Perforation Laboratory Testing: How Close is Close Enough?

NAPS-2018-21

AUTHORS:

Phil Crabtree - Chevron
David Underdown - Consultant
Brenden Grove - Halliburton Jet Research Center

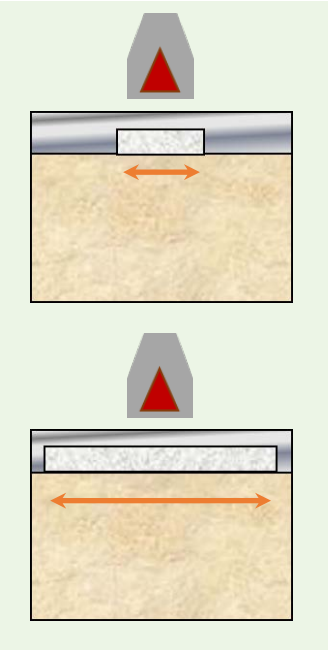
PERFORATORS.ORG
INTERNATIONAL PERFORATING FORUM

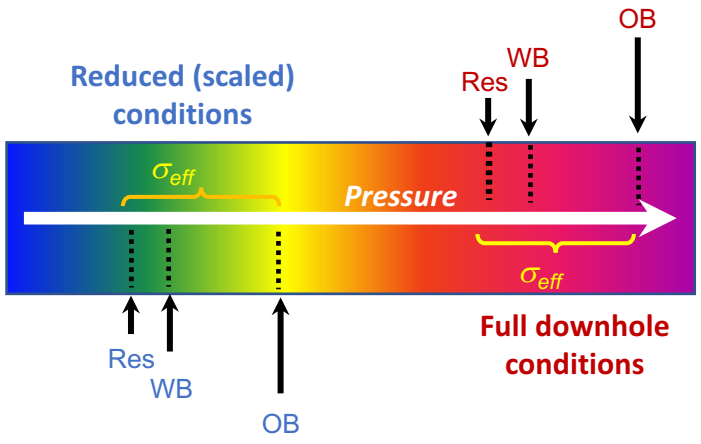
Outline

- Test program description
- Objectives
- Results
- Conclusions

Test Program Description & Objectives

- 4 laboratory experiments
- Explored 2 parameters
  - Cement puck geometry (lateral dimension)
  - Test pressures (full downhole, vs. reduced/scaled)
- Same starting static effective stress for all
- Several key performance indicators investigated:
  - Casing hole size
  - Formation penetration depth
  - Tunnel stability & formation fracture pattern
  - Flow performance





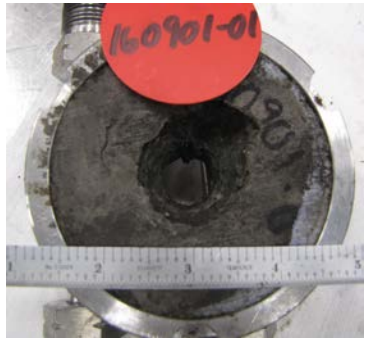
Test #	Type	Overburden stress (psi)	Reservoir pressure (psi)	Wellbore pressure (psi)	Effective stress (psi)	Static overbalance (psi)	notes	Objective
1	Section 2+	22,700	14,700	16,100	8,000	1,400	Standard cement puck geometry	Assess influence of cement puck diameter
2	Section 2+	22,700	14,700	16,100	8,000	1,400	Larger diameter cement puck	
3	Section 4	22,700	14,700	15,000	8,000	300	Full downhole pressure	Assess influence of absolute pressures
4	Section 4	10,000	2,000	2,300	8,000	300	Reduced (scaled) pressure	

- *25g BH charge*
- *Castlegate sandstone, OMS saturated*
- *Simulating Q125 casing*

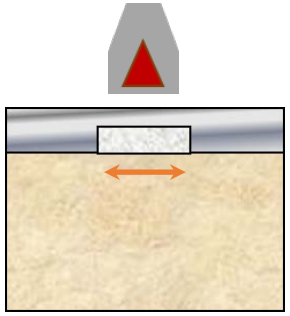
Program Results

Effects of cement puck size – cement hole diameter

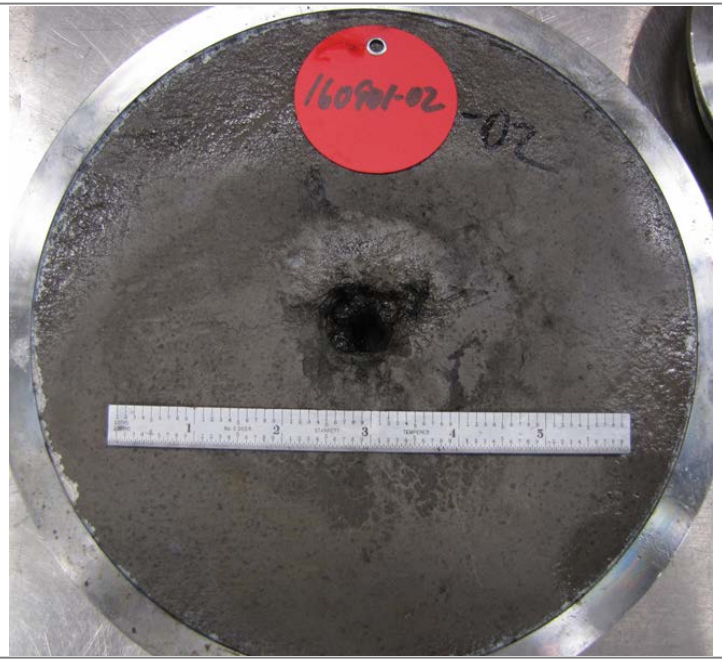
Test 1



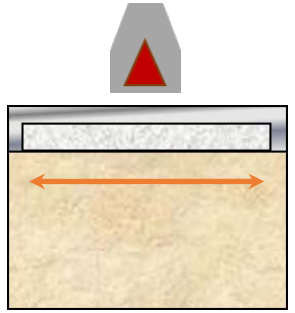
Cement exit; hole dia~1.2”



Test 2



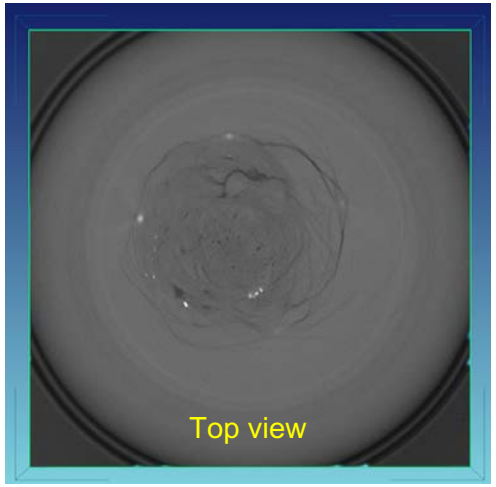
Cement exit; hole dia~0.7”

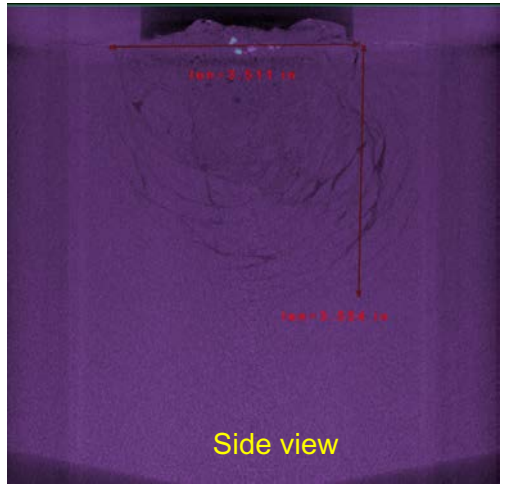


Program Results

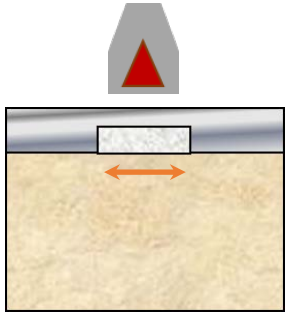
Effects of cement puck size – sandface fractures

Test 1

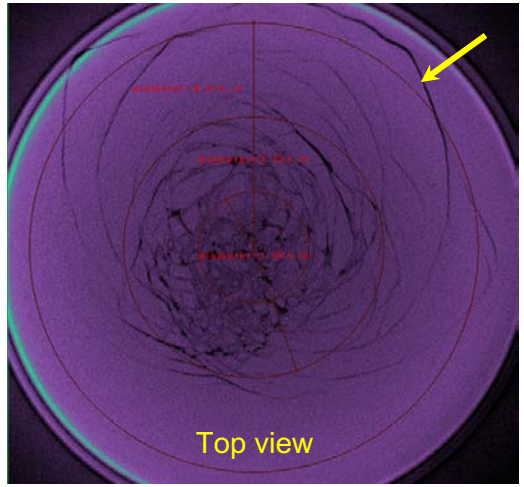


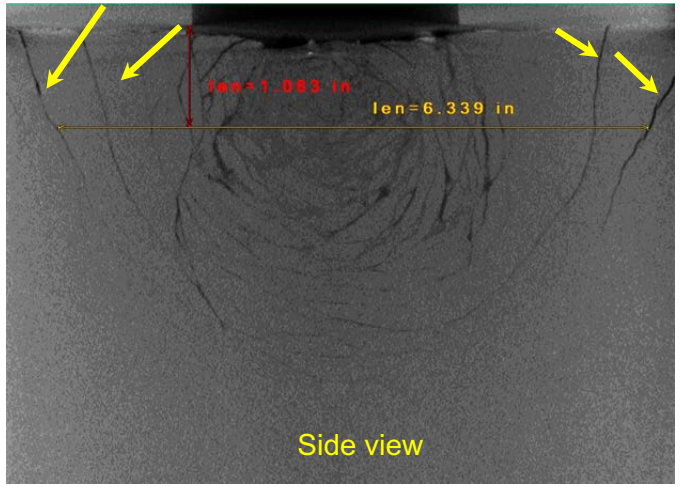


fractures at core perforated surface: extent limited to region of cement contact

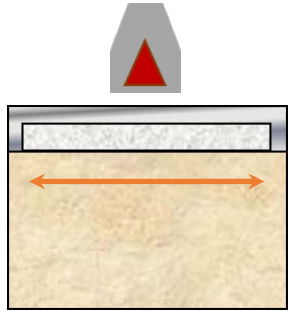


Test 2





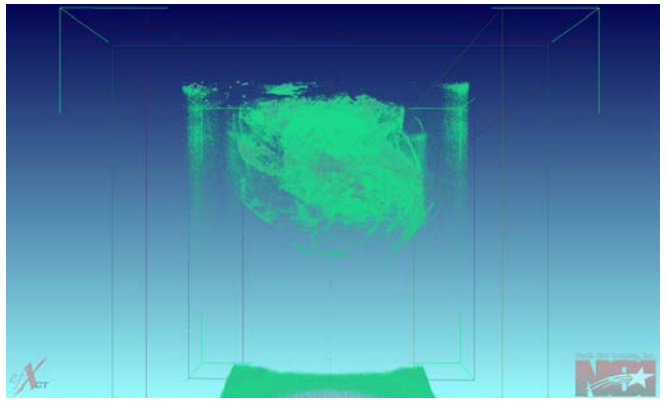
fractures at core perforated surface: extent expanded to increased cement contact

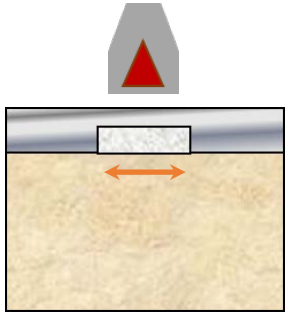


Program Results

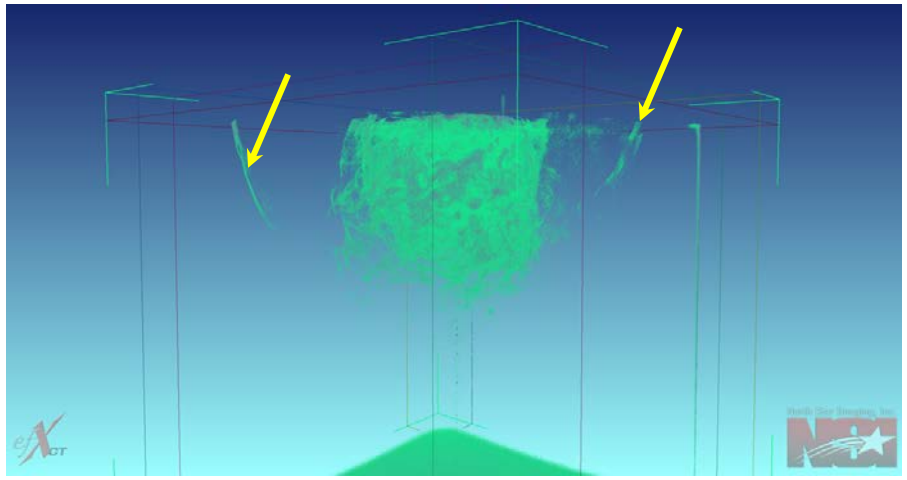
Effects of cement puck size – sandface fractures

Test 1

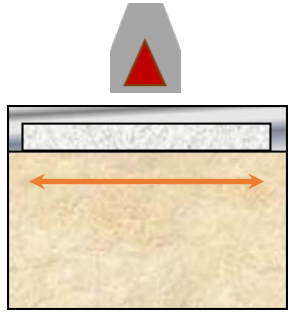




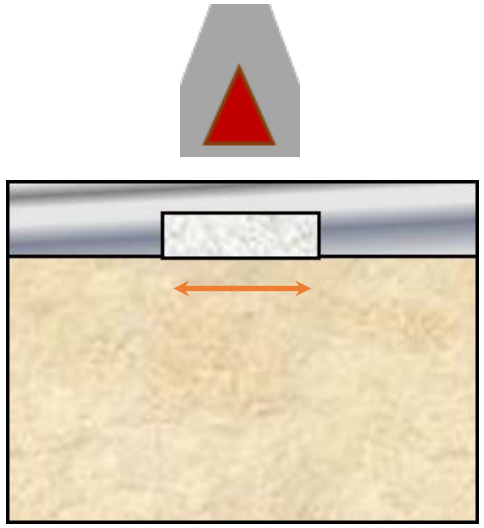
Test 2

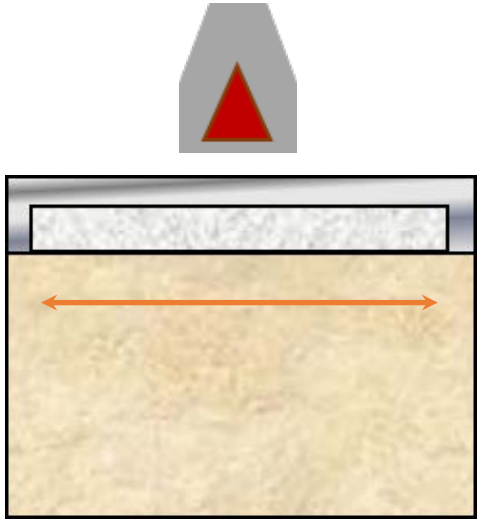


3D view of expanded zone of fractures at core perforated surface



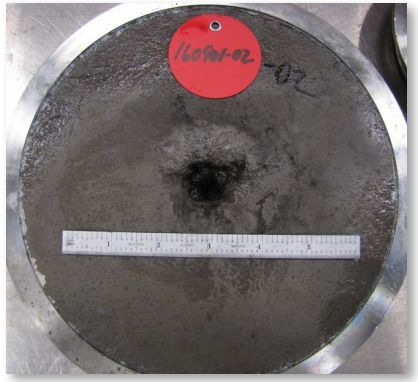
Program Results

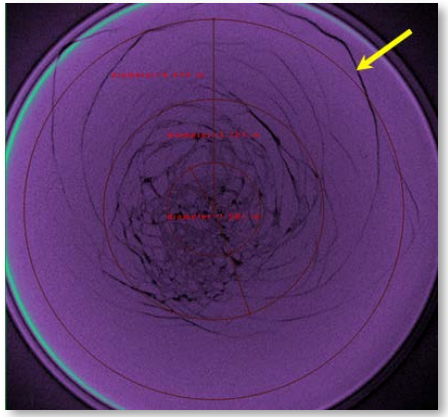


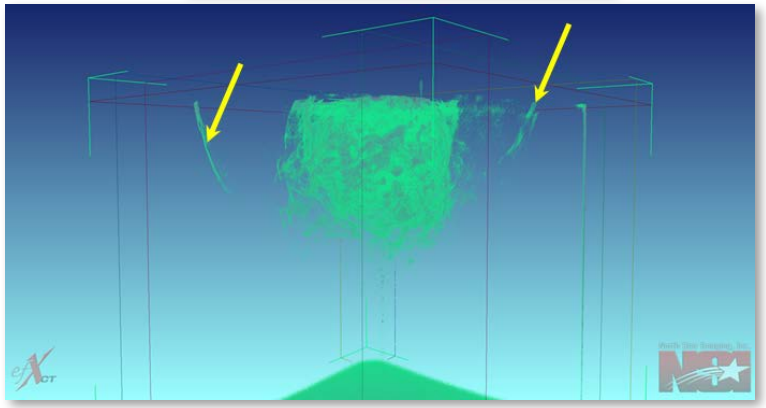


Conclusion:

Cement puck lateral dimensions
can influence
cement hole diameter
and
sandface fracture pattern





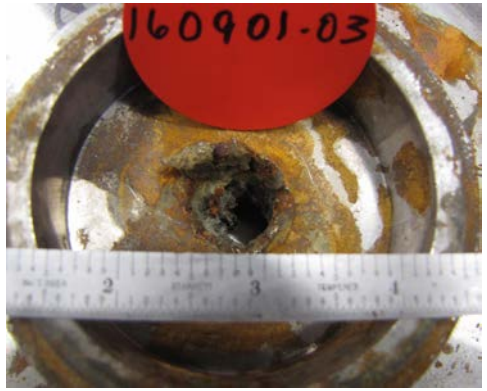


Program Results

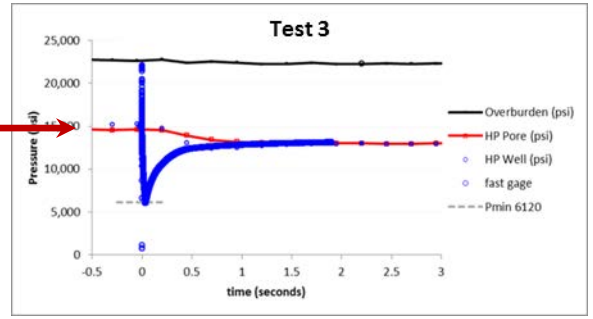
Full vs scaled pressure - casing hole size

Test 3

Downhole Pressure



Wellbore pressure = 15,000 psi

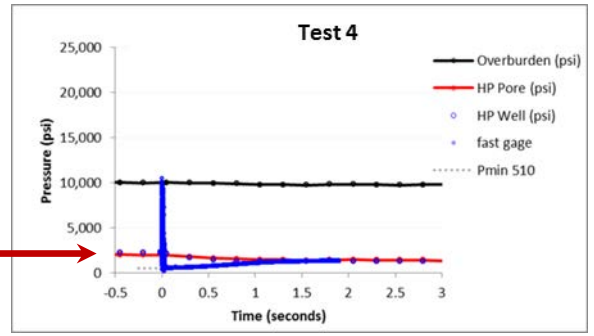


Casing EH dia ~ **0.56”**

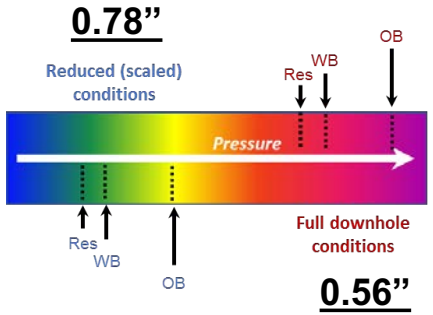
Test 4

Scaled Pressure

Wellbore pressure = 2,300 psi



Casing EH dia ~ **0.78”**



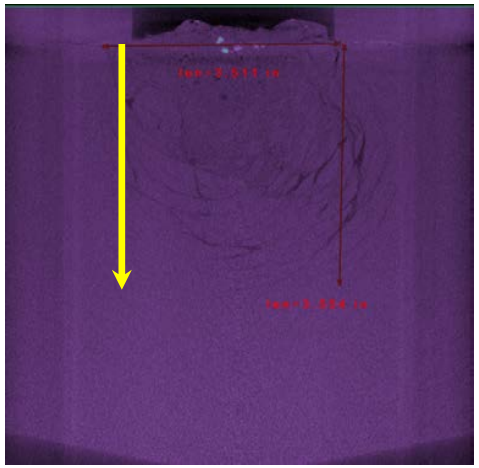
Conclusion:
Testing pressures can influence hole size in casing

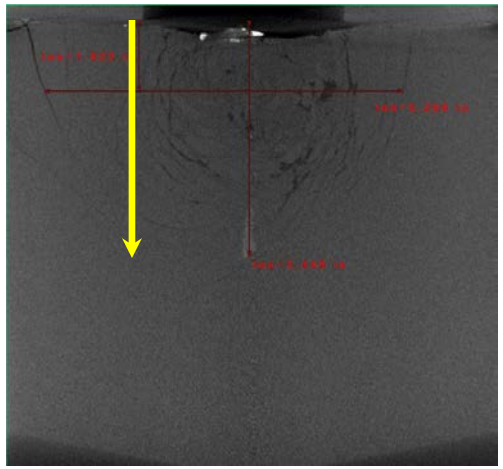
Program Results

Full vs scaled pressure – formation penetration depth

Tests 1,2 *

** See next slide for discussion on test 3 core*

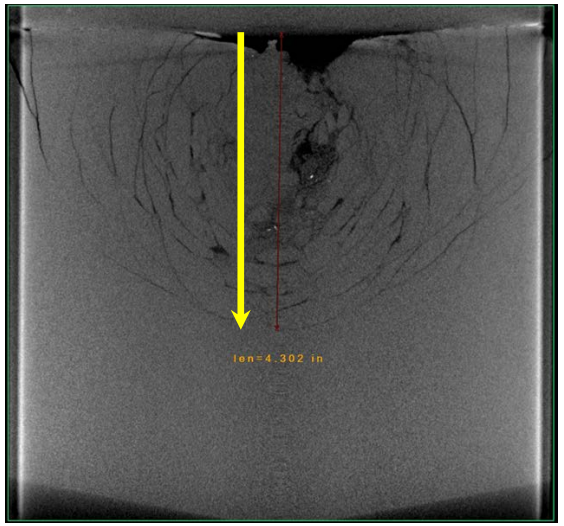




Full pressures:

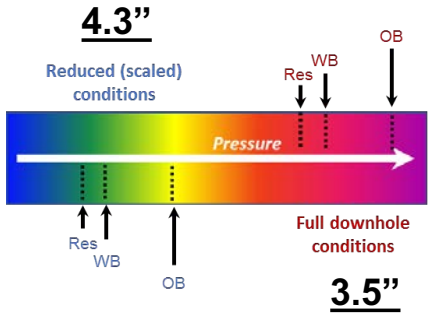
Penetration depth ~ **3.5”**

Test 4



Scaled pressures:

Penetration depth = **4.3”**

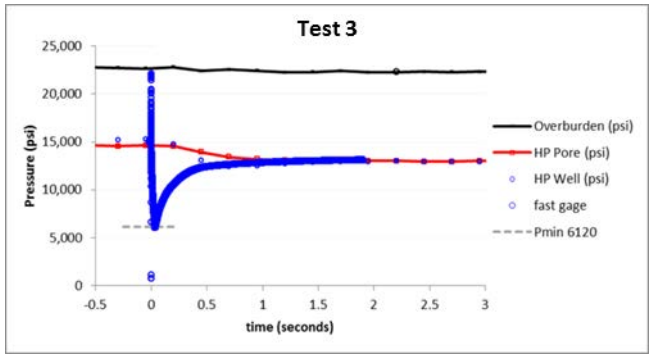


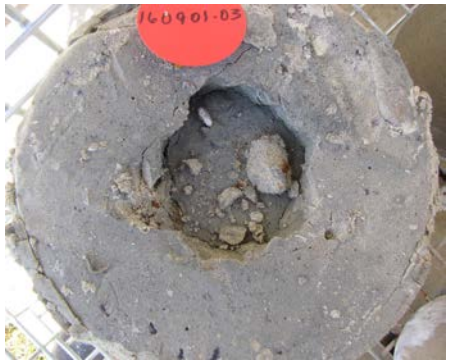
Conclusion:
Testing pressures
can influence
Penetration depth in formation

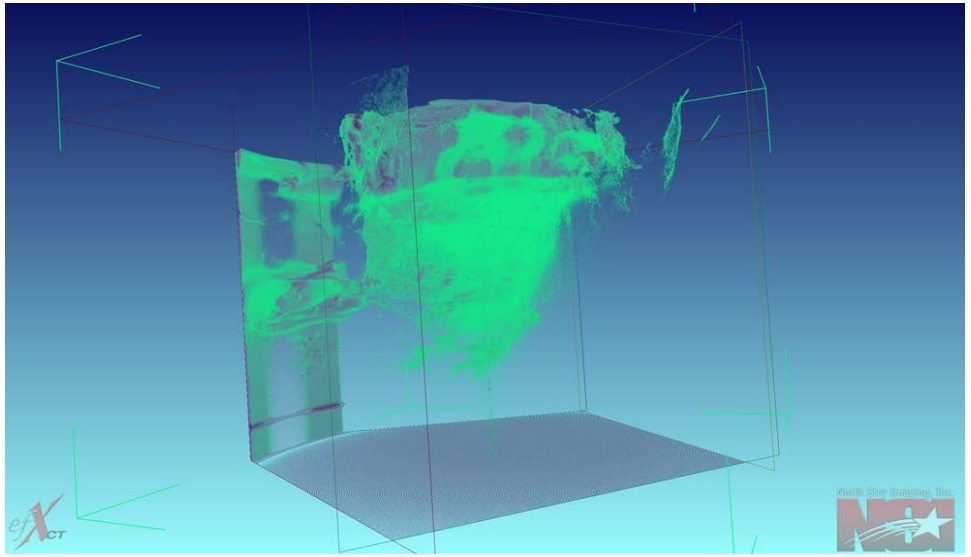
Program Results

Test 3 discussion

- During post-perforation flow:
  - Confining sleeve ruptured
  - Resulting in confining fluid (water) rushing into core
  - Partially washing out perforation tunnel
- This was caused by core material behind the confining sleeve eroding, due to one or more of the following:
  - Excessive DUB / DES (see next slide)
  - Excessive flow rates





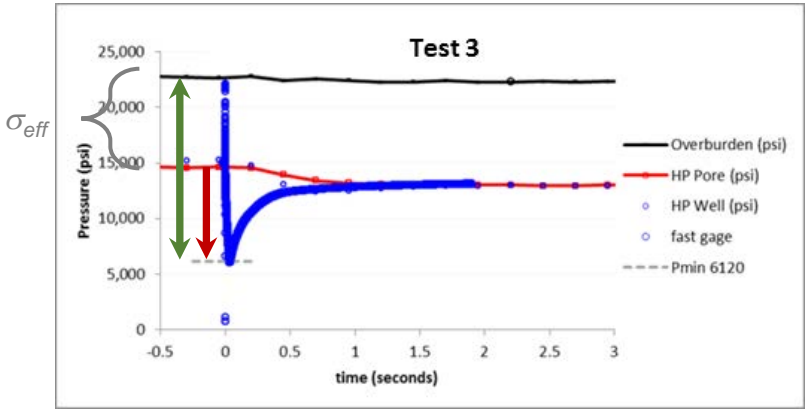


Program Results

Tests 3 and 4 (shot-time pressure transients)

Test 3

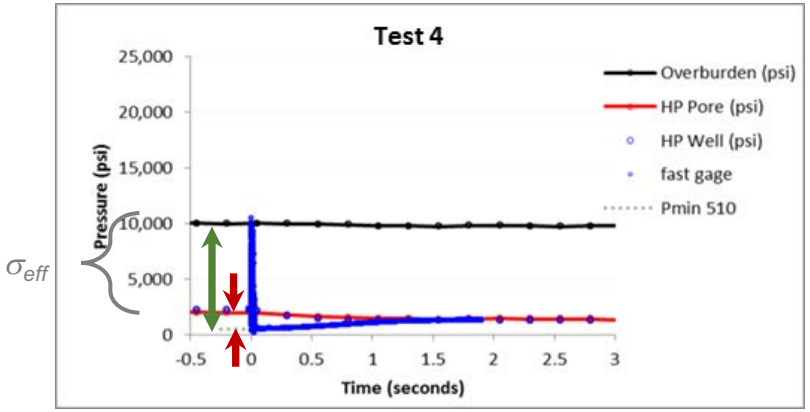
Downhole Pressure



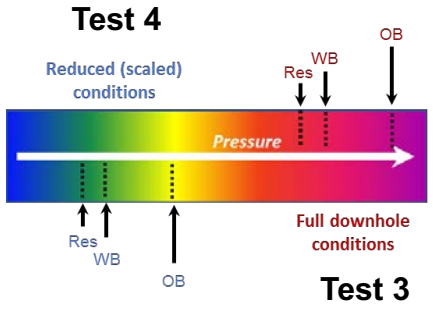
Pmin	6,120
Pore start	14,700
DUB	8,580
Overburden start	22,700
DES	16,580

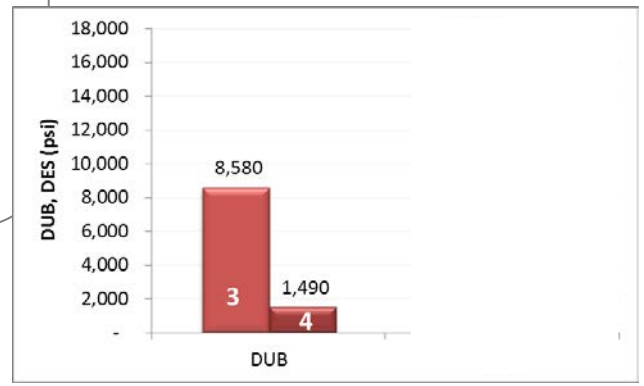
Test 4

Scaled Pressure



Pmin	510
Pore start	2,000
DUB	1,490
Overburden start	10,000
DES	9,490





- DUB = Dynamic underbalance (critical parameter for ***cleanup***)
- DES = Dynamic effective stress (may be critical parameter for ***tunnel stability***)

Program Results

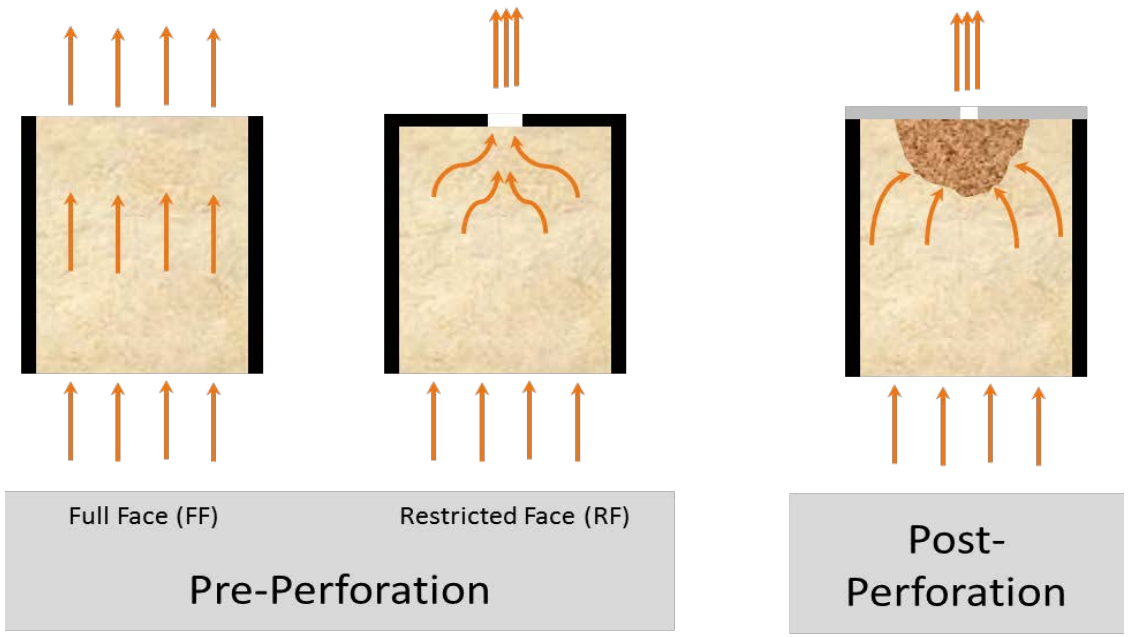
Tests 3 and 4 (flow)

- Pre-perforation flow
  - Core prep involved flowing in 2 configurations (FF, RF…sketch below)
  - Multiple rates in each configuration
  - Establish productivity index (PI) = Q/dP for each configuration (PI_{FF}, PI_{RF})
  - *Flowed at absolute pressures matching planned post-perf flow*

- Perforated cores were flowed over a similar range of dP values as pre-perf flow
  - $PI_{postperf}$ established

- Analysis
  - Post-perf PI normalized to pre-perf PI…to establish PR
  - $PR(FF) = PI_{postperf} / PI_{FF}$
  - $PR(RF) = PI_{postperf} / PI_{RF}$

.

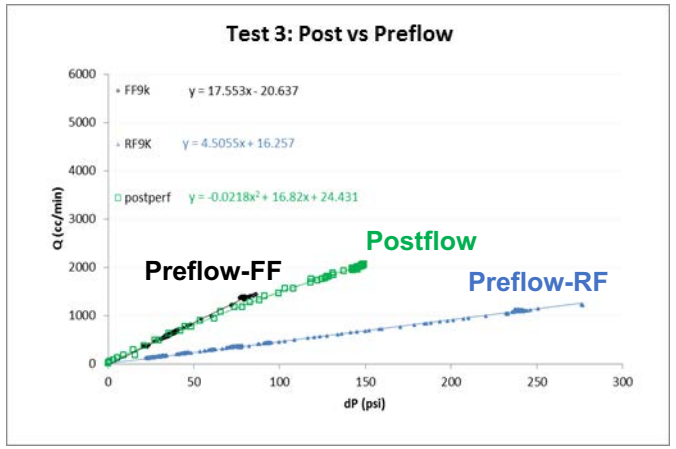


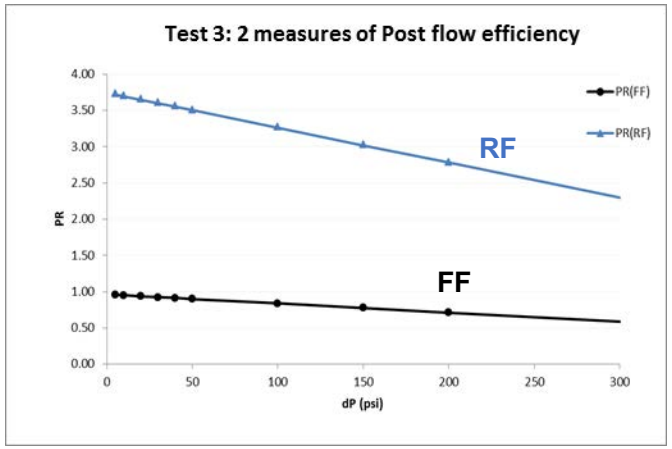
Program Results

Tests 3 and 4 (flow results)

Test 3

Downhole Pressure



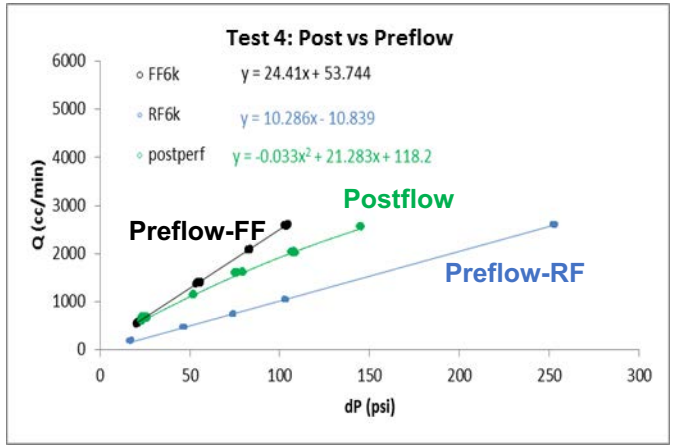


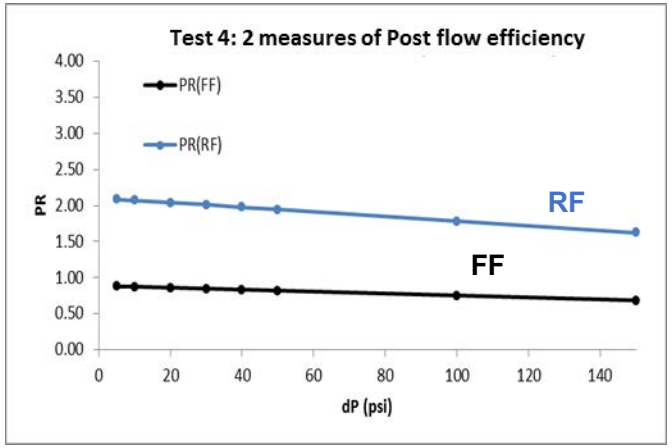
Q vs dP

PR vs dP

Test 4

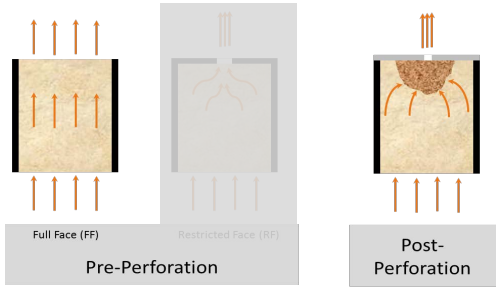
Scaled Pressure



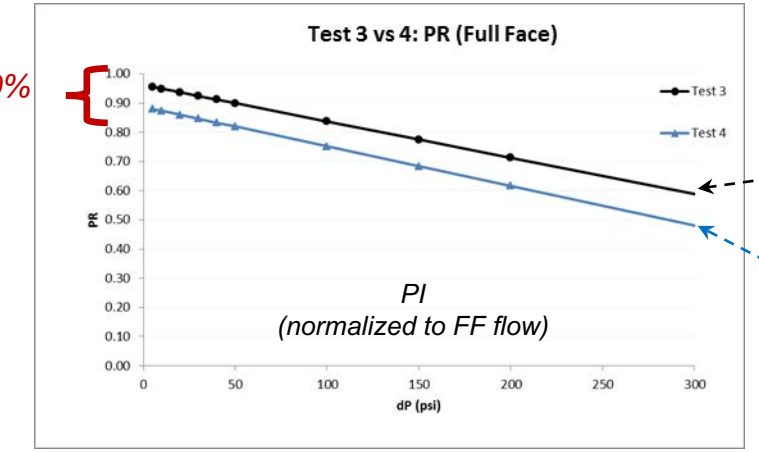


Program Results

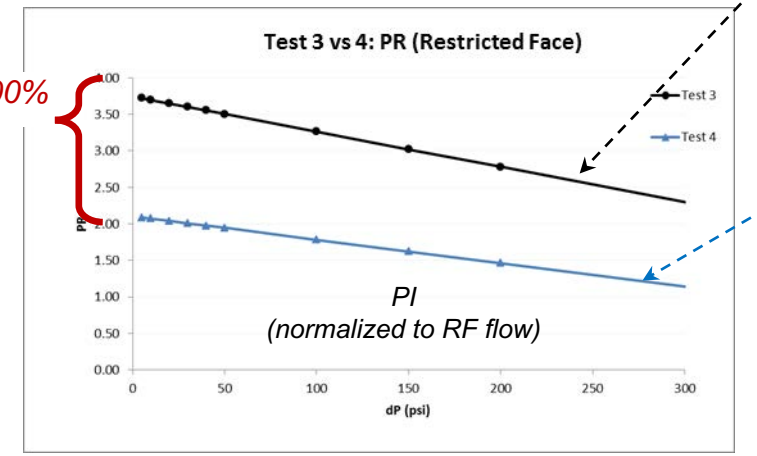
Test 3 vs Test 4 (flow comparison)

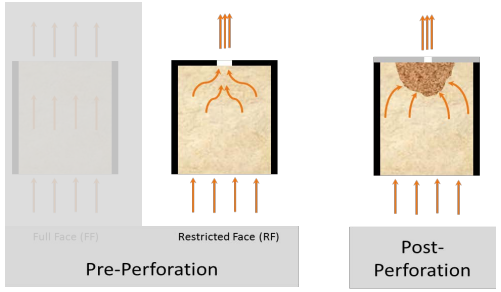


Δ ~ 10-20%



Δ ~ 80-100%





Downhole Pressure (Test #3)

Scaled Pressure (Test #4)

Conclusion:
Testing pressures can influence flow performance

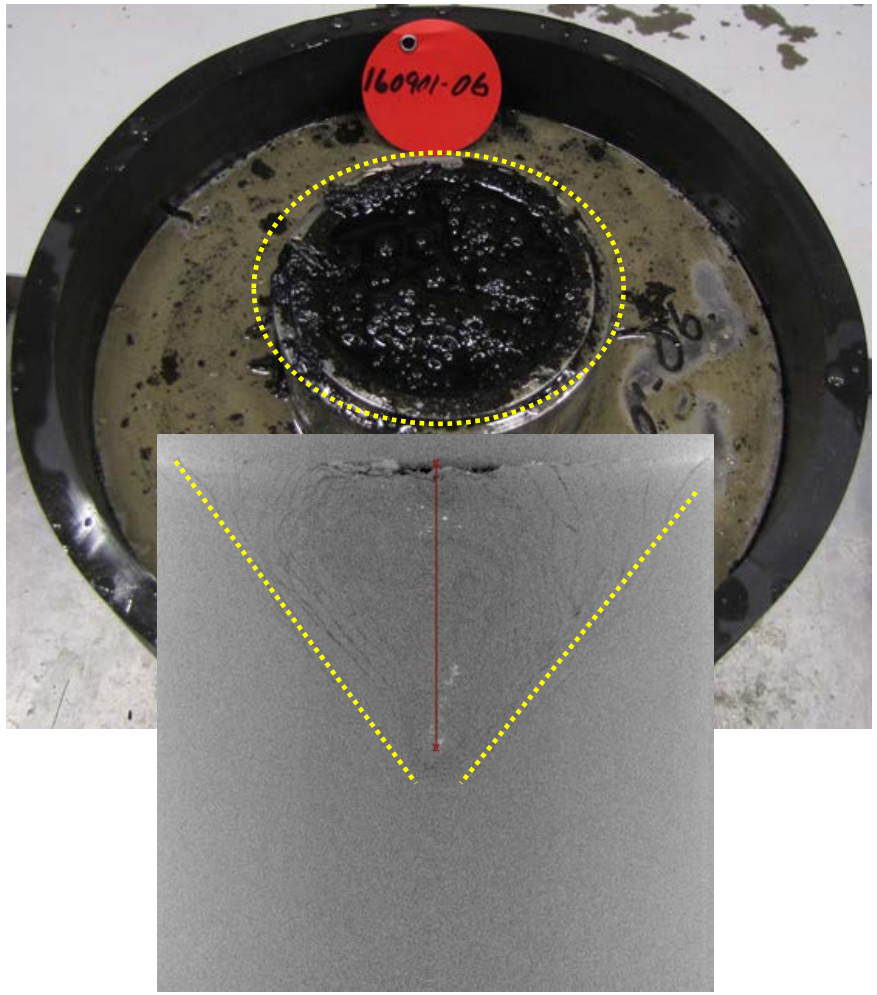
Summary and Conclusions

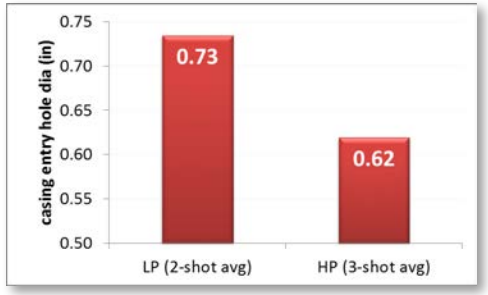
- 4 laboratory tests were conducted, to investigate 2 parameters
  - Cement puck geometry (lateral dimension)
  - Test pressures (full downhole, vs. scaled/reduced)

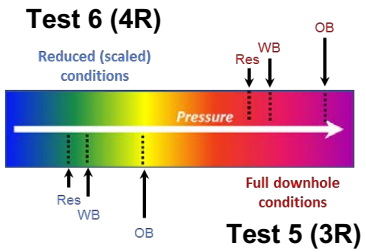
- Conclusions
  - Cement puck geometry can influence the results
    - Fracture pattern at perforated rock face
    - Exit hole diameter in cement (at cement/rock interface)
  - Test pressures can influence the results
    - Casing hole diameter (wellbore pressure influence)
    - Perforation depth (simply matching effective stress is not adequate)
    - Tunnel stability (dictated by transients, which generally don't scale with static conditions)
    - Flow performance
  - Core size
    - large diameter (eg >=9") important to minimize core boundary effects, especially with larger charges

PS - Repeat testing

- Tests 3 and 4 were repeated (but *without* flow)





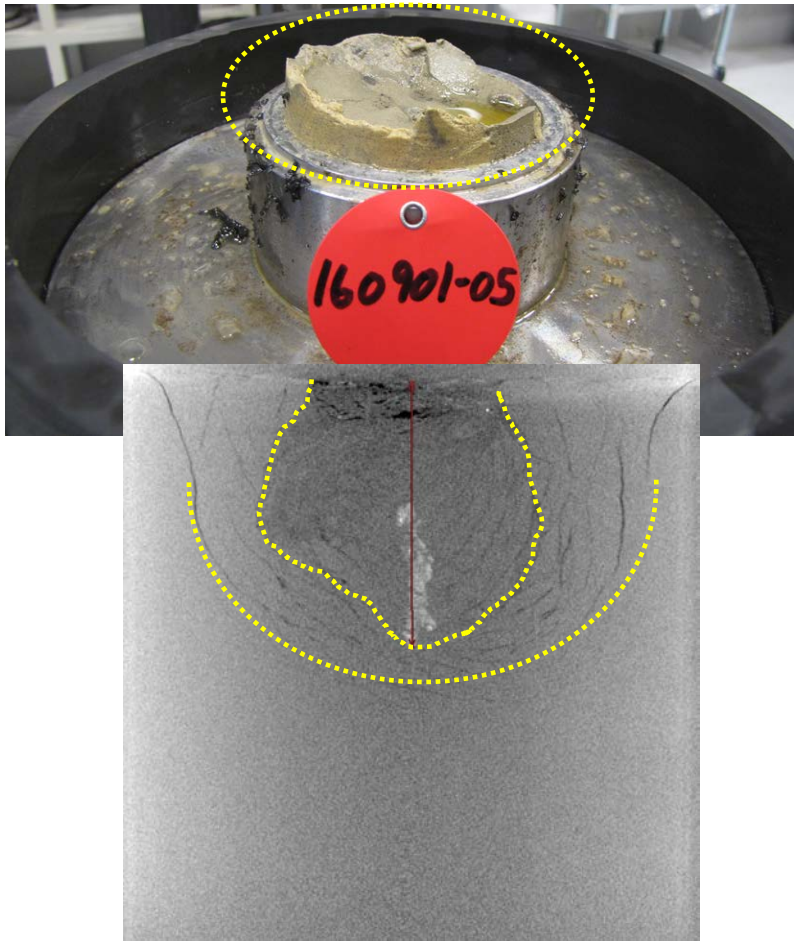


Wellbore debris	
← gun debris only	formation debris →

Perforation envelope	
← conical	hemispherical →

Perforation cavity	
← full	partially empty →

Penetration depth	
← 3.4”	3.1” →



QUESTIONS? THANK YOU

NAPS-2018-21

AUTHORS:

Phil Crabtree - Chevron
David Underdown - Consultant
Brenden Grove - Halliburton Jet Research Center

PERFORATORS.ORG
INTERNATIONAL PERFORATING FORUM