



Argentine Petroleum Section



INTEGRATED HYDRAULIC FRACTURING DESIGN for HORIZONTAL WELLS in UNCONVENTIONAL RESERVOIRS

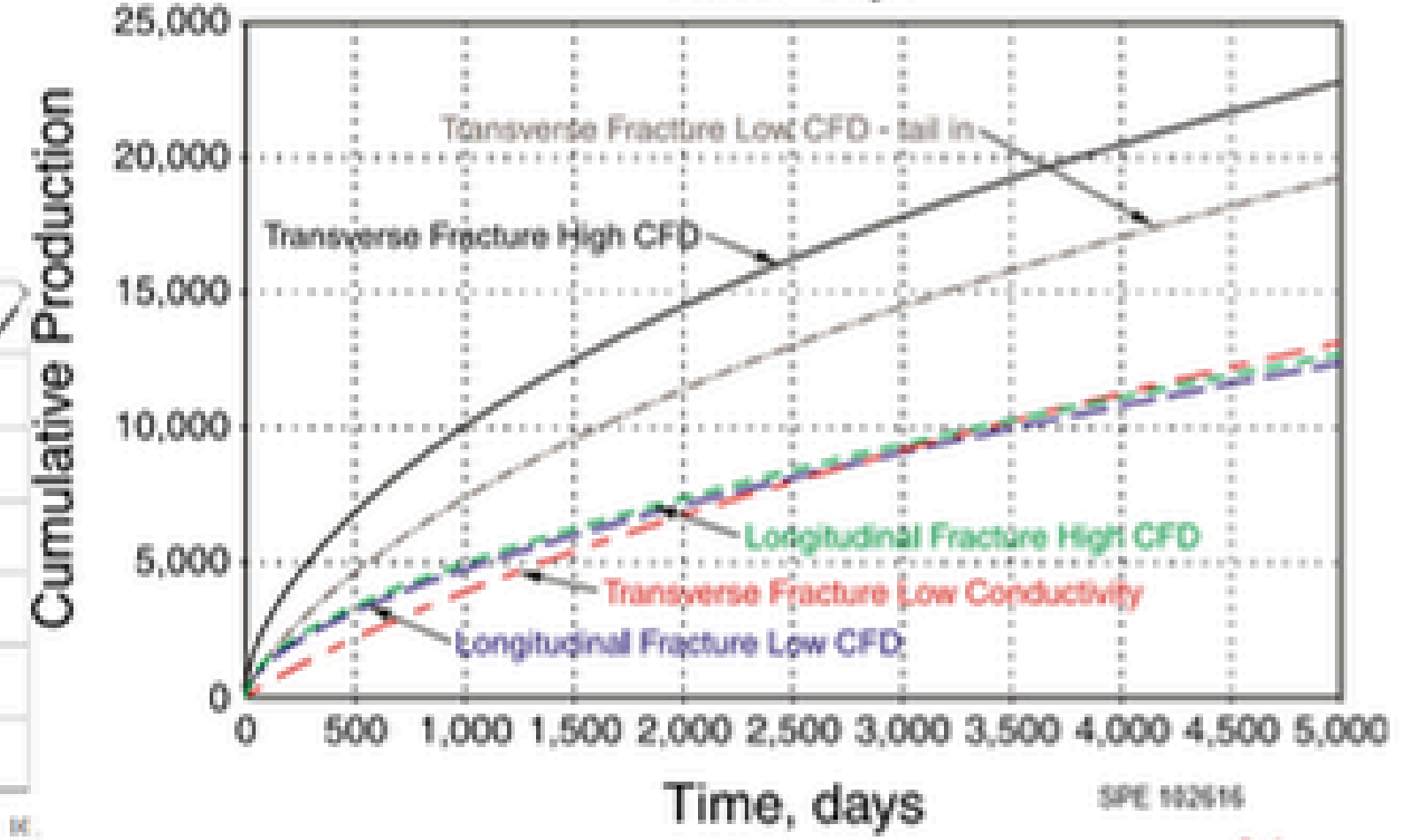
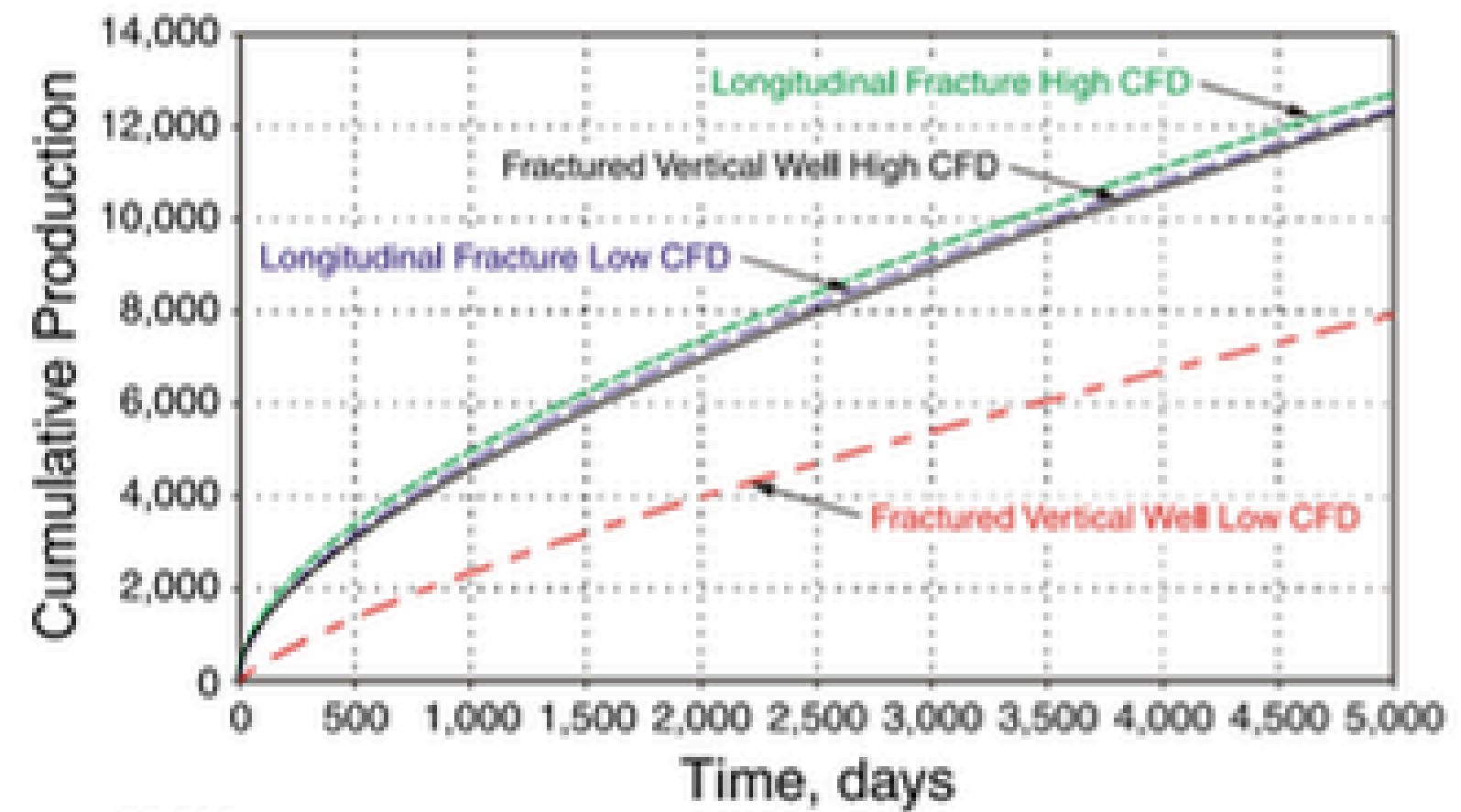
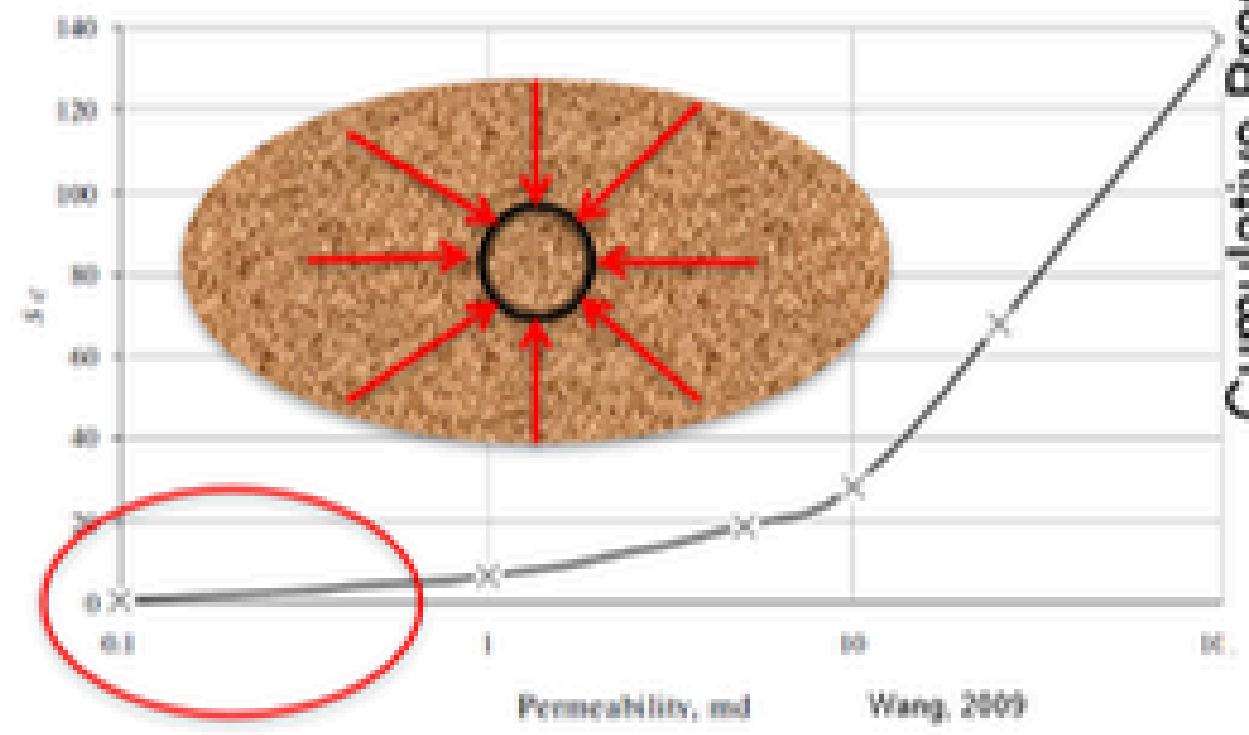
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Multi-fractured Horizontal Wells – Subsurface Advantages

- Based on Reservoir Engineering analysis, multi-fractured horizontal wells provide the highest productivity index
 - No other combination is better
 - Large number of fracs provides higher IPs but incremental production decreases with the number of stages
 - Reservoir deliverability after fracture vs economic trade-off
- Transverse hydraulic fractures are only attractive at low permeability
 - Below ~0.5 mD, it is the best option. Choke flow is negligible
- Multi-fractured horizontal wells with transverse hydraulic fractures are the best answer for UR unless other exceptional reservoir characteristics dictates the opposite

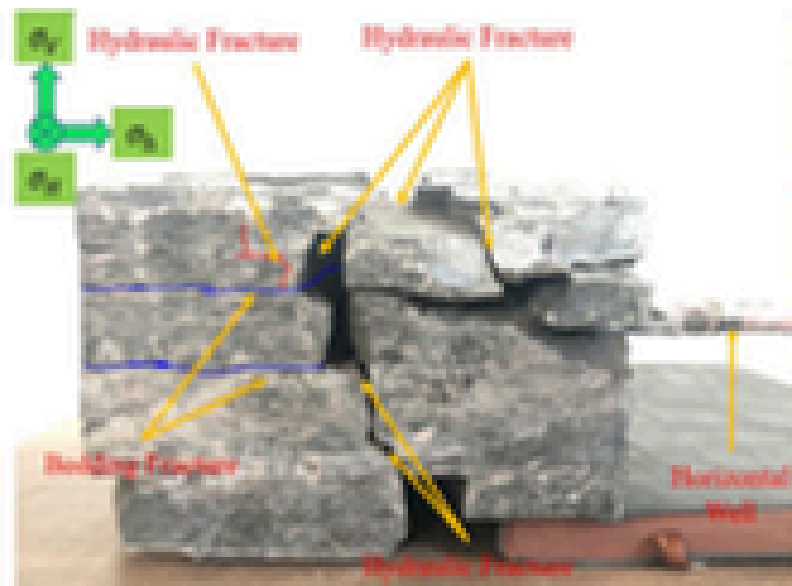
$$s_c = \frac{kh}{k_{fw}} \left(\ln \left(\frac{h}{2r_w} \right) - \frac{\pi}{2} \right)$$

$$J_{DTH} = \frac{1}{(1/J_{DV}) + s_c}$$

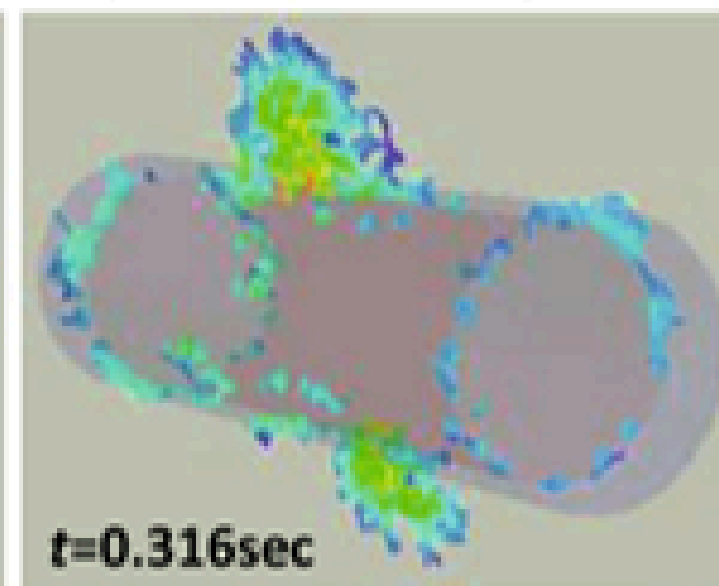
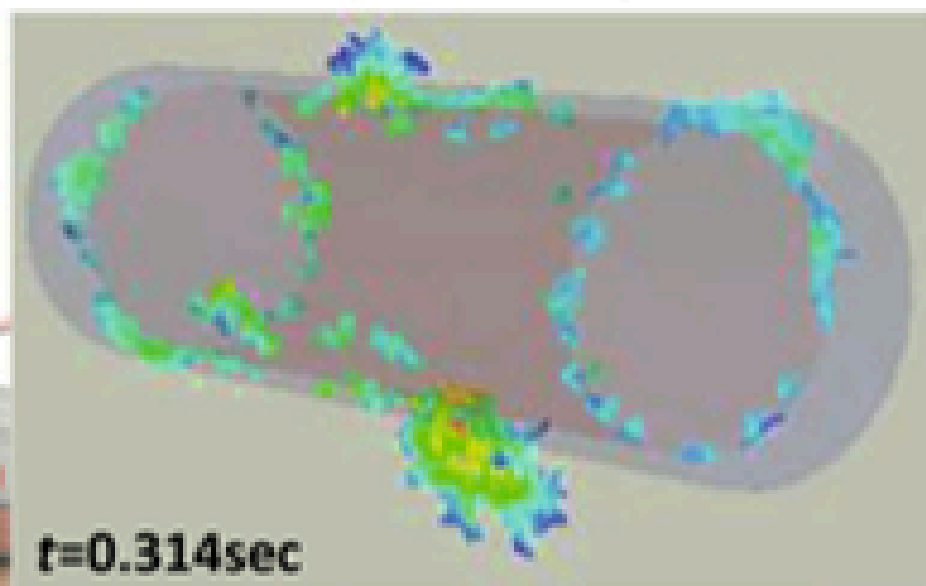


Hydraulic Fracture Initiation – Some Thoughts over the Years

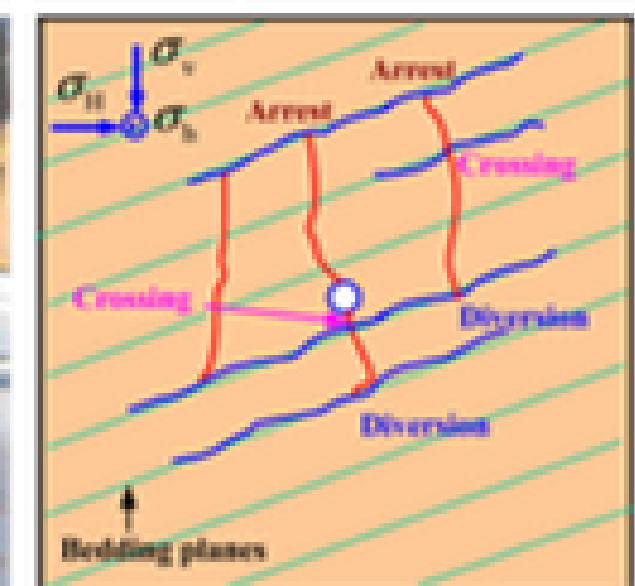
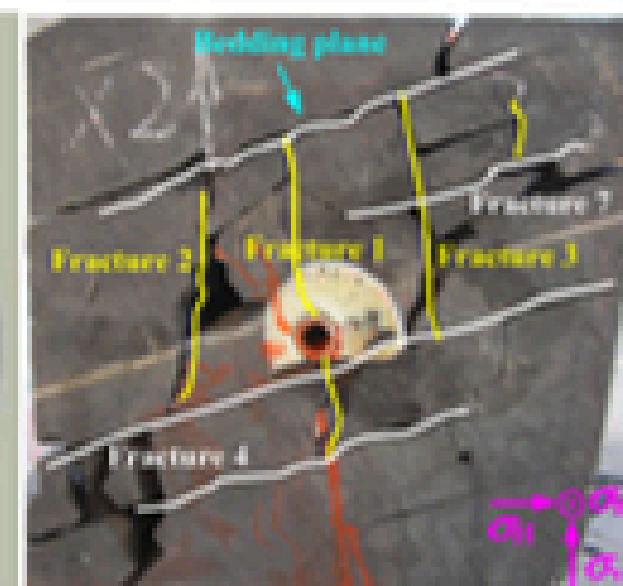
- “Perforation penetration beyond 4 to 6 inches (10 to 15 cm) into the formation is not required for fracturing because fracture initiation from a perforation generally begins near the sand-face and propagates towards the preferred fracture plane”, *Behrmann & Elbel (1991), reiterated in Behrmann & Nolte “Perforating Requirements for Fracture Stimulations”, 1998*
- “Introducing a wellbore into a formation alters the in-situ state of stress and creates a new stress field near the wellbore. Because of the near-wellbore stress field, a fracture has the tendency to initiate along the wellbore” – *Abass et al “Non-planar Fracture Propagation from a Horizontal Wellbore: Experimental Study”, 1996*
- “It is easier to create an axial fracture than a transverse fracture” – *Soliman & Boonen, “Review of Fractured Wells Technology”, 1997*
- “The relative magnitude of the breakdown pressure clearly indicates that ... it is easier to create an axial fracture than a transverse fracture. This will explain the sometimes-complex path that arises while fracturing a horizontal well” – *Soliman et al, “Geomechanics Aspects of Multiple Fracturing of Horizontal and Vertical Wells”, 2008*



Zhai, et al.



Benouadah, et al.



Hong, et al.

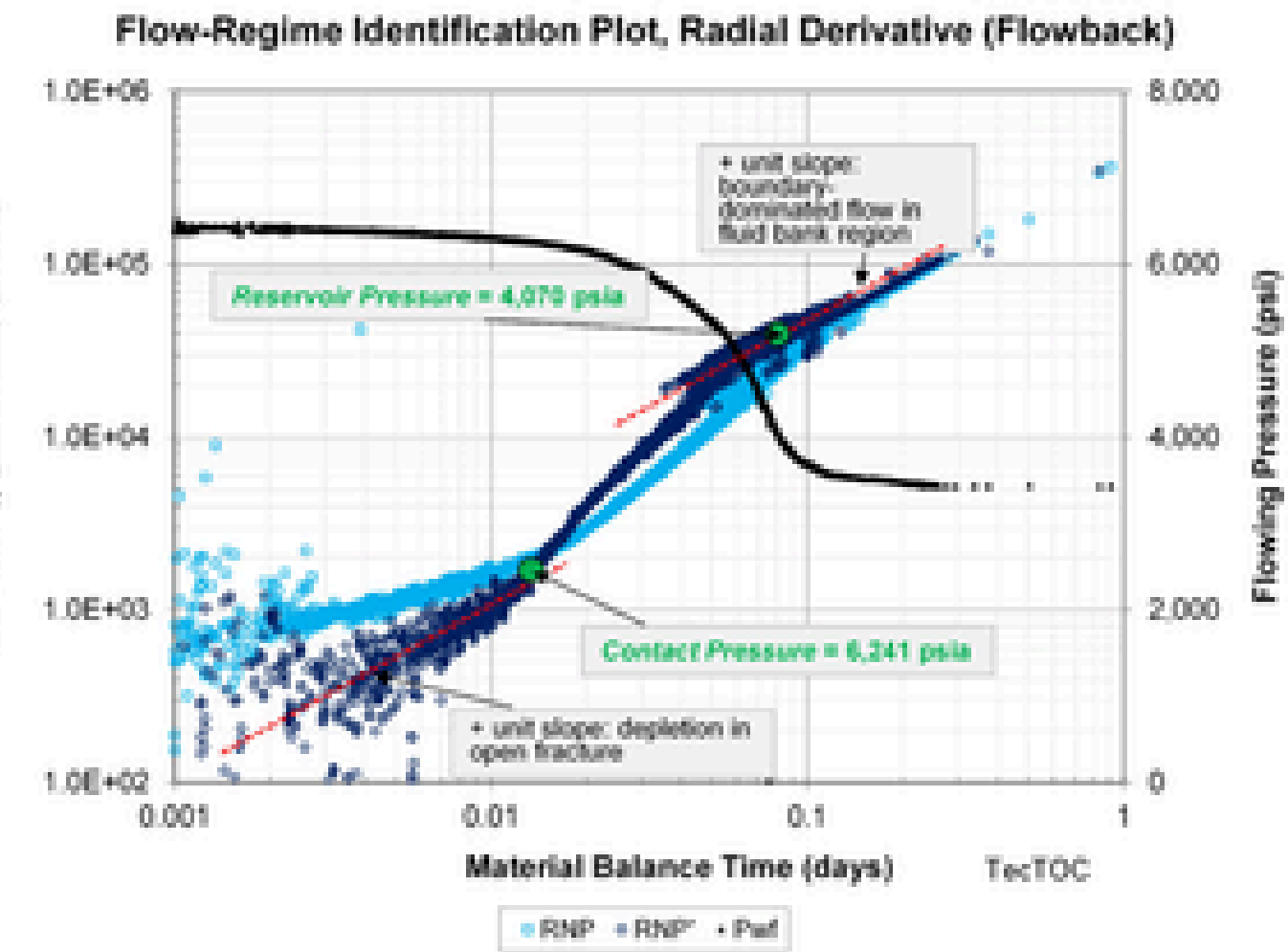
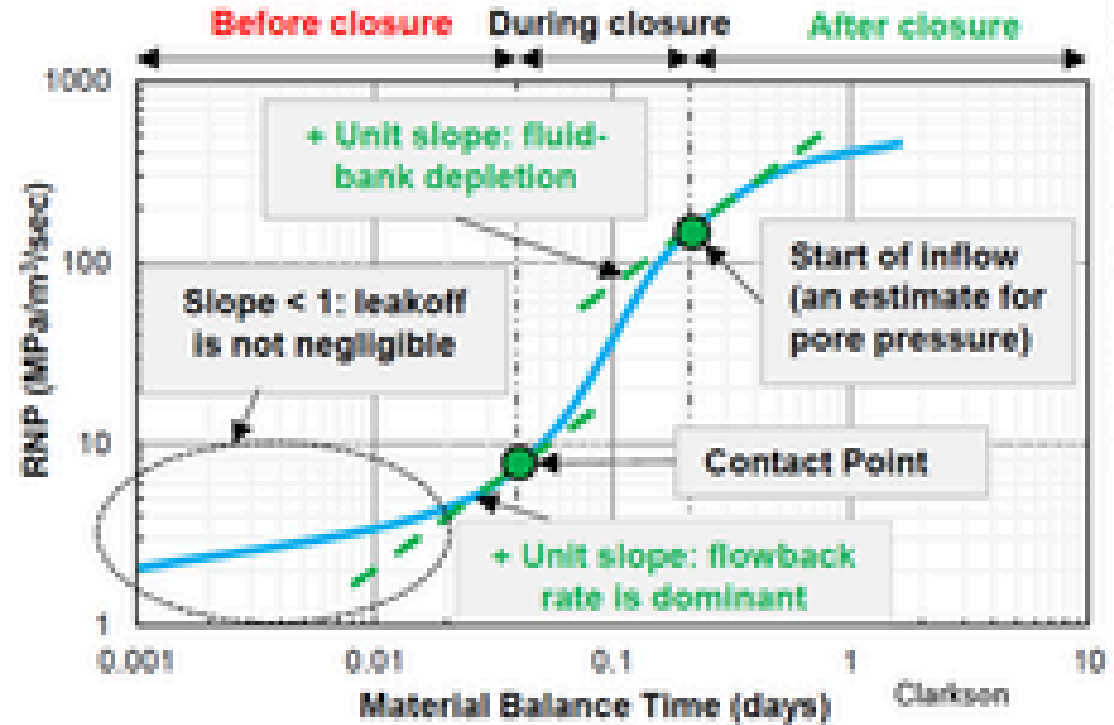
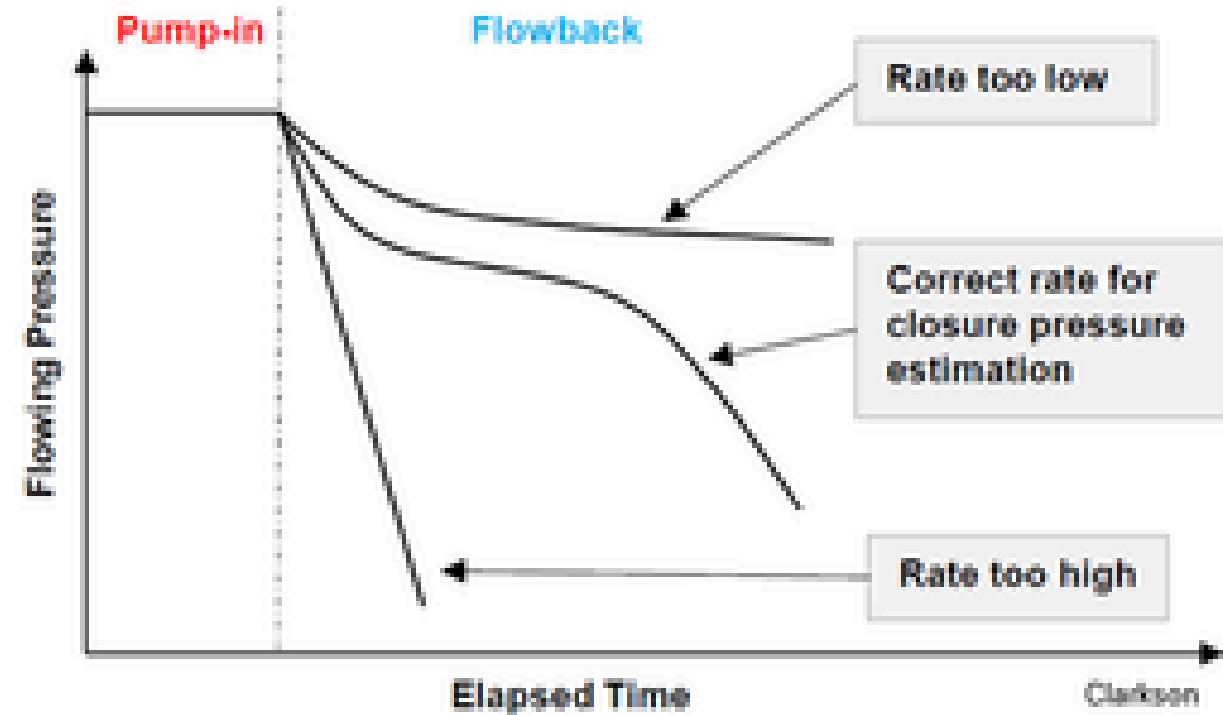
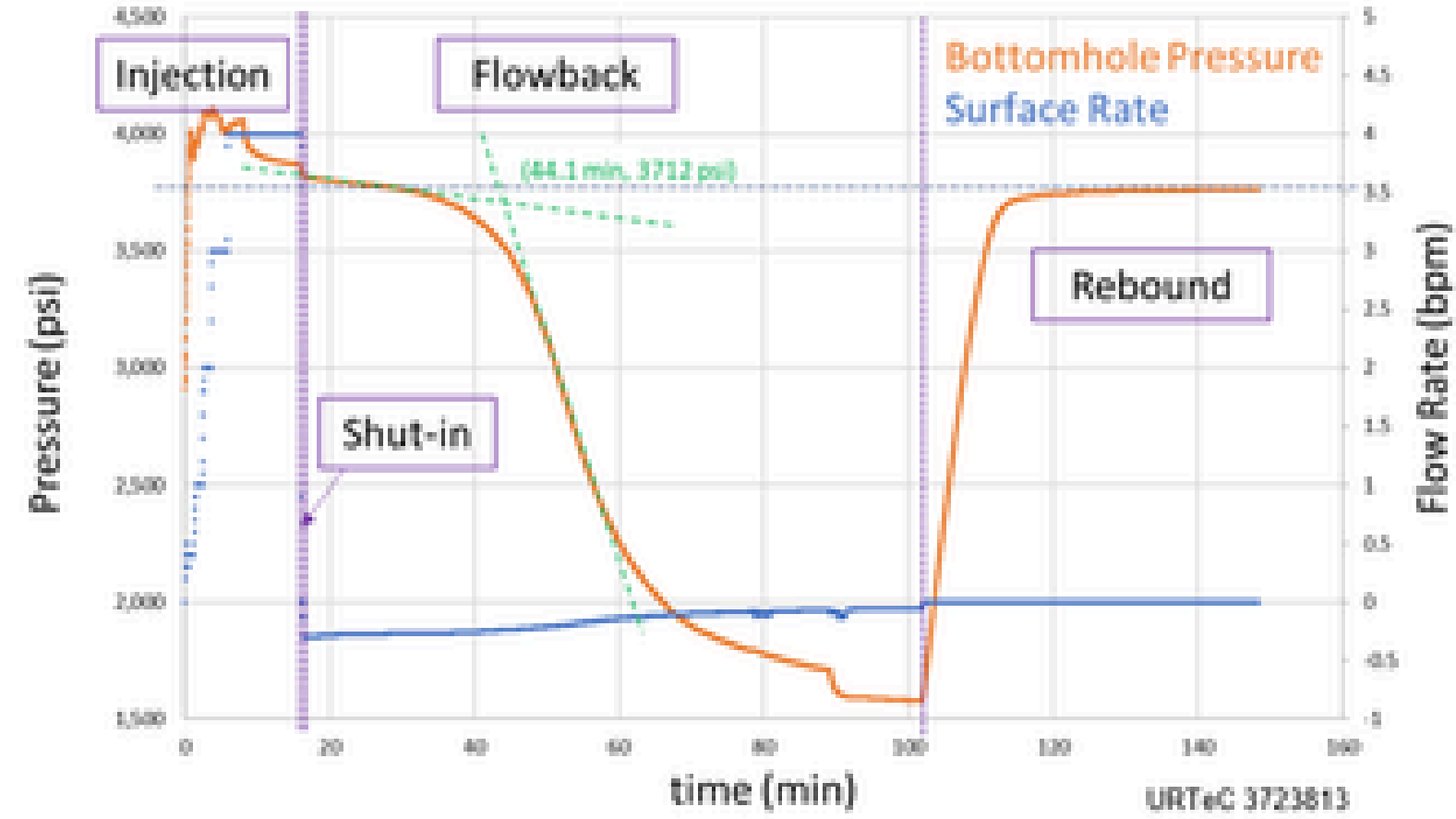
Pre-Frac Tests - FBRT

- Fundamentals

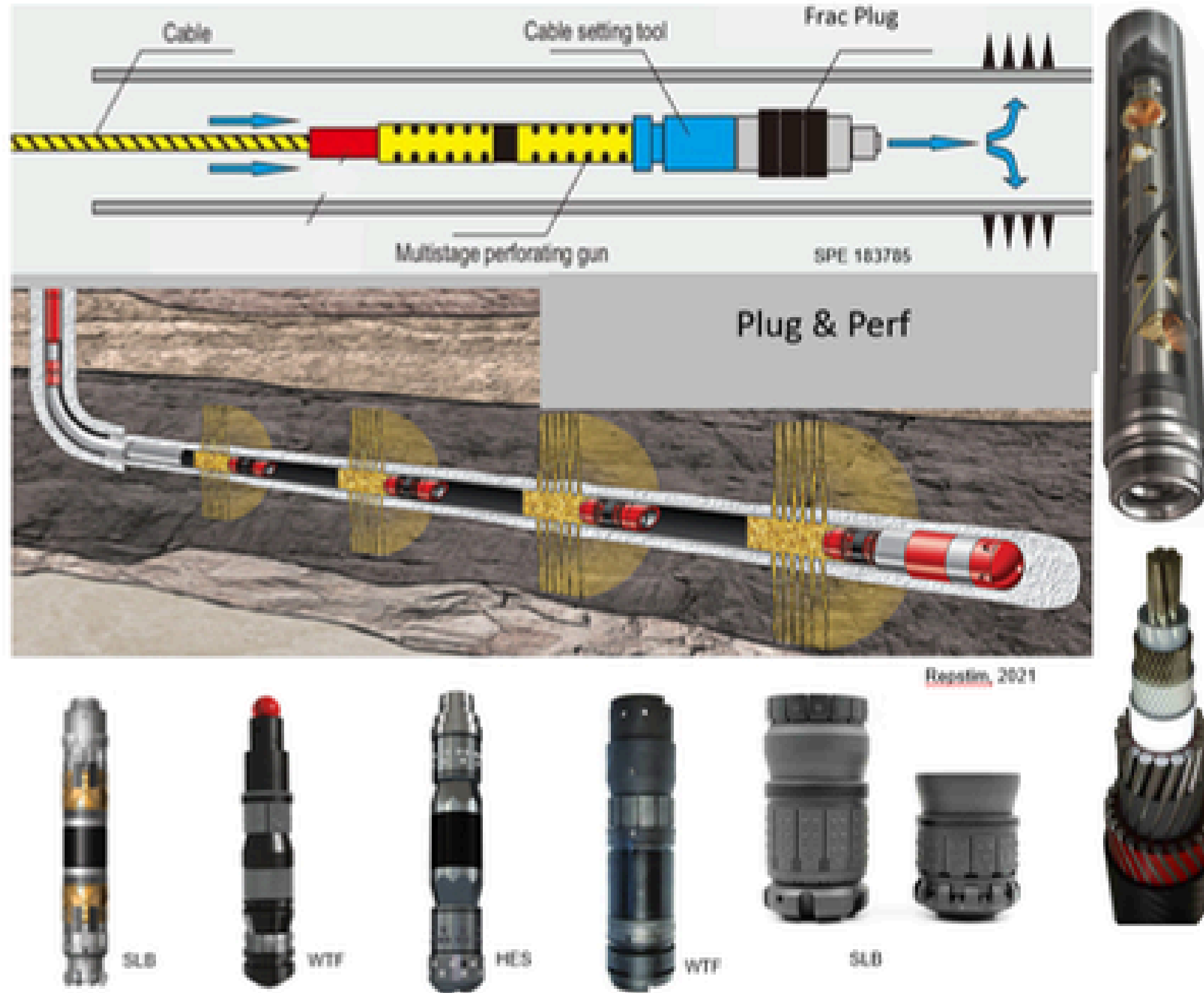
- Initially during pump period all is the same
- Main change is during fall-off period. Instead of pressure decline by diffusion, a controlled flowback is established leading to much shorter operational and closure time. It is also possible to estimate pore pressure if certain flow regimes are identified
- Flowback rate needs to be within certain range. Use a fixed choke
- If fracture is nearly static it is possible to apply PTA theory

- Main advantages

- Short time
- Relatively easier interpretations. Unambiguous results



Plug & Perf Methodology at a Glance



- **Fundamentals**

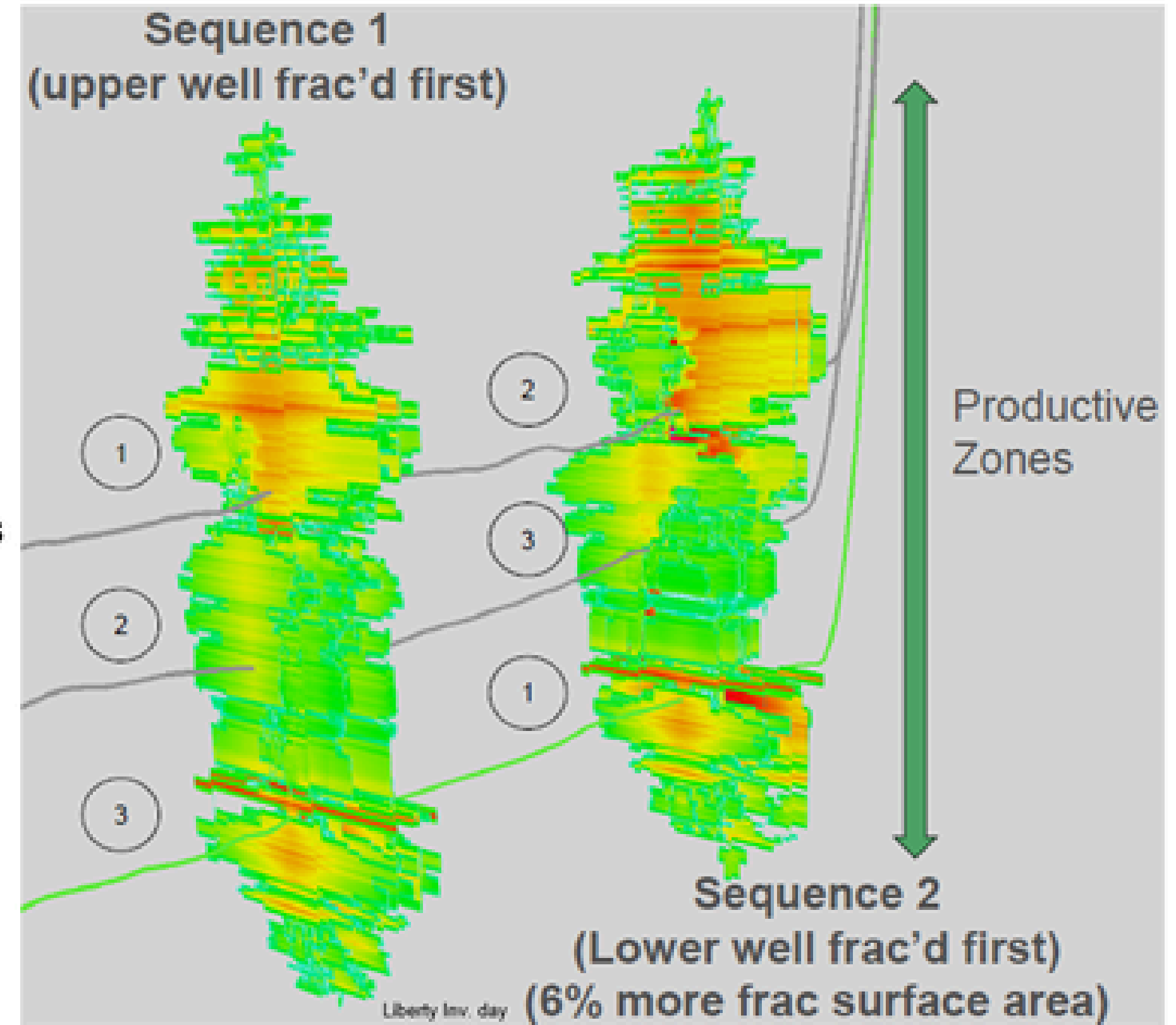
- The method allows for setting a mechanical fracture plug and perforating multiple zones called "clusters" in a single cable run while pumping in the horizontal section
 - Addressable switches to perforate +20 clusters
- The integrated technologies are derived from traditional plug setting and perforating techniques used in conventional wells. Everyone in the field knows them!
- It aims to create and propagate a fracture in each cluster

- **Technology Evolution**

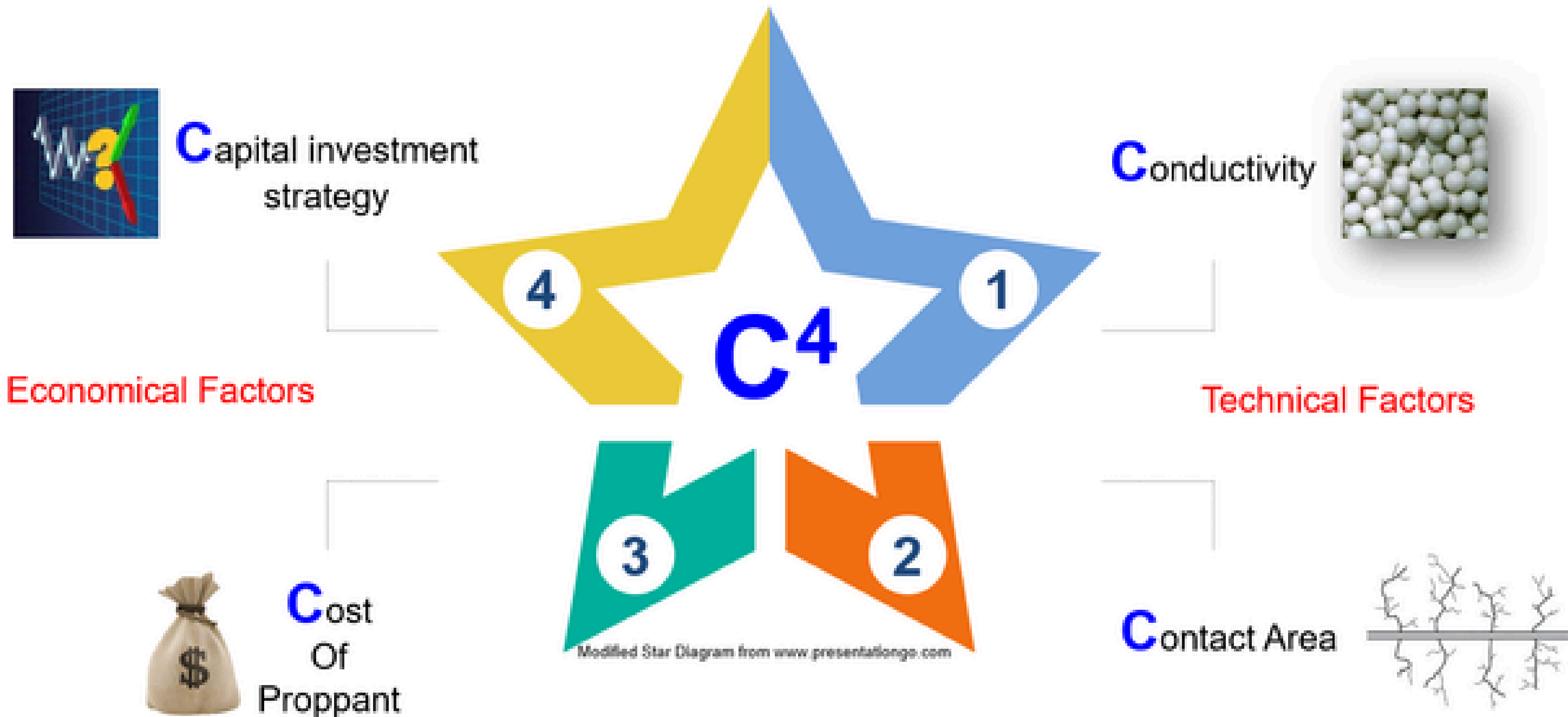
- Continuous improvements in plug designs have allowed for a reduction in material volumes by eliminating or reducing the need to rotate the plugs
- Perforating charges have evolved substantially
- Oriented perforating is the new north!

Frac Sequencing Optimization

- Tendency in the industry, driven by conventional developments, to develop one bench at a time
- Sequencing optimization must be done vertically and laterally simultaneously
 - Tank-style completions take advantage of this concept
- In unconventional reservoirs not always best landing zone is the lowest one so tackling development in the conventional way may pose a serious risk
 - Given the high density of wells required to drain reserves once a bench is drilled that rock volume is depleted and full of fractures. Drilling thru that zone might be highly complicated
- Stress shadowing occurs in all directions
 - Good understanding of stress field allows defining best fracturing sequence that provides larger contact area. In general, is bottom-up but do your homework in your area!
 - When multiple stacked wells are fractured evaluate the best sequence that might include jumping from one well to another located at different landing points



Main Drivers on Proppant Selection – C⁴ Concept



Optimum = Trade-off of Technical factors driven by Economical factors

Monitoring – After Fracturing – Downhole Camera & Caliper

- Key characteristics
 - Both technologies aim to visualize and/or measure perforation entry holes to provide direct evidence of hydraulic fracture initiation and propagation, casing deformations, parted casings, slipped frac plugs, etc. Goal is to optimize the completion design and to help fixing integrity problems
- Downhole camera
 - It is a tool featuring high-resolution color digital cameras, built-in LED lighting and in some models 360-degree rotation capacity
 - It requires a clean wellbore
 - It can be conveyed with an acoustic caliper for validation
- Calipers
 - Acoustic
 - It uses ultrasonic transducers to map the shape and size of perforations at cluster level even in turbid or cloudy fluids
 - Not always there is perfect match between both tools
 - Multi-finger
 - Mechanically-based tool that has multiple fingers that deflect and measure variations in diameter
 - Mostly used to detect casing deformations

