Perforation Flow Laboratory:
Six Decades of Insights into Field Perforating Performance

Brenden Grove, Larry Behrmann, David Atwood, Andy Martin, Philip Kokel, Jeremy Harvey, Thomas Christensen
Perforating Flow Laboratory – 6 Decades and Counting

- Historical context
- Capability evolution
- Advances & milestones
  - relevance to field, benefit to industry
- Common themes
- Outlook for the future
Perforating Flow Laboratory – Evolution of Test Standards

1920
1940
1960
1980
2000

WellFlow Index (WFI)
Linear flow

Core Flow Efficiency (CFE)
Linear flow

Core Flow Efficiency
Radial or Linear flow

Halleck et al. 1997

Bell et al. 1972
Regalbuto et al. 1985
Liu et al. 1988
Deo et al. 1989

Concrete: penetration

Rock: penetration

Temperature

Flow

Debris

Section 1

Concrete: penetration

Section 2

Rock: penetration & flow

Then...

2013 Latin American Perforating Symposium
Perforating Flow Laboratory – Evolution of Lab Capabilities

- Independent control of confining, wellbore $P$
- Perforating gun system (multiple charges)
- Transient pressure measurements
- Transient pressure control
- Precision flow control
- Automation
- Flow visualization

2013 Latin American Perforating Symposium
Productivity & skin

Reduce skin = increase production
Productivity & skin

Natural completions

- Shot density
- Phasing
- Penetration depth
- Perforation damage

Stimulated completions

- Weak rocks – sand control (GP / FP)
- Tight rocks – hydraulic fracturing
- Carbonates - acidized

SPE 12781

Weak rocks – sand control (GP / FP)
Tight rocks – hydraulic fracturing
Carbonates - acidized

2013 Latin American Perforating Symposium
Perforating Flow Lab - Fundamental Advances in Industry Knowledge

Penetration related

Perforator/rock interaction, comparison vs. bullets (plugging, etc.)

Formation strength effect

Wellbore pressure effect

Formation stress effect

Rock based penetration model

Reservoir pressure effect

Penetration depth = f (formation strength, stress, reservoir pressure, etc.)
Perforating Flow Lab - Fundamental Advances in Industry Knowledge

Cleanup, skin, & completion related

1920  1940  1960  1980  2000

Static UB known to be important since 50’s

Production through the perforations. High productivities are indicated when jet perforating in oil or salt water with pressure differentials into the well bore using a perforator which does not cause carrot plugging.

Allen & Worzel (1956)

Perforating strategies for stimulated completions

(late 80’s)

carbonates / acidizing (2000s)

Integrated perf + fluids (2004-5)

Fundamental nature of perf damage (2011)

Static UB not required!!

Static underbalance skin (1991)

optimum static underbalance (1995)

Dynamic underbalance discovered (~2001)

Perforation cleanup

Multiple perfs (all perfs are NOT created equal) (1994)
Common Theme & Goals

- **Theme**
  - Perforating is a SYSTEM operation

- **Goals:**
  - Understand reservoir response
  - Understand wellbore & completion responses

System = Gun & charges + Wellbore + reservoir
Keys to Success

- Know what to measure & control
- Measure & control it
- Interpret, and ultimately apply to downhole
- Integration
Recent & Future Trends

- More accurately replicate downhole environment
  - Formation properties
  - Dynamic conditions
  - Fluids
  - Drilling damage
- Harsher environments (HP, HT)
- Prove product (and system) performance, validate models
- "test drive" perforating techniques, before field trial
- Evaluate sanding potential; life-of-well studies
- High rate gas
Ultimate Goals Remain the Same

Well Performance
- Productivity, injectivity
  • Well skin
  • Penetration
  • Perforation efficiency

Reliability
- Well performance over the long term
  • Flow efficiency deterioration
  • Sanding

Operations
- Perforating
  • Efficient well control
  • Gunshock

Safety
- Well control during perforating
  • Explosive pressure at surface

Ultimate Recovery
- Natural producers & injectors
- Stimulated (frac'd, acidized)
- Sand prevention / sand control
- Conventional / unconventional / HPHT
Summary

- Perforating flow laboratory, 6 decades of:
  - Fundamental discoveries
    - Penetration depth
    - Perforation cleanup
  - Field techniques developed / demonstrated / refined
    - Natural completions
    - Sand control
    - Hydraulic Fracturing
    - Acidizing
  - Predictive models developed / validated / calibrated

Integration essential (multidisciplinary; expts+modeling)
Reduce risk & uncertainty for field operations
Relevance to field is key!
Outlook

All of this will continue – and become more important in the future, as:

- Field conditions get more severe
- Accurate prediction of downhole performance becomes more critical
- Operations get less risk-tolerant

Field techniques developed / demonstrated / refined
- Natural completions

Laboratory testing can be essential piece of the puzzle:
- Ensure the optimal technology is selected for field application
- Improve confidence in expected field performance

Maximize well productivity & operational efficiency
Minimize risk to field operations and completion equipment

Integration essential (multidisciplinary, exp.; modeling)
Reduce risk & uncertainty
Relevance to field is key!
Perforation Flow Laboratory: Six Decades of Insights into Field Perforating Performance

Thank You

Brenden Grove, Larry Behrmann, David Atwood, Andy Martin, Philip Kokel, Jeremy Harvey, Thomas Christensen