Perforation Flow Laboratory: The Past, The Present, The Future

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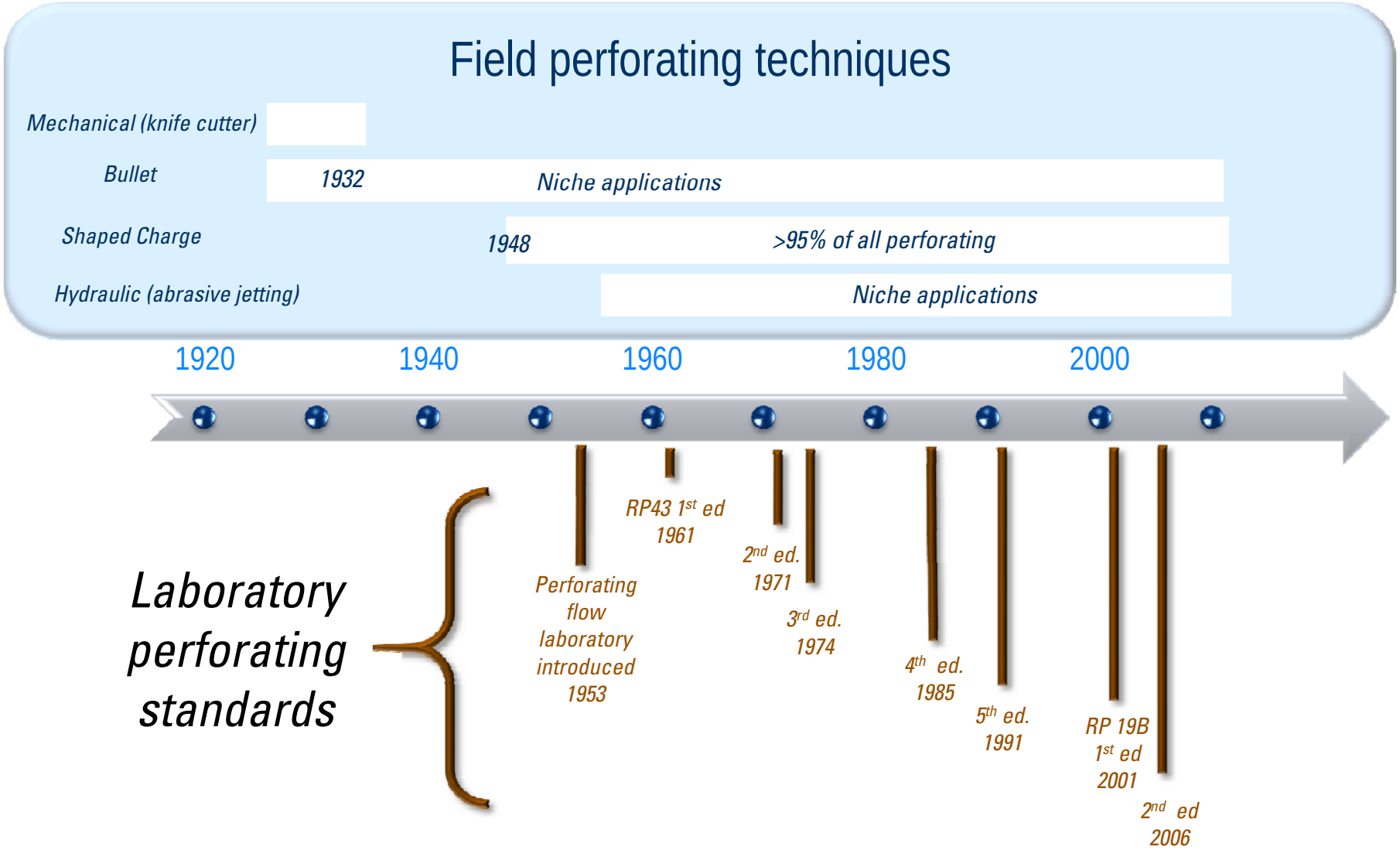
Schlumberger

Perforating Flow Laboratory – 60th Year

- Historical context
- Capability evolution
- Advances & milestones
  - relevance to field, benefit to industry
- Common themes
- Outlook for the future

Perforating Flow Laboratory – Historical Context



Perforating Flow Laboratory – Evolution of Test Standards

WellFlow Index (WFI) Linear flow

Core Flow Efficiency (CFE) Linear flow

Radial flow also conducted

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

Halleck et al. 1997

Core Flow Efficiency Radial or Linear flow

1920 1940 1960 1980 2000

RP43 1st ed 1961

2nd ed. 1971

3rd ed. 1974

4th ed. 1985

5th ed. 1991

RP 19B 1st ed 2001

2nd ed 2006

Section 1 — Concrete: penetration

Section 2 — Rock: penetration & flow

Then…

1 Concrete: penetration

2 Rock: penetration

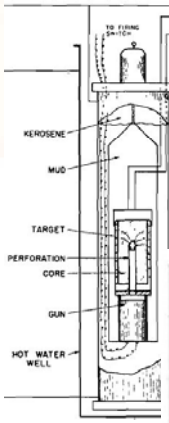
3 Temperature

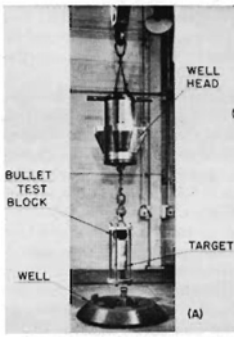
4 Flow

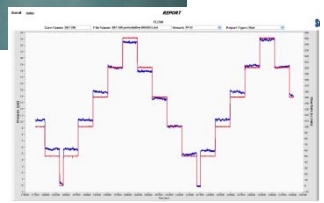
5 Debris

Now…

Perforating Flow Laboratory – Evolution of Lab Capabilities

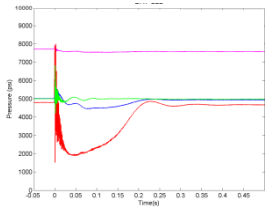


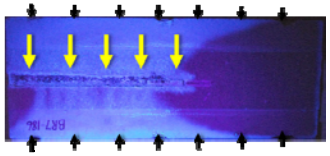




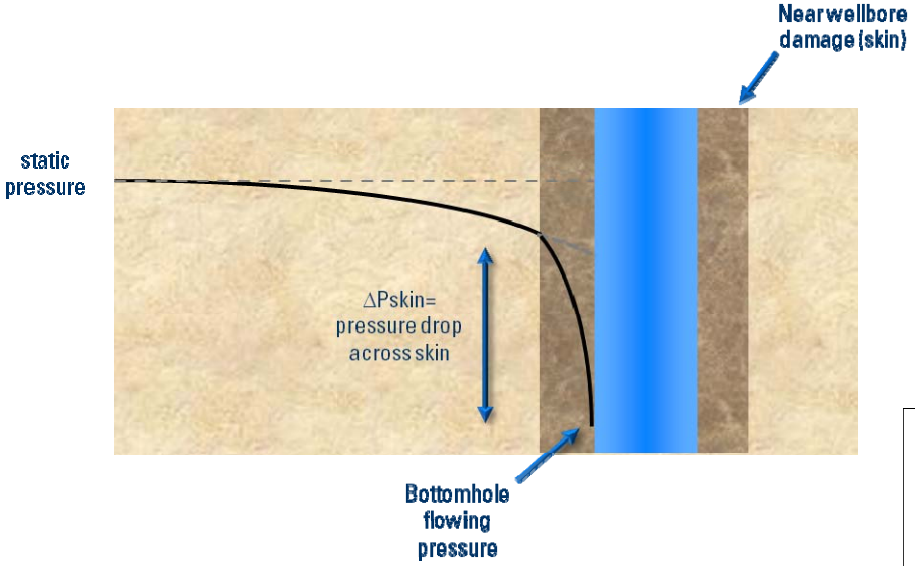
- *Independent control of confining, wellbore P*
- *Perforating gun system (multiple charges)*
- *Transient pressure measurements*
- *Transient pressure control*
- *Precision flow control*
- *automation*
- *Flow visualization*

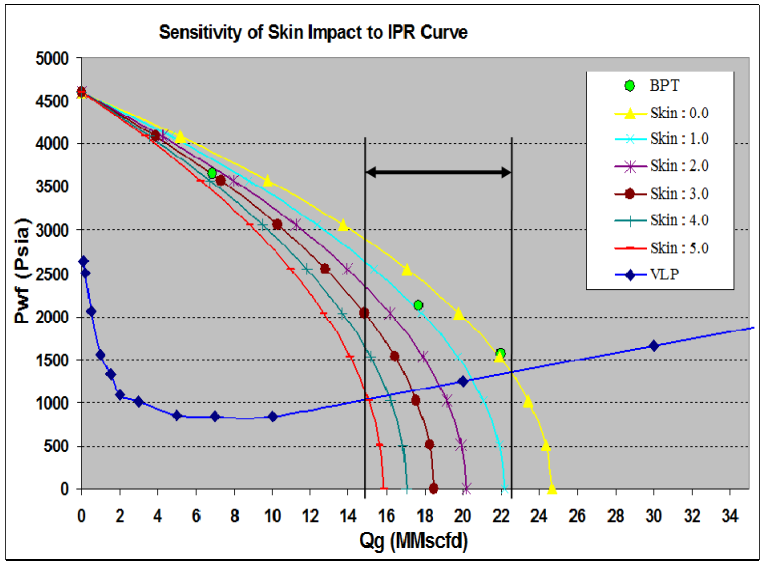
1940 1960 1980 2000





Productivity & skin

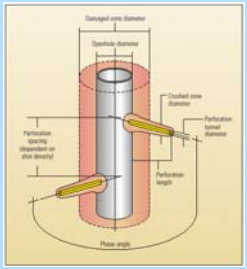




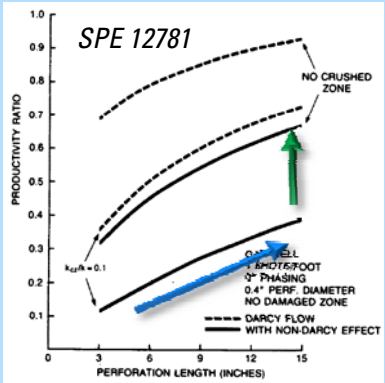
Importance of reducing skin

Productivity & skin

Natural completions

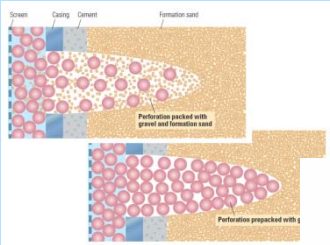


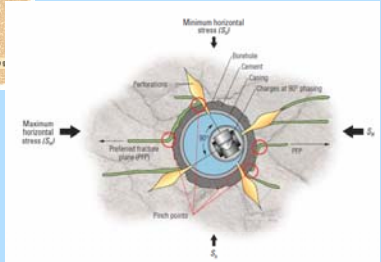
- Shot density
- Phasing
- Penetration depth
- Perforation damage



Stimulated completions

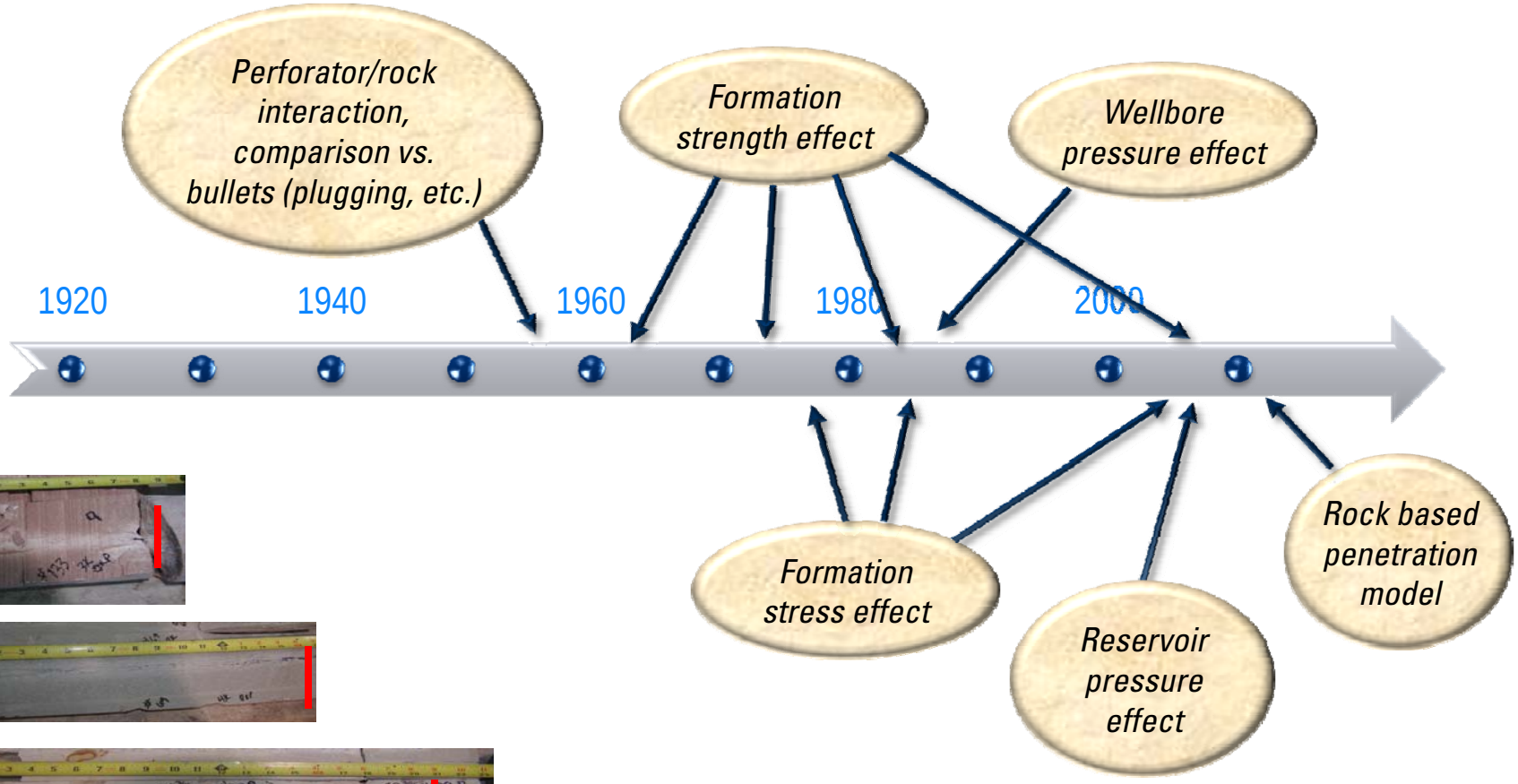
- Weak rocks – sand control (GP / FP)
- Tight rocks – hydraulic fracturing
- Carbonates - acidized





Perforating Flow Lab - Fundamental Advances in Industry Knowledge

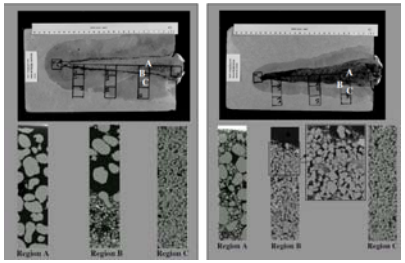
Penetration related



Penetration depth = f (formation strength, stress, reservoir pressure, etc.)

Perforating Flow Lab - Fundamental Advances in Industry Knowledge

Cleanup, skin, & completion related



Fracturing (late 80's)

weak rocks (1990s)

carbonates / acidizing (2000s)

Perforating strategies for stimulated completions

Integrated perf + fluids (2004-5)

1920 1940 1960 1980 2000

Fundamental nature of perf damage (2011)

Static UB known to be important since 50's

Static underbalance skin (1991)

optimum static underbalance (1995)

Dynamic underbalance discovered (~2001)

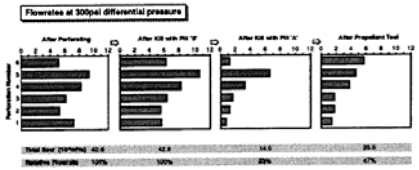
Perforation cleanup

Static UB not required!!

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)

Multiple perfs (all perfs are NOT created equal) (1994)



Milestones

Bullets, jets
Penetration & plugging
Well fluid & pressure differential effect on flow

- First work
  - Allen & Atterbury (1953) – SPE 319
  - Allen & Worzel (1956) – API 56-112
  - Krueger (1956) – API 56-126
  - Bell, et al. (1959) – API 59-249

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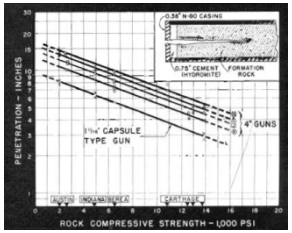
cations So it is, axiomatically, that one simple test method will not satisfy all testing requirements. It remains that to realistically evaluate gun-perforator performance, the test conditions must approach those under which the perforator will ultimately be applied.

- Penetration
  - Thompson (1962) – API 62-191
  - Saucier & Lands (1978) – SPE 6758
  - Halleck et. al. (1988) – SPE 18245
  - Behrmann & Halleck (1988) – SPE 18243
  - Harvey et al. (2011) – SPE 181546



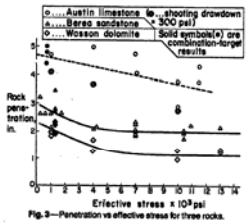


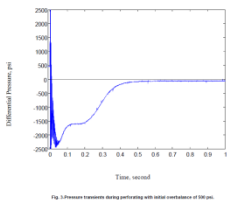
Fig. 3—Penetration vs effective stress for three rocks.

- Perf cleanup & Flow regimes
  - Bell, Brieger & Harrigan (1972) – SPE 3444
  - Deo, Tariq, & Halleck (1989) – SPE 16896
  - Halleck & Deo (1989) – SPE 16895
  - Hsia & Behrmann (1991) – SPE 22810
  - Behrmann (1996) – SPE 30081
  - Walton et al. (2001) – SPE 71642

Downhole flow regime into a perf tunnel; Modeling, relevance to lab testing

Static UB

Dynamic UB



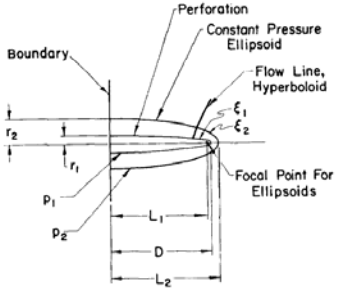
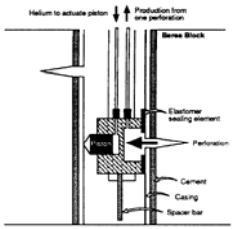
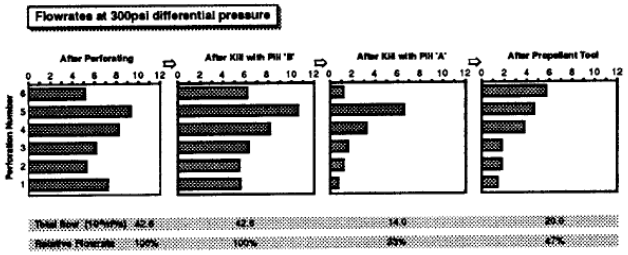


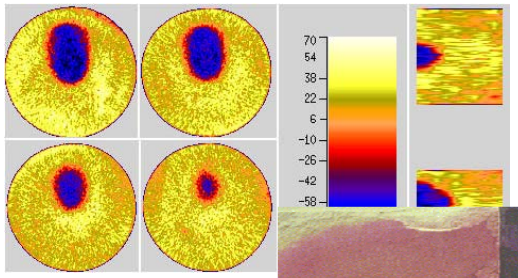
Fig. 2—Model of simplified down-hole system.

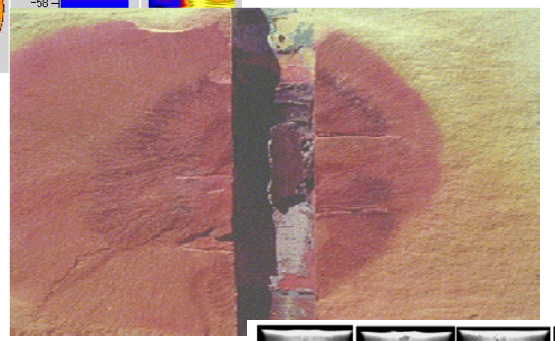
Milestones

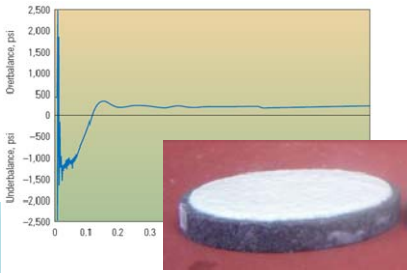


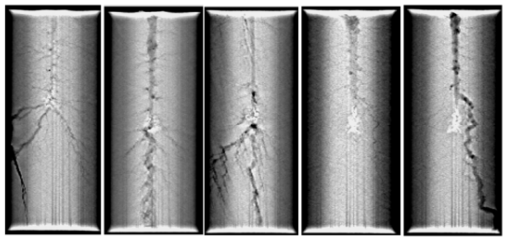


- System effects, heterogeneity, etc.
  - Mason et al. (1994) – SPE 28554
- Weak sands & sand control (sand production, GP impairment, etc.)
  - Blok et al. (1996) – SPE 36481
  - Behrmann et al. (1997) – SPE 38639
  - Venkitaraman et al. (1997) – SPE 38144
  - Walton et al. (2001) – SPE 71458
  - Walton et al. (2004) – SPE 90123
- Fracturing
  - Behrmann & Elbel (1991) – SPE 20661
- Acidizing
  - Bartko et al. (2007) – SPE 105022
- Perf system / fluid / formation interactions
  - Chang et al. (2004) – SPE 82203
  - Chang et al. (2005) – SPE 94596







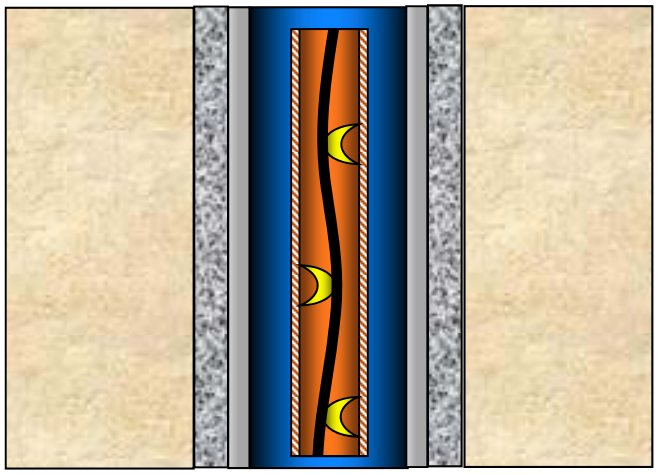


Common Theme & Goals

- Theme
  - Perforating is a SYSTEM operation

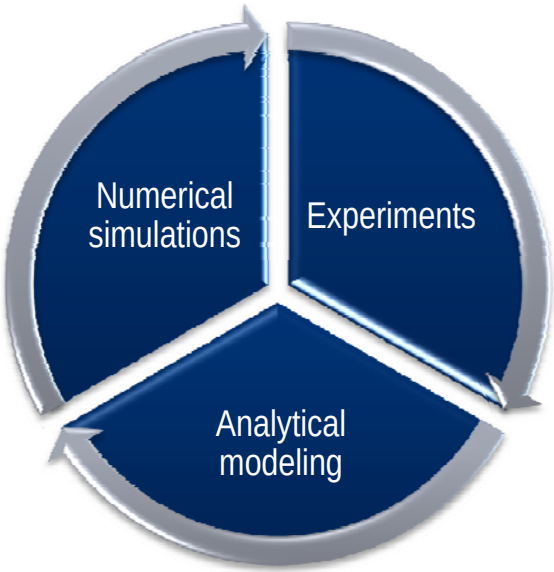
- Goals:
  - Understand reservoir response
  - Understand wellbore & completion responses

System =
gun + charges +
wellbore + reservoir

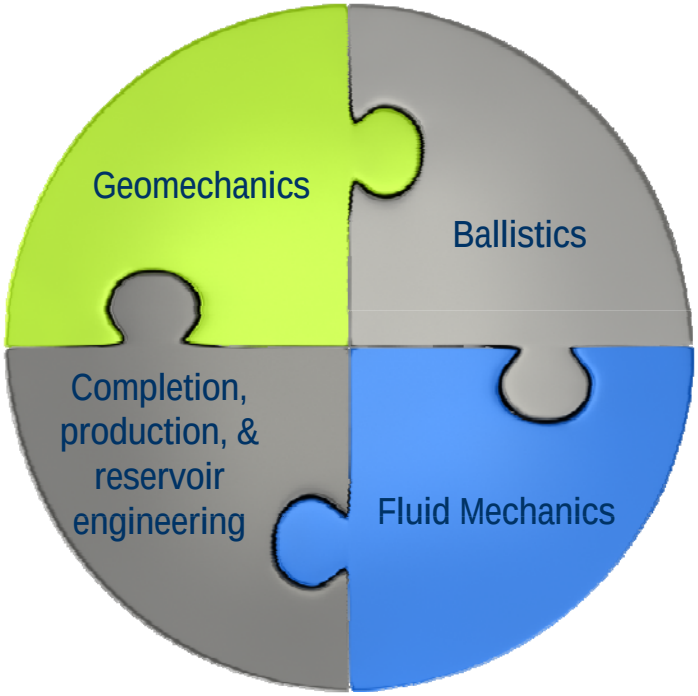


Keys to Success

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

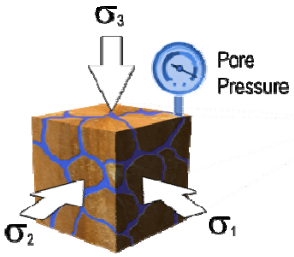


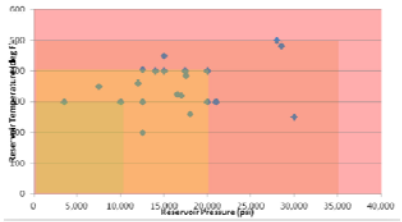
System = gun + charges + wellbore + reservoir



Recent & Future Trends

- More accurately replicate downhole environment
  - Rock properties (UCS, porosity, perm) – reservoir core sample ideal
  - Static conditions (stress, P, T)
  - Dynamic conditions
  - Fluids (both reservoir and wellbore)
  - Drilling damage
- Harsher environments (HP, HT)
- Prove product (and system) performance, validate models
- "test drive" perforating techniques, before / in conjunction with field testing





Ultimate goals remains the same

Maximize well productivity & operational efficiency

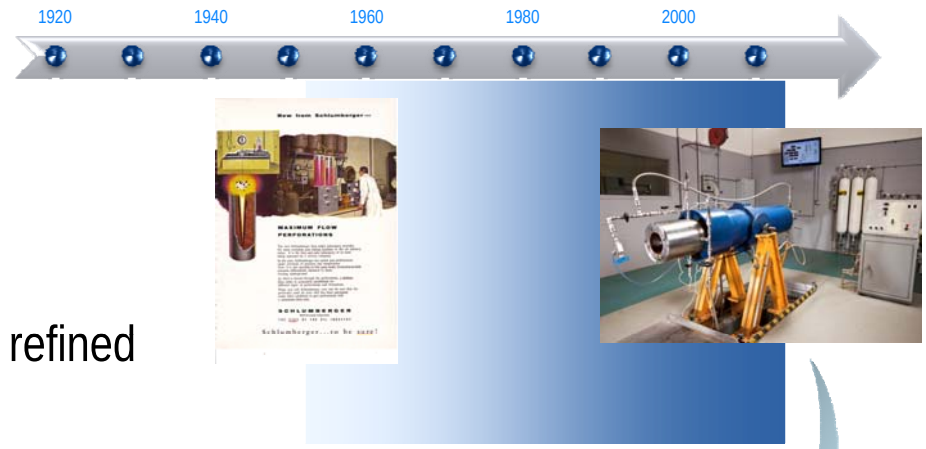
Minimize risk to field operations and completion equipment

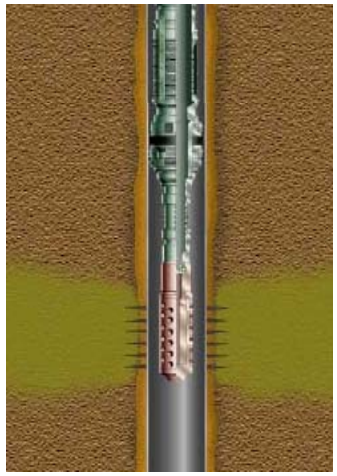
By the way…

- *Predictions (Behrmann, 2007):*
  - *Slow down in increasing Section I penetration.*
  - *Focus shift to reservoir rock under downhole conditions.*
  - *Focus shift to well productivity (away from Section 1 performance).*
  - *Openhole perforating*
  - *Systems optimized for specific reservoirs and completion types.*
  - *Systems integrated with completions, stimulation operations.*
  - *"One trip well".*

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

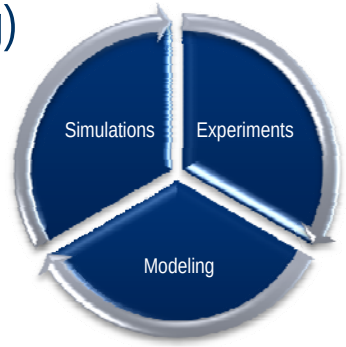




Integration essential (multidisciplinary; expts+modeling)

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

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cations So it is, axiomatically, that one simple test method will not satisfy all testing requirements. It remains that to realistically evaluate gun-perforator performance, the test conditions must approach those under which the perforator will ultimately be applied.

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