Advanced Modeling of Perforating System Performance

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Why Perforate?

- Penetration
- Cleanup
- Inflow Performance
- Gun Shock

Integrated Workflow for Job Design
Why Perforate?

- Perforating is a fundamental part of any well completion.
- It provides the connection between wellbore and virgin reservoir rock.
- It provides the conduit for processes such as hydraulic fracturing or acid stimulation.
- The success of a gravel pack completion strongly depends on perforating parameters.
Additional Benefits of Good Perforating Practices

- Operational efficiency improves such as reduced cleanup periods during a well test or reduced N$_2$ or completion fluid requirements to fire guns.

- Deep, clean perforations prolong the life of a well by reducing near-wellbore pressure drop.

- High pressure drop leads to many well problems: scale and asphaltene buildup, fines migration or condensate banking, water coning or production below bubble point.
Modeling a Perforated Completion – 4 Stages

- Stage 1: Gathering Data
- Stage 2: Perforation Tunnel Geometry Estimation
- Stage 3: Perforation Tunnel Condition
- Stage 4: Inflow Performance Estimation
- Stage 5: Wellbore & Completion Effects
How Do We Choose the Best?

- Section 2 Penetration Tests in Stressed Rock

- Section 4 Flow Efficiency Tests in Stressed Rock

- Model
Perforation Time Scales

- Charge detonation
- Perforation tunnel (& initial damage) created
- Jet Formation

Pressure inside the gun varies widely, in both time and space (shocks subsiding, gun internal pressure decaying and reaching spatial equilibrium)

- Gun-wellbore-formation interactions
- Wellbore dynamics
- Perforation cleanup

- Reservoir response
- Fluid column response
- Hardware & completion response

Time (sec)

10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 10^{0} 10^{1} 10^{2}

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Gun internal has reached spatial equilibrium, begins to “see” and interact with wellbore
Road to a Comprehensive Rock-Based Penetration Model

- Getting Away from Concrete
- >1,000 Experiments in Stressed Rock
- Formation effects
  - Weak to strong rocks tested
  - Largest ever range of stresses: 1,000 to 20,000 psi (~70 to 1,400 bar)
  - Pore pressure influence
  - Range of rock types
- Charge effects
  - Different families of charges used
  - Carrier and capsule charges
From *Effective* stress to *Ballistic* stress

\[ DOP = f(\text{effective stress}) \]

\[ P_{\text{eff}} = P_c - P_p \]

Ballistic pore pressure coefficient (bppc) “a”

\[ P_{\text{ball}} = P_c - a \times P_p; \ a \sim 0.5 \]

DoP = f(ballistic stress)

 bppc is a rock property

1980

1990

2000

2010

Confirmed at higher stresses

- **HVIS 2007**
- **SPE 111778**
- **SPE 151846**
Single Formation Parameter: \textit{Ballistic Indicator Function}

- Formation characterized by a single term
  - $F_{bi}$ combines UCS and ballistic stress
- High UCS rocks have less dependence on stress

\begin{equation}
F_{EI} = UCS + F_{bi}P_{eff}
\end{equation}

\textbf{Before $F_{bi}$:} Multiple performance curves for single charge

\textbf{With $F_{bi}$:} collapse to a single curve
Penetration Model – Formation Effects

- Penetration decreases exponentially with increasing $F_{bi}$

Universal behavior
- Carrier & capsule systems
- 2” to 4-1/2” gun sizes

$$DoP = DoP_{ref} e^{\alpha_0 (F_{bi,ref} - F_{bi})}$$
Penetration Model – Charge Effects

- Significance of having two parameters
  - 1st parameter \( (DoP_{\text{ref}}) \), gives general indication of how “high” the curve is
  - 2nd parameter \( (\alpha_0) \) is related to charge optimization (i.e. for “hard” vs. for “soft” targets)

\[
DoP = DoP_{\text{ref}} e^{\alpha_0 (F_{bi,\text{ref}} - F_{bi})}
\]

Figure 10 – Implications of charge optimization
Road to a Dynamic Underbalance Perforation Cleanup Model

- Static UB known since at least early 1950’s
  - Used successfully (though not always with consistent results) for 5-6 decades
  - First cleanup models not until 1980’s
- Dynamic UB phenomena reported 2001
  - Extensively proven effective in field (multiple environments)
  - Additional laboratory studies through mid-2000s to better understand the physics
  - Extensive laboratory program launched late 2000’s

Much more complicated than penetration
Perforation cleanup deals with at least 2 main elements:
- How efficiently does perf flow? (Q/dP)
- Where does flow come from?

DUB perforation cleanup is dictated by:
- Wellbore pressure transients *
- Formation properties

- Multiple parameters (magnitude, recovery duration, rate)
- Understanding & controlling wellbore pressure transients
Dynamic Underbalance Perforation Cleanup Model

Status
- Model developed
- Considers wellbore pressure transients and formation properties
- Implemented into inflow simulator

EWAPS 12-8
Gun Shock Model

- Gun system acts as a pressure source/sink generating pressure waves in the wellbore.
- Pressure waves acting on cross-sectional area changes produce gun shock loads.
- Model predicts interactions among gun, wellbore, reservoir, and completion hardware.
Workflow for Predicting Perforating System Performance

- Rock based penetration model
- Wellbore dynamics prediction
- DUB cleanup model
- Inflow prediction (net and per-zone)
Summary

- Shaped charges should be characterized in stressed rock, not concrete.
- Perforation cleanup dependant on shot-time wellbore dynamics, formation properties, wellbore fluids.
- Gunshock depends on gun/wellbore/formation interactions.
- Accurate models for penetration depth, cleanup, and gun shock phenomena are essential for reliable estimation of well performance and operational risk.
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Thank You

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