI}$
- Requires at least 3 different rock/stress combinations to characterize a shaped charge
Schlumberger Public

Sandstone vs Carbonates Rock Model

- Austin Chalk: 3000 psi, UCS
- Indiana Limestone: 7600 psi, UCS
- Carthage Marble: 20,000 psi, UCS
- Similar function with different coefficients
Penetration work flow - SPE 127920

New section 2 rock test

3 rock/stress combinations
(Ballistic Indicator Function, F_B)
Characterize charge
(Harvey et al)

Direct link to rock

New Model

Casing, Fluid
(Saucier, Regal butto, etc)

New penetration model
(Harvey et al)

3 December 2013, 12
Challenges for Carbonate Model

- Models require Unconfined Compressive Strength (UCS) as an input
- We can link Sandstone UCS to log data such as density, and compressional and shear sonic velocity. There are several correlations that can be used. Also there seems to be a reasonable handle on permeability.
- In Carbonates rock strength and permeability can very considerably over a short interval
- Good local knowledge and good local correlations are required for accurate analysis. This may require quality core data to calibrate logs. Liaise with local Geomechanics and Petrophysics Advisors.
Perforation Tunnel Condition

Balanced Perforation

- Casing
- Cement
- Undamaged formation
- Formation damage
- Perforation debris
- Crushed and compacted low-permeability zone

3000 psi Underbalanced Perforation

- Casing
- Cement
- Undamaged formation
- Formation damage
- Low-permeability zone and perforation debris expelled by surge of formation fluid
Nature of Perforation Damage—Sandstone

- SEM close to edge of perforation tunnel
- With clean perforation, sand grains are whole and cemented (top)
- With damaged or dirty perforation, sand grains are fractured and not cemented together (bottom). The crushed or damaged zone is weak and low permeability
Nature of Perforation Damage—Carbonate

- Thin section showing the detail of the edge of the perforation tunnel for a Carbonate
- The rock fabric is crushed reducing both permeability and porosity
Damage Removal—Carbonate

- Perforation damage is removed by:
  - High static underbalance
  - Dynamic Underbalance
  - Acid wash

[Images showing dye flow paths and static/dynamic underbalance indicators]
Static Underbalance Model—SPE 86542

- Underbalance Experiment
- 8 Limestone and 5 Dolomite cores shot with 3 different charges
- All under 3000 psi stress
- Static underbalance range from 500 to 4000 psi
- Single shot skin measured
- In 1990’s SPE 30081 presented underbalance model for Sandstone
- This model does not seem to apply for Carbonates (upper graph)
- Cleanup seems to depend on peak dynamic underbalance, UCS and rate of dynamic underbalance (bottom graph)
Experiments in Carbonates—SPE 105022

- Series of tests design to investigate if the way carbonates are perforated affects matrix acid treatments
- Indiana Limestone cores (low permeability) shot with same shaped charge under a variety of conditions
- Test 1 was static underbalance (4700 psi pore pressure, 3700 wellbore pressure)
- Test 2 was DUB (generated 3000 psi)
- Test 3 simulated a gas filled borehole
- Test 4 was DUB perforating with static overbalanced in acid
- CAT scans taken before and after acidizing
Matrix Acidizing & Perforating—SPE 105022

Test 1
U/B, non-PURE
After Matrix Acid

Test 2
PURE
After Matrix Acid

Test 3
Gas
After Matrix Acid

Test 4
PURE in acid
Before Matrix Acid

Test 4
PURE in acid
After Matrix Acid
Acid Injection at 0.5 gal/min

Test 1
U/B, non-PURE
Narrow tunnel, branched wormhole, 3700 psi injection pressure

Test 2
PURE
Wider tunnel, straight wormhole, 2700 psi injection pressure

Test 3
Gas
Narrow tunnel, branched wormhole, 2500 psi injection pressure

Test 4
PURE in acid
Widest tunnel, straight wormhole, 90 psi injection pressure

Use DUB overbalanced in acid
Clean Perforations Improve Acid Stimulation

What we often get

- Stimulation fluid initiation
  - Base
  - Tip
- Fluid spending
  - Rock & Debris
  - Rock
- Injectivity
  - High P
  - Low P
- Pass damage
  - Not efficient
  - Efficient
- Coverage
  - Bad
  - Good
- Post stimulation skin
  - High
  - Low

What we want
Case Studies
Elimination of Acid Wash

• Underbalanced perforating does not always produce clean perforations
• Often acid wash has been applied pre-production or pre-stimulation
• DUB perforating, however, has delivered clean perforations eliminating acid wash in Sandstones (SPE 77364)
• In Middle East Carbonates, the same technique of DUB perforating with guns run on Wireline has also eliminated acid wash
• Typically tight intervals are acid fractured, while other intervals flow naturally
High-Rate Stimulation Through IC—SPE 83950

- First high rate stimulation through a subsea intelligent completion
- Key to success was a uniform and known casing EH. Testing carried at with 2 ¼” DP shaped charges to determine hole size and perforation coefficient
- Plan was to run guns centralized for uniform entrance hole and determine number of holes based on 2500 psi pressure drop at 50 bbl/min
DUB TCP In Horizontal Well—IPTC 13815

- 2612 ft (1912 ft net) perforated on TCP in a horizontal producer offshore Abu Dhabi
- Shoot and pull string used with 2 7/8” DUB guns in overbalance
- Acid bullheaded into formation easily
- Well came in above expectations and was producing at a high rate 1 year later
**DUB Improves Production and Efficiency—SPE 101278**  (Case Study 07-PR-077)

- Objective to try to produce wells before stimulation
- Wells perforated with DUB
  - Limited to 2” guns in 7” liner
- Well one was put on production after 10 months
  - 2800 BOPD, fast cleanup
- Well two on production soon after perforating
  - 3000 BOPD, skin +3.4 before acid and -2.6 after matrix acid

**Objective achieved**
CT DUB in Acid Mexico—SPE 143735

- Intervention in 3 wells—one severely damaged
- Ran 2” DUB guns on CT with a highly stable emulsified acid
- Followed by VES acid system
- Well B was extensively damaged by various treatments, but recovered some production after DUB in acid

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Optimize Stimulation in Pakistan—Case Study 11-TS-0107

• Challenge to provide deep clean perforations on exploration well
• Used DUB with DP charges
• Reduced surface pumping pressure required for acid stimulation
  — 7000 psi to 3500 psi
Open Hole Perforating—Middle East

- Challenge to provide gain water injection in low perm intervals
- Perforating with enhanced diversion
- 16 wells perforated followed by bull heading matrix acid treatment
- Injection rates improved and injection pressure reduced
- After 6 months results of improved injection sweep seen at oil producers
Special Gun—North Sea

- Carbonate formation completed with propped hydraulic fractures
- CT used to perforate and clean out. Typically takes 3 days to perforate, frac and clean out for each zone frac’d
- Perforating and clean up can be done in a single trip using pump-over gun saving substantial time and cost

Surface test flowing through the CT BHA and gun

2 ½” gun inside a housing. The annular space provides a flow path to the bottom of the gun. Typically 29 shots in a 7 ft gun
Perforating Carbonates

- Carbonate completion
- Questions?

Questions?