Carbon Storage and Management

3–4 SEPTEMBER 2024 | KUALA LUMPUR, MALAYSIA

Perfororation Techniques for Injectivity Enhancement for CCS Projects

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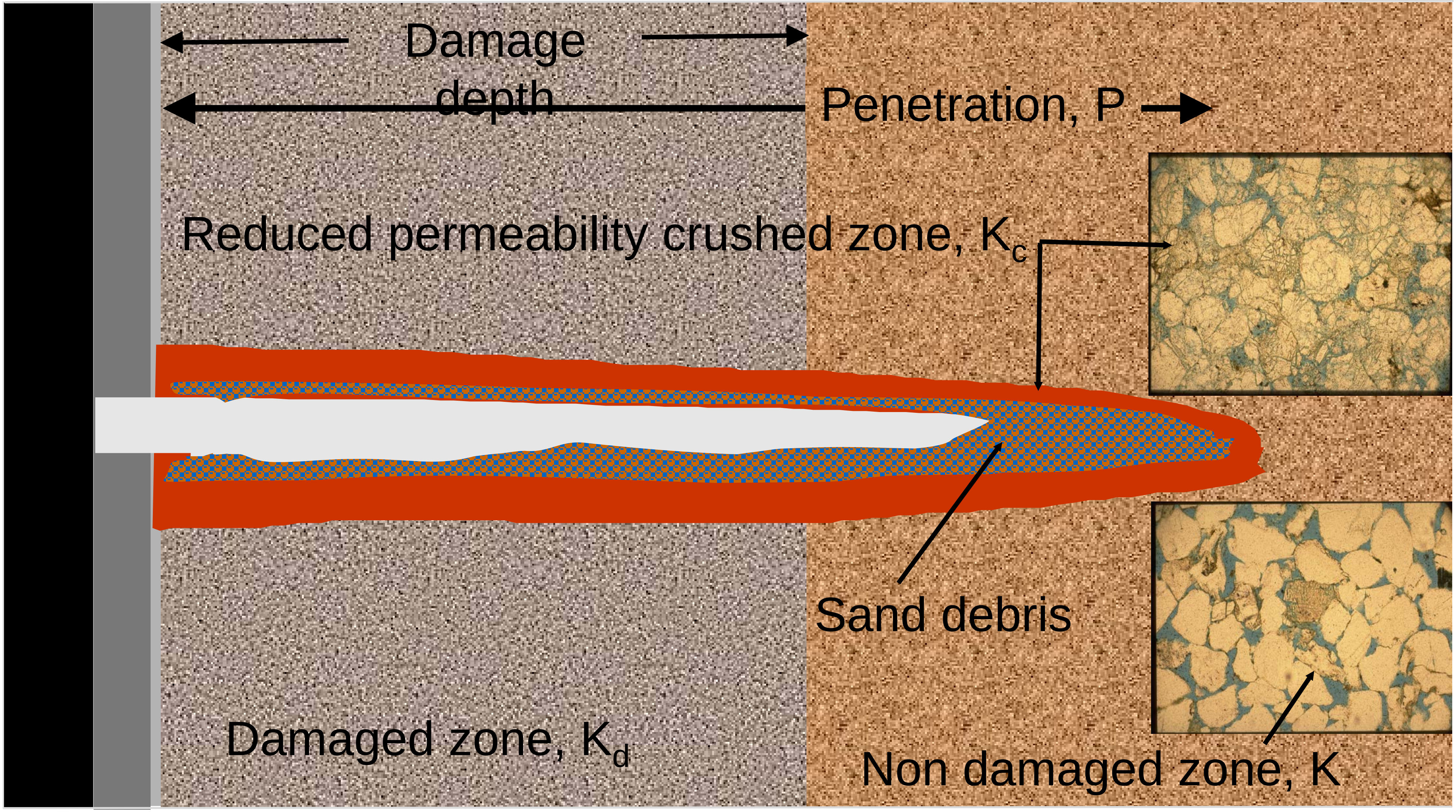
SLB

Agenda

- Perforation Damage
- Perforation Tunnel Clean up
- Static and Dynamic Underbalance
- Propellant

Crushed Zones in Perforation Tunnels



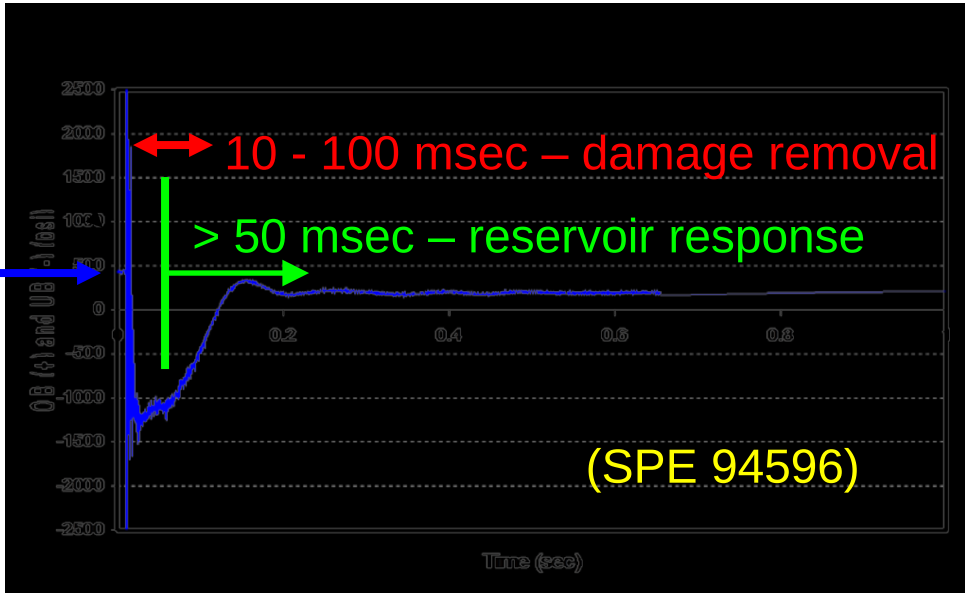
Sequence of Perforating Events and Borehole Dynamic

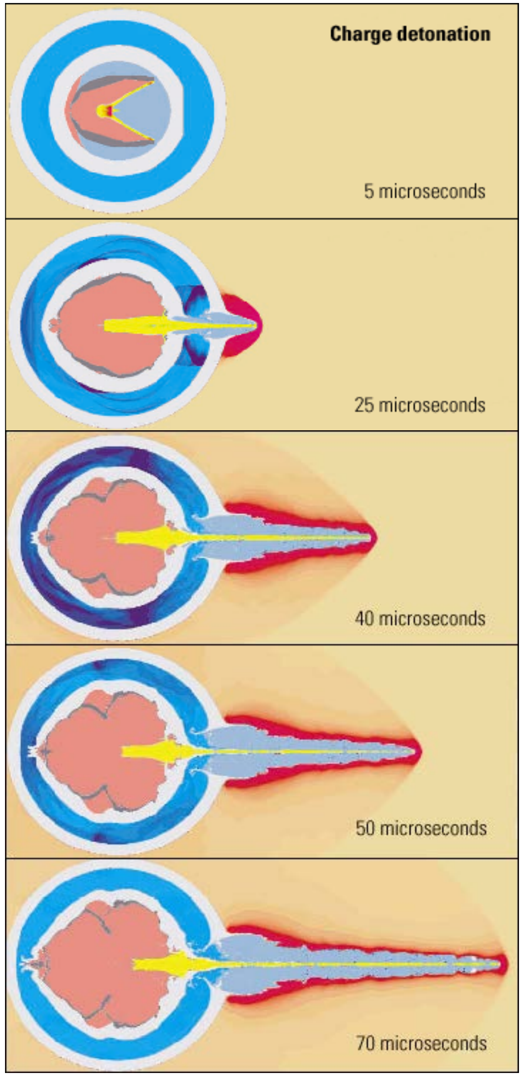
(SPE 97363)

- 0 – 15 microsecond – birth of jet
- 15 – 250 microsecond – creation of cavity in rock
- 3 – 15 millisecond – initial response of wellbore fluid
- 10 – 100 millisecond – perforation damage removal
    - Dynamic Underbalance
- > 50 millisecond – response of reservoir

Initial over balance

possible to get DUB when borehole is balanced or slightly over balanced

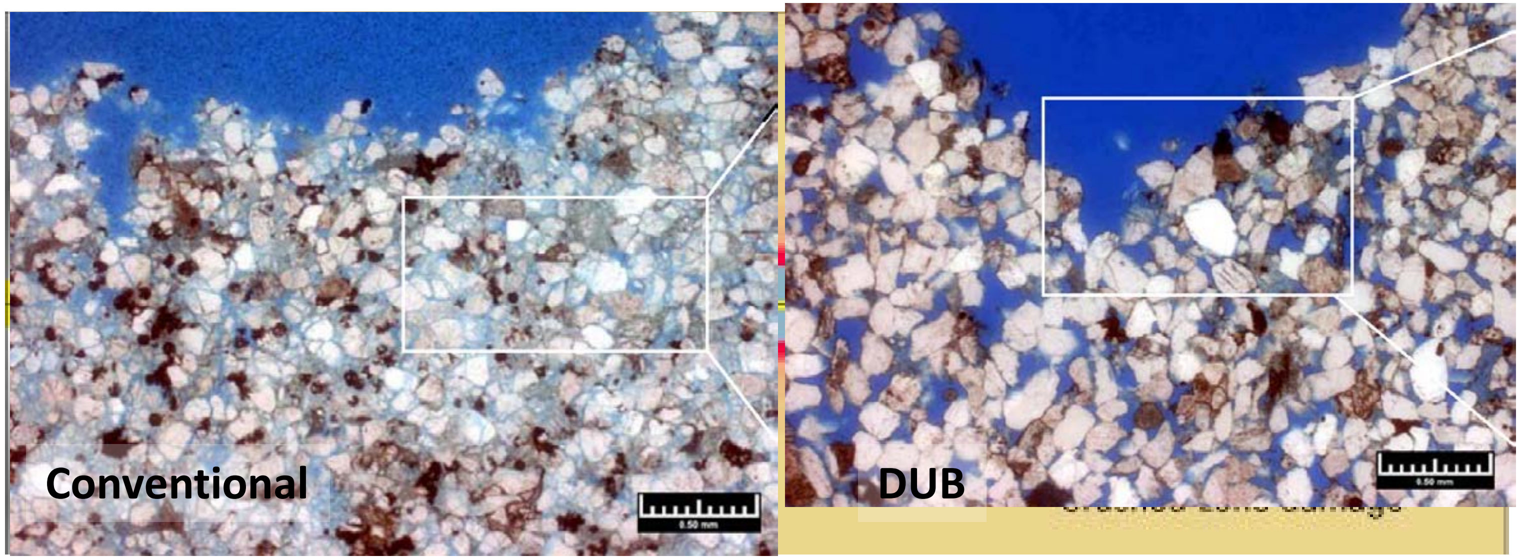




Dynamic Underbalance Perforation (DUB)

(SPE 97363)

- Obtains clean perforations by utilizing underbalance period to remove perforating debris & crushed formation.
- Combines perforating system design and wellbore conditions to control downhole pressure transients at the time of perforating.

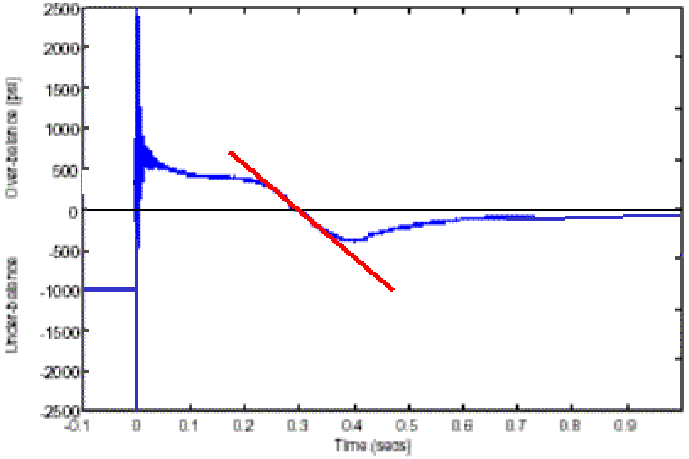


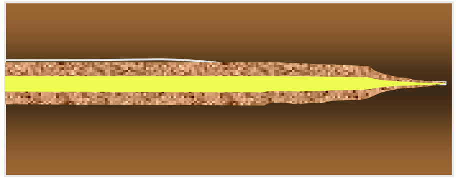
Berea Sandstone Micrographs from perforated core thin sections *(blue = perforation tunnel)*
Note clean sand grains in the DUB case

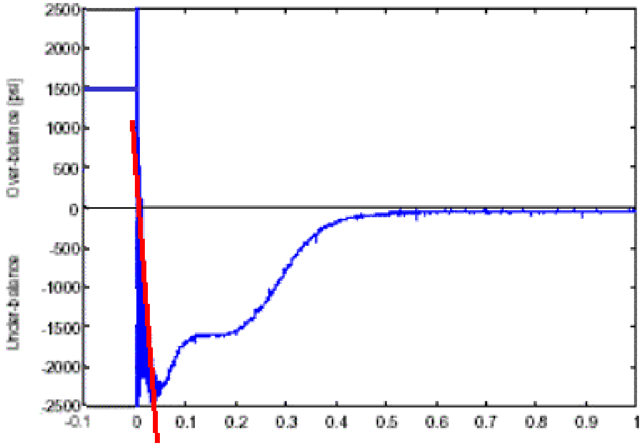
Conventional vs. Dynamic Underbalance

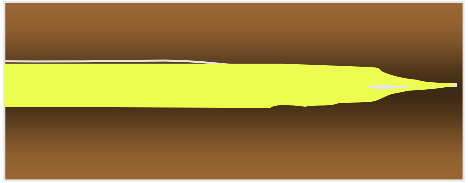
- *Conventional Underbalance (this example):*
- BHP before perf. = 1000 psi UB
- Instantaneous UB = No (< 0.1 sec)
- Max UB < 500 psi (variable, borehole dependent)
- Kc/K = 0.047 -> PR < 70%

- *Dynamic Underbalance (this example):*
- BHP before perf. = 1500 psi OB (can be slightly OB)
- Instantaneous UB = 2500 psi
- Max UB = 2500 psi (for this case) (Max UB is reservoir pressure dependent)
- Kc/K = 1 -> PR = 100%



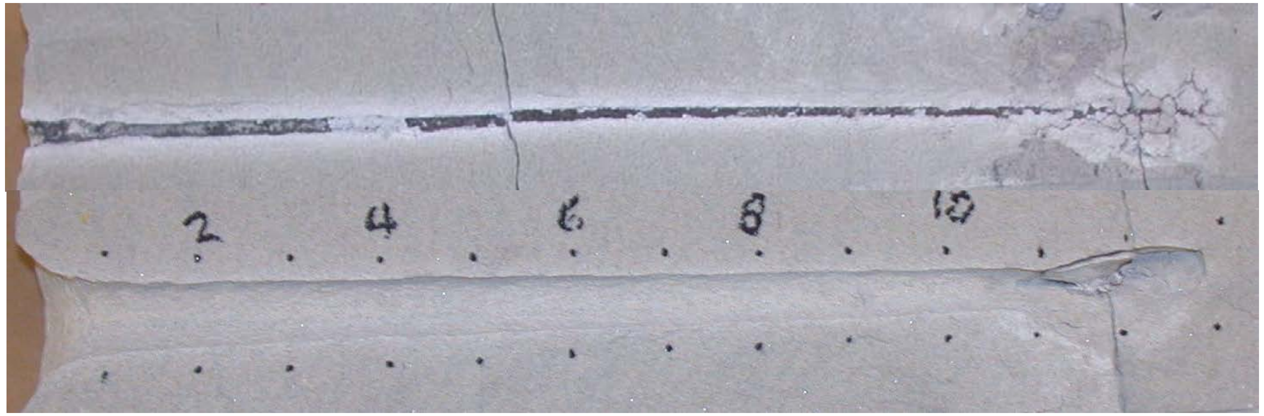






- https://www.slb.com/completions/well-completions/perforating/perforating-gun-systems/hollow-carrier/pure-clean-perforations-system

PURE vs. Non-PURE Gas and Liquid Core Test



Non-PURE

Pore fluid: GAS (Dry N2)

PURE

Non-PURE

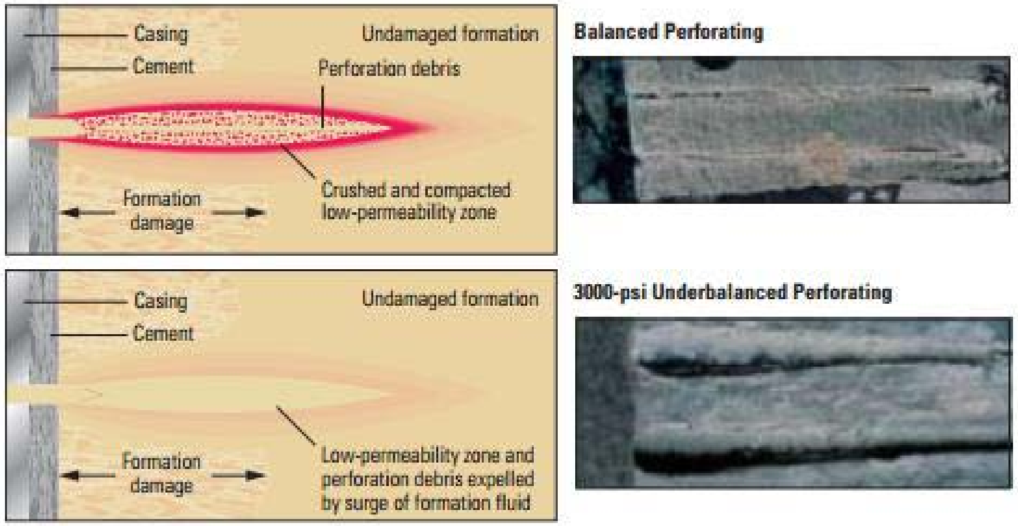
Pore fluid: LIQUID (brine)

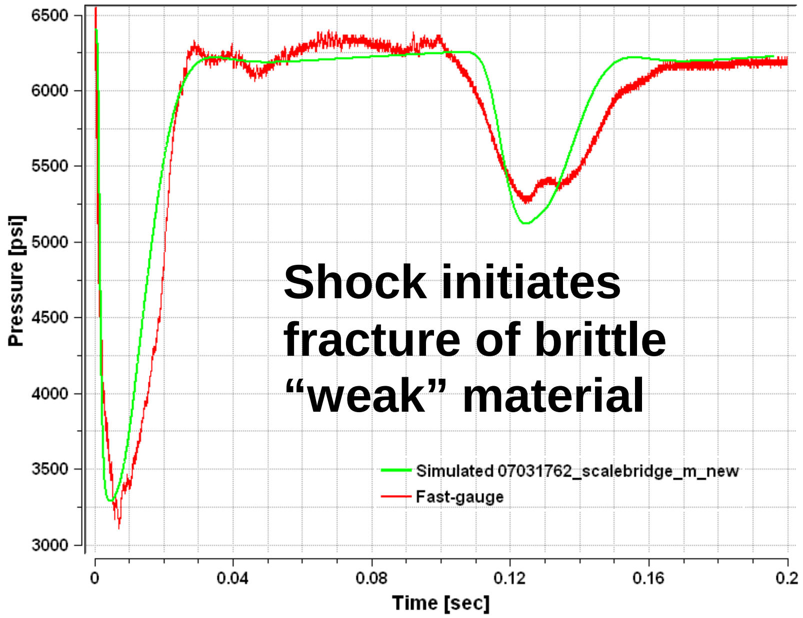
PURE

- https://www.slb.com/completions/well-completions/perforating/perforating-gun-systems/hollow-carrier/pure-clean-perforations-system

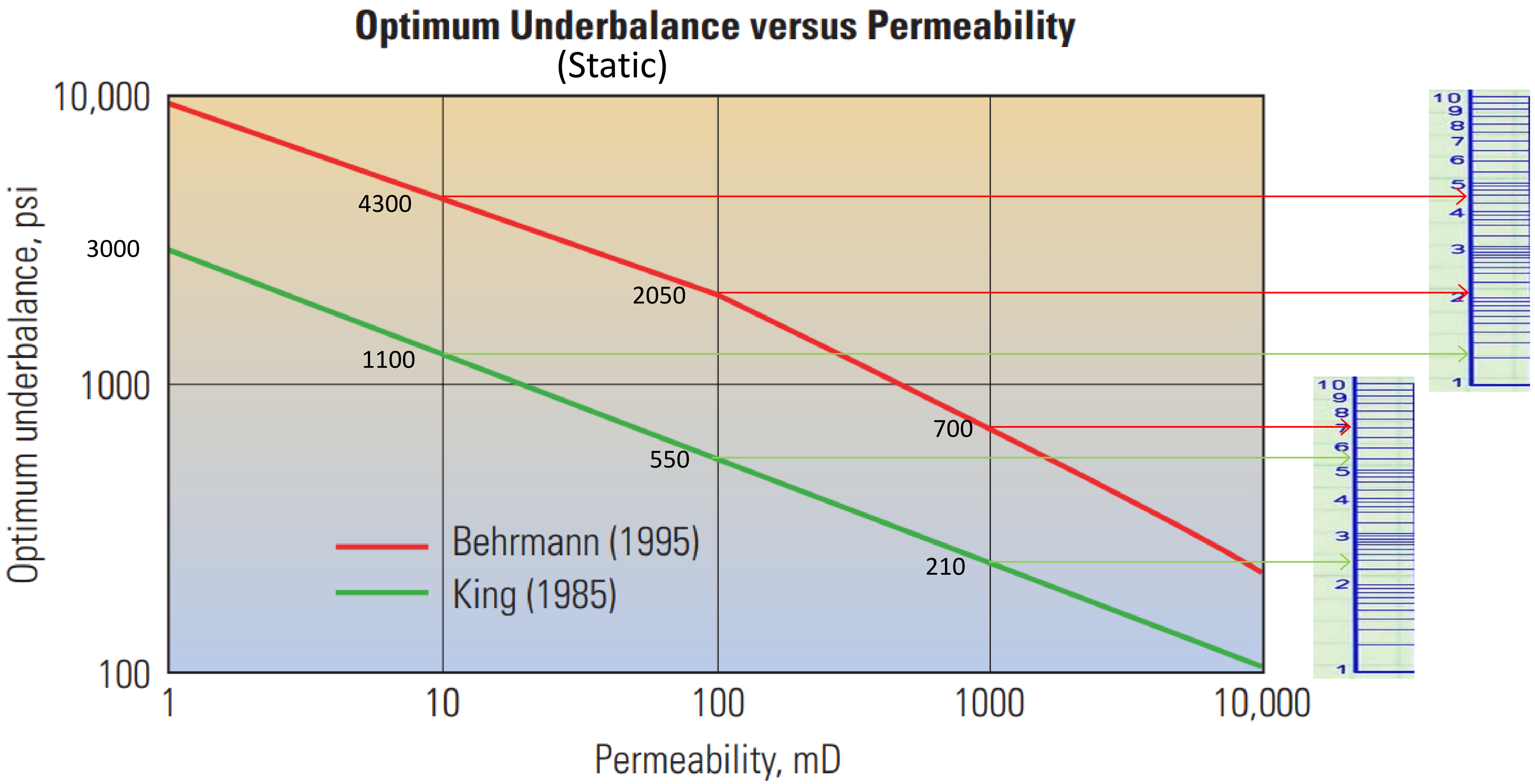
P3 – PURE post-perforating (SPE -144080-MS)

- P3 is an adaptation of PURE that does not perforate the casing.
- Implosion chamber with atmospheric air at the surface is placed across a perforated interval in the well to be treated to create Dynamic underbalance.
- Dynamic underbalance is the term given to a rapid and large (violent) drop of pressure in the well bore when the implosion chamber is activated.
- The pressure drop is usually short lived 15 – 50 ms
- Any “loose” material in the perforation tunnels (or near wellbore) is sucked into the wellbore and some into the P3 chamber.



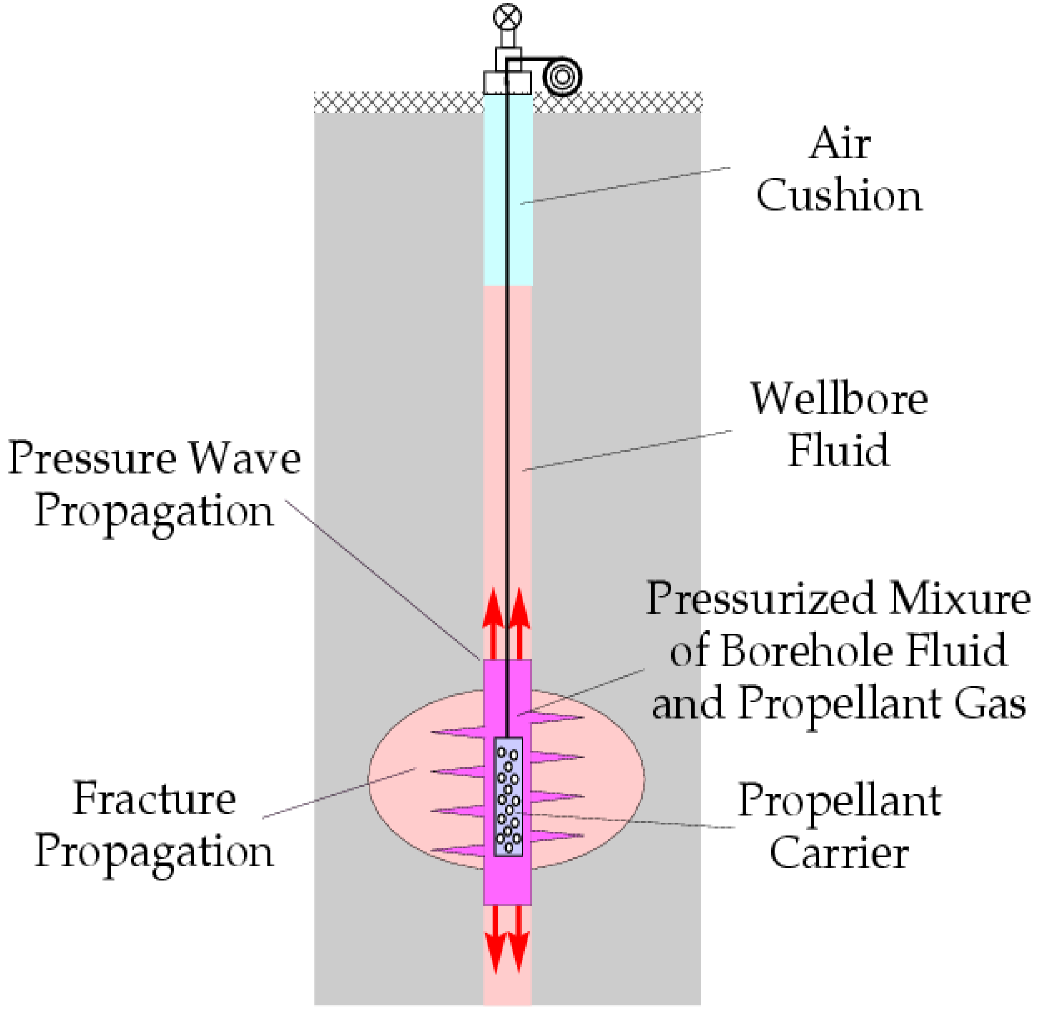


How Much Static Underbalance is Required?

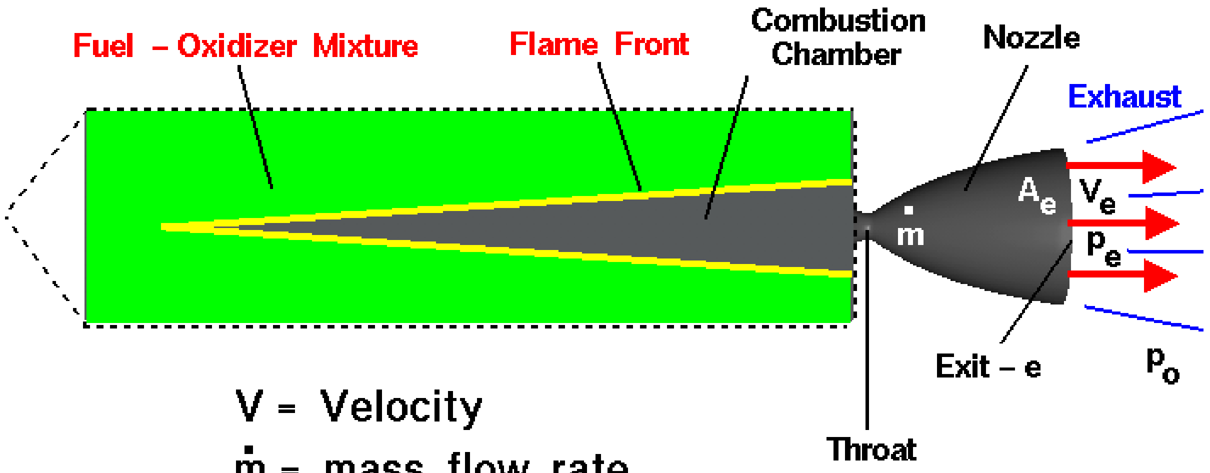


Propellant Fracturing Physics

- Propellant burning
- Borehole pressurization
- Bubble expansion upward and downward
- Borehole/perforation breakdown
- Fracture initiation and propagation



Propellant Surface Burn



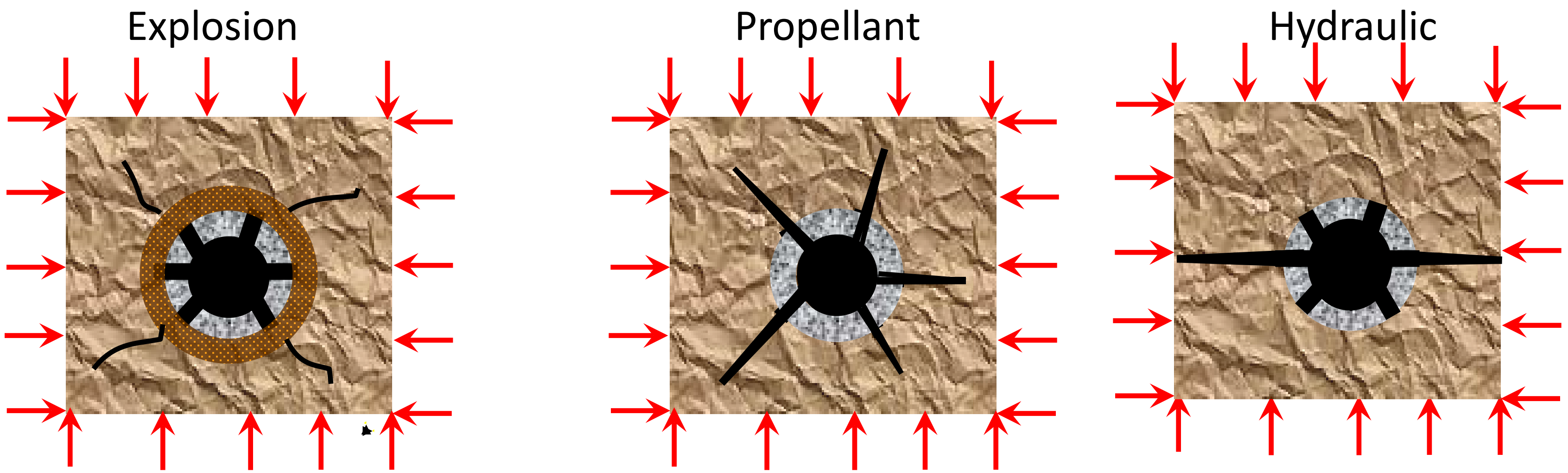
V = Velocity

$\dot{m}$ = mass flow rate

p = pressure

Thrust = $F = \dot{m} V_e + (p_e - p_0) A_e$

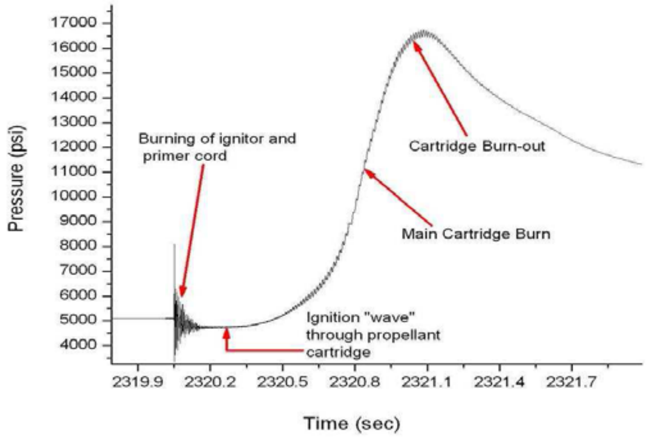
Comparison of three fracturing processes



	Explosion	Propellant gas	Hydraulic
Peak pressure (psi)	$10^6 – 10^7$	$10^3 - 10^4$	10^3
Pressure rise time (sec)	$10^{-7} - 10^{-5}$	$10^{-4} - 10^{-2}$	$10^1 - 10^2$
Pulse Duration (sec)	$10^{-6} - 10^{-5}$	$10^{-2} - 10^{-0}$	$10^3 - 10^4$
Number of fractures	Various	3-10	1
Fracture length (ft)	< 3	< 10	$10^1 - 10^2$
Fracture pattern	Tiny damaged zone	Multiple radial	Single by-wing
comments	Wellbore damage & crush zone		Direction dominated by in-situ stresses

Propellant Performed Past Research

Propellant Lab Stimulation
(90 Phased Perforated Core)



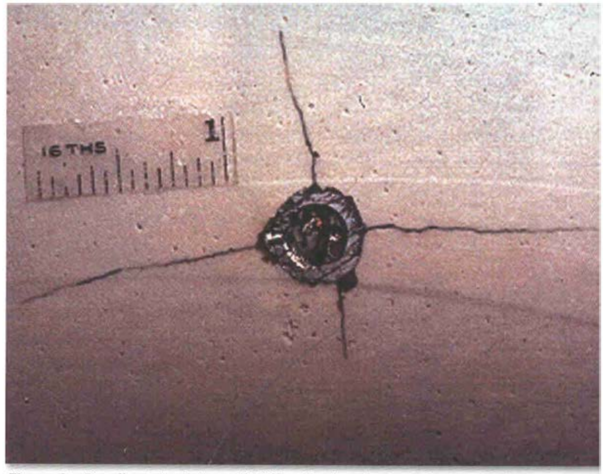
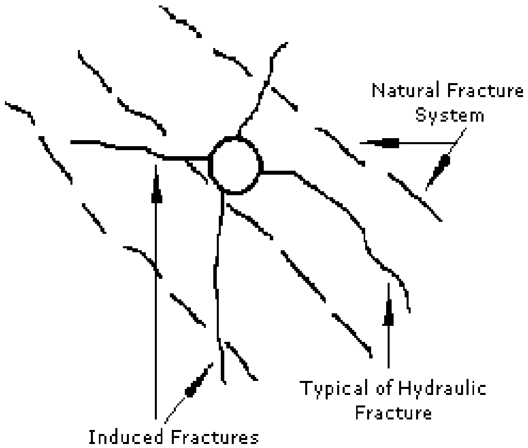
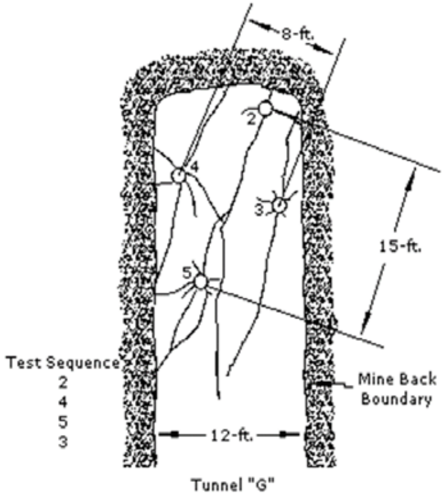


Figure 3 – *Propellant stimulation with 90° perforation phasing (Laboratory Scale).*

Mineback
(Sandia Lab)

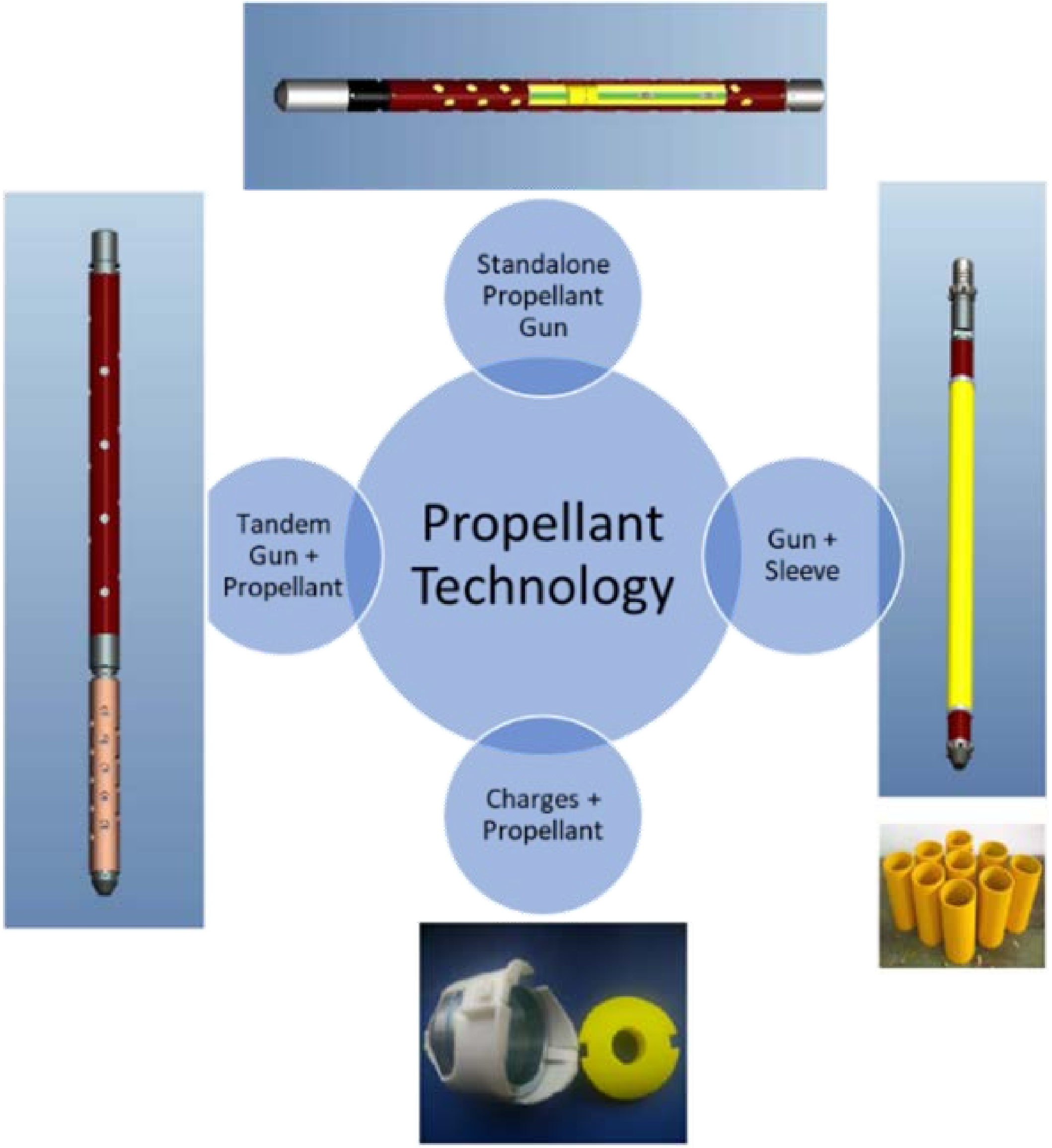


Typical fracture pattern from cased hole with 90° phasing in a fractured reservoir



Sandia mine back

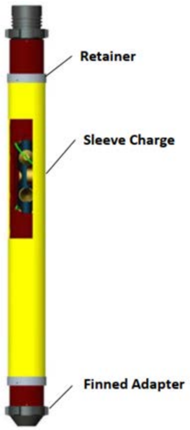
Propellant Technology

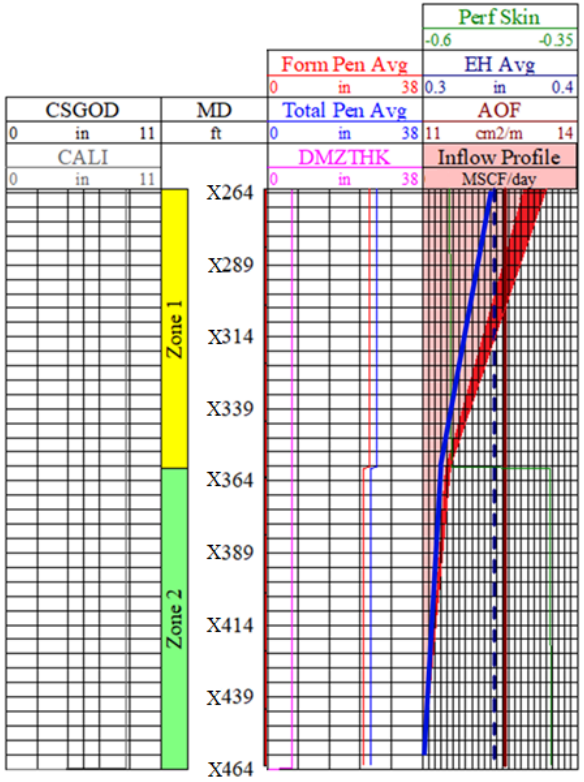


Propellant Perforation Enhancement at Well BRGA-3 in Malaysia

Well-B 77 degree deviated well 2 7/8 in HSD Coiled Tubing Conveyed Perforation

- Low Perm B Sand 201 ft PJN2906 & PJO2906 at 6 spf with 118 ft (102.6 kg) MPSleeve 73 Propellant
- Lower B Formation X463-X360 ftmd
- Upper B Formation X360-X464 ftmd
- Perforation Gun + Propellant Sleeve Well-B - Well Test Compared to Cased Perforated Completion SPAN Model indicate Infinite Conductivity Fractures created





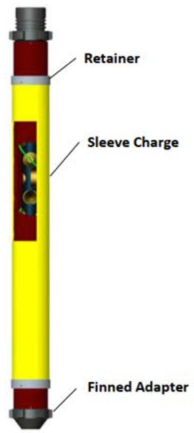
Production profile for tested flowrate – high perf skin (blue line)
Substantial red shading (right most track) of sleeve propellant above clean perf
<u>Infinite conductivity higher rate than a low skin perforation skin (red line)</u>

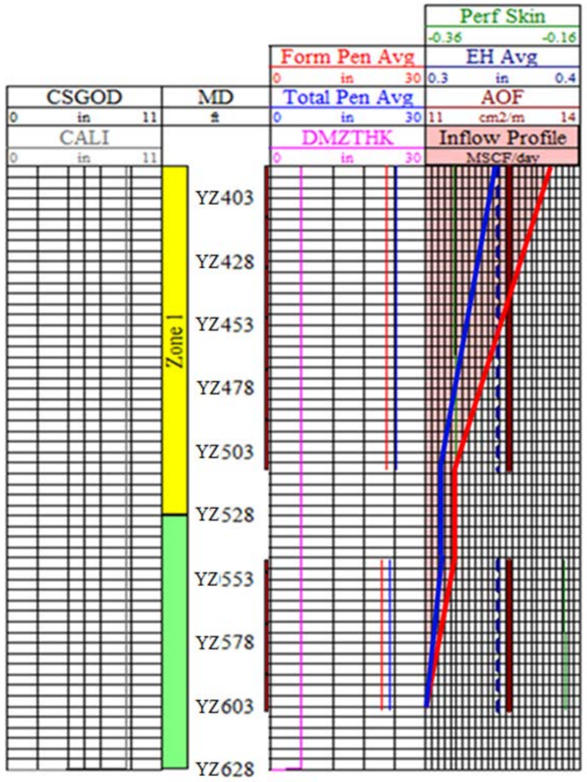
SPE 219646 • The First Coiled-Tubing-Conveyed Long Propellant Sleeved Perforation Gun in Highly Deviated Wells – Well Performance • C K Khong

Propellant Perforation Enhancement at Well BRGA-2 in Malaysia

80 degree deviated well 2 7/8 in HSD Coiled Tubing Conveyed Perforation

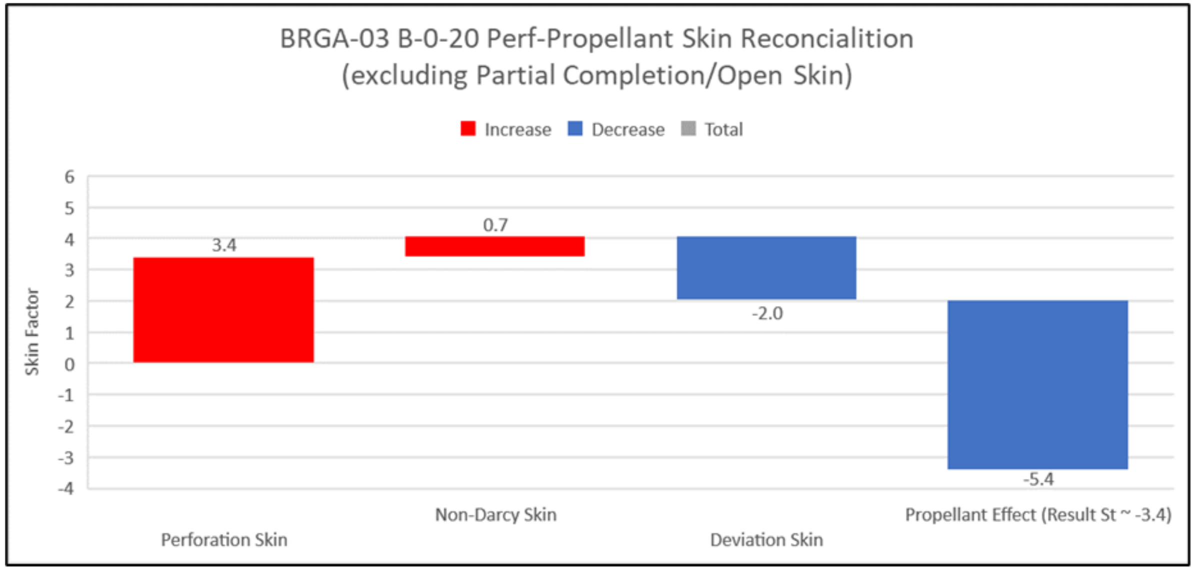
- Low Perm AL Zone 60 ft PJN2906 & PJO2906 at 6 spf with 13 ft (11.4 kg) MPSleeve 73 Propellant
- Low Perm AU Zone 120 ft PJN2906 & PJO2906 at 6 spf with 31 ft (27 kg) MPSleeve 73 Propellant
- Perforation Gun + Propellant Sleeve Well-A - Well Test Compared to Cased Perforated Completion SPAN Model indicate enhancement by Finite Conductivity Fractures created

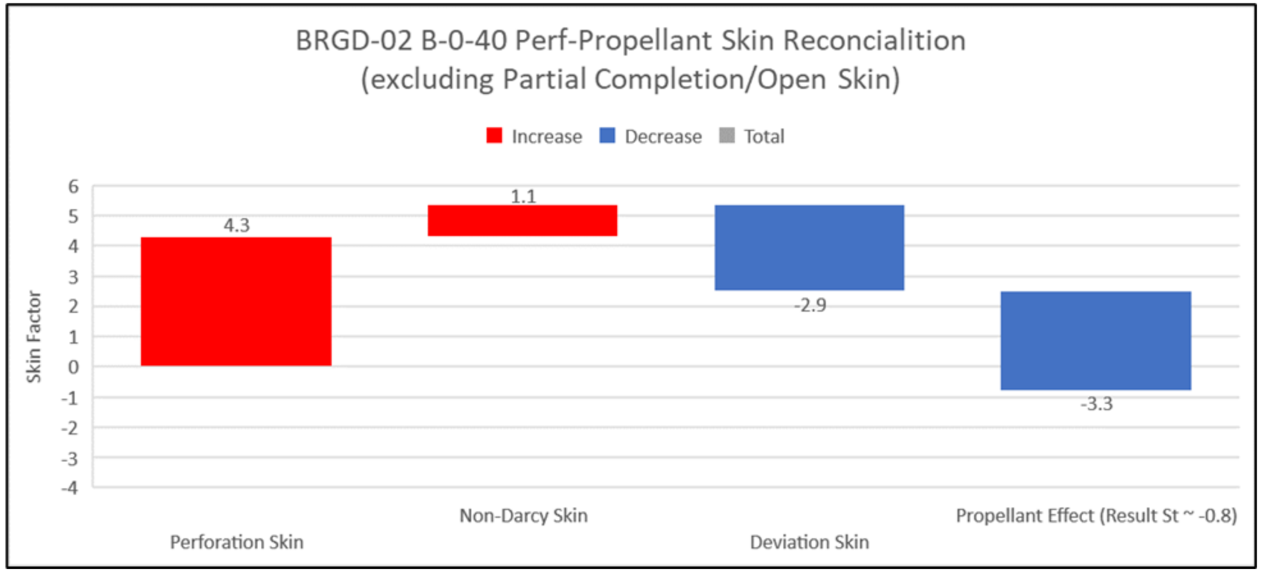




Production profile for tested flowrate – high perf skin (blue line)
Minor red shading (right most track) of sleeve propellant above clean perf
Finite conductivity similar rate to low skin perforation skin (red line)

Skin Reconciliation to evaluate various skin effects





Fracture Half Length by Propellant
Evaluation based on Measured Production Test Rate

Well Name	Reservoir	Average Measured Test Rate (MMscfd)	Karakas & Tariq Modeled Rate (MMscfd)	Productivity Ratio From Equation 1	Skin Propellant	Karakas & Tariq Perf Skin from Table 5
BRGA-3	0_20	4.0	1.685	2.37	-5.23	3.53
BRGD-2	0_40	1.2	0.715	1.68	-3.16	3.61

$$Stotal = Spropellant + Sperf + Sdev + Snondarcy$$

$$Stotal = -\ln\left(\frac{Rwa}{Rw}\right)$$

$$Fracture\ half - length = Rwa = Rw * e^{(-1*Stotal)}$$

*Rw=4.25 in

Well Name	Reservoir	Skin Propellant from Table 6	Karakas & Tariq Perf Skin from Table 5	Karakas & Tariq Deviation Skin	Karakas & Tariq Non-Darcy Skin	Skin Total	Approx Fracture Half-Length (ft)
BRGA-3	0_20	-5.23	3.53	-2.0	0.7	-3.00	7.1
BRGD-2	0_40	-3.16	3.61	-2.9	1.1	-1.35	1.4

Acknowledgements / Thank You / Questions