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MUSCAT, OMAN

Novel Coiled Tubing Perforation Approach Avoids Overflushing in Multistage Hydraulic Fracturing Operations in a Horizontal Well

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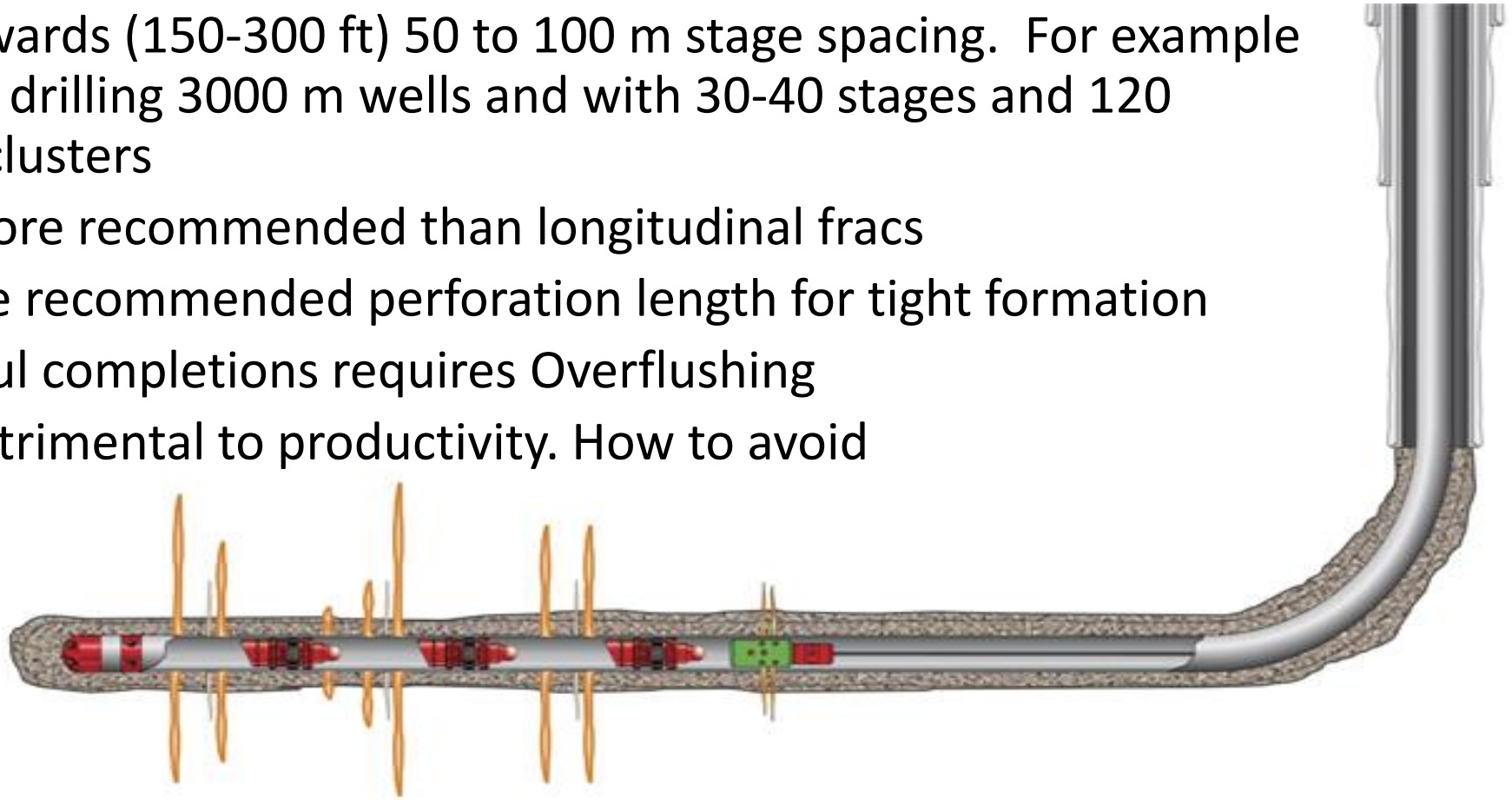
Horizontal Wells Challenges in Tight Formation

- Understand the subsurface variability. It takes dozens of wells to understand if a play has potential and what the sweet spots are.
- Understand the causes of subsurface variability via diagnostics
- Determine the big levers that are controlling production
  1. Horizontal Well Length
  2. Type of Hydraulic Fractures (longitudinal or Transverse)
  3. Number of fractures
  4. Effective fracture height and length
  5. Well Spacing
- May need between 3 and 10 wells with good controls
- All frac models simulate frac geometry but:
  1. Can not provide realistic frac geometry
  2. Have problems with production estimation

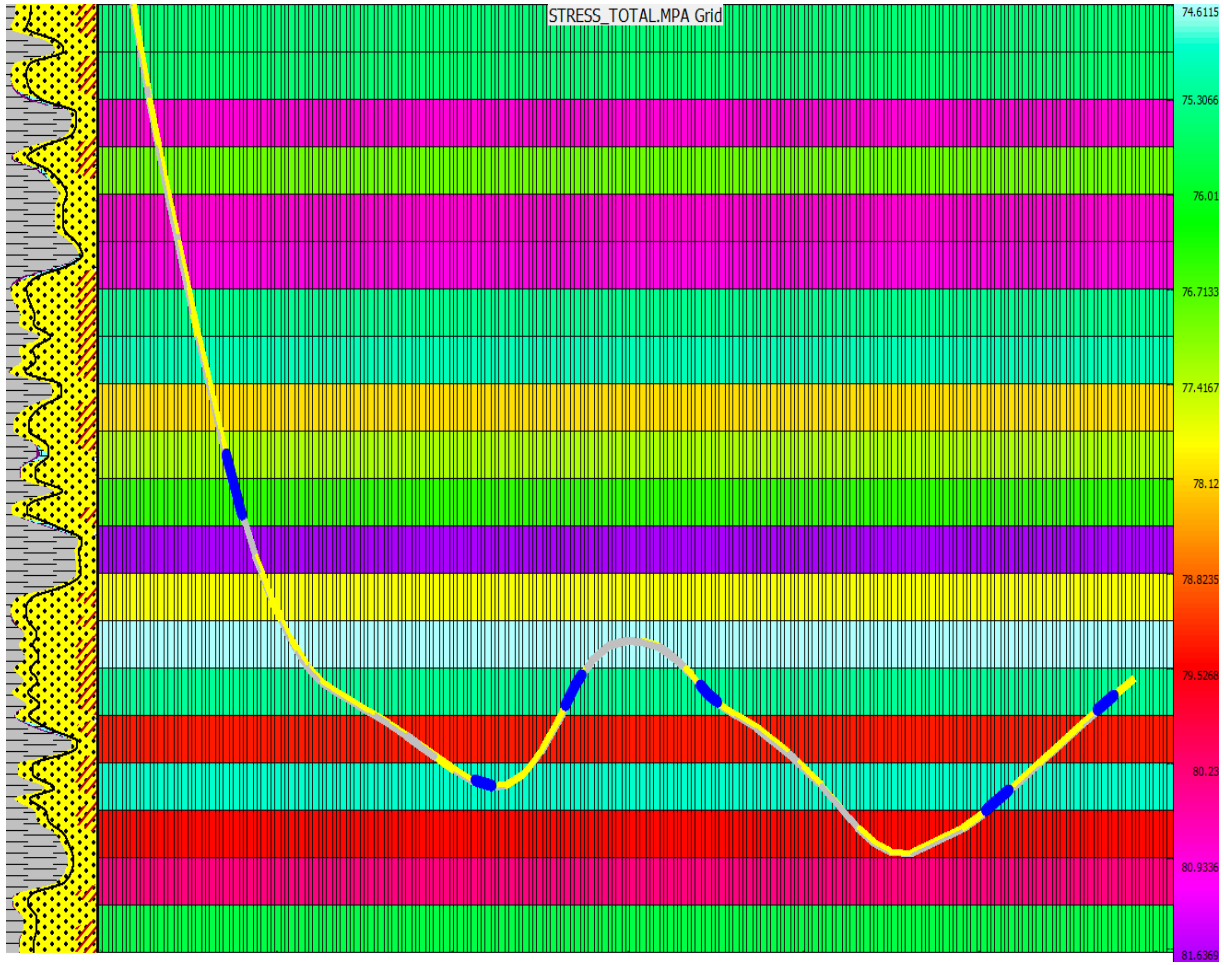
Horizontal well Industry Trends in Tight Formation

- The trend is towards longer wells and shorter stage spacing.
- Industry is trending towards (150-300 ft) 50 to 100 m stage spacing. For example in the Bakken, they are drilling 3000 m wells and with 30-40 stages and 120 individual perforation clusters
- Transverse Fracs are more recommended than longitudinal fracs
- 4 time the well ID is the recommended perforation length for tight formation
- Time efficient successful completions requires Overflushing
- Overflushing can be detrimental to productivity. How to avoid

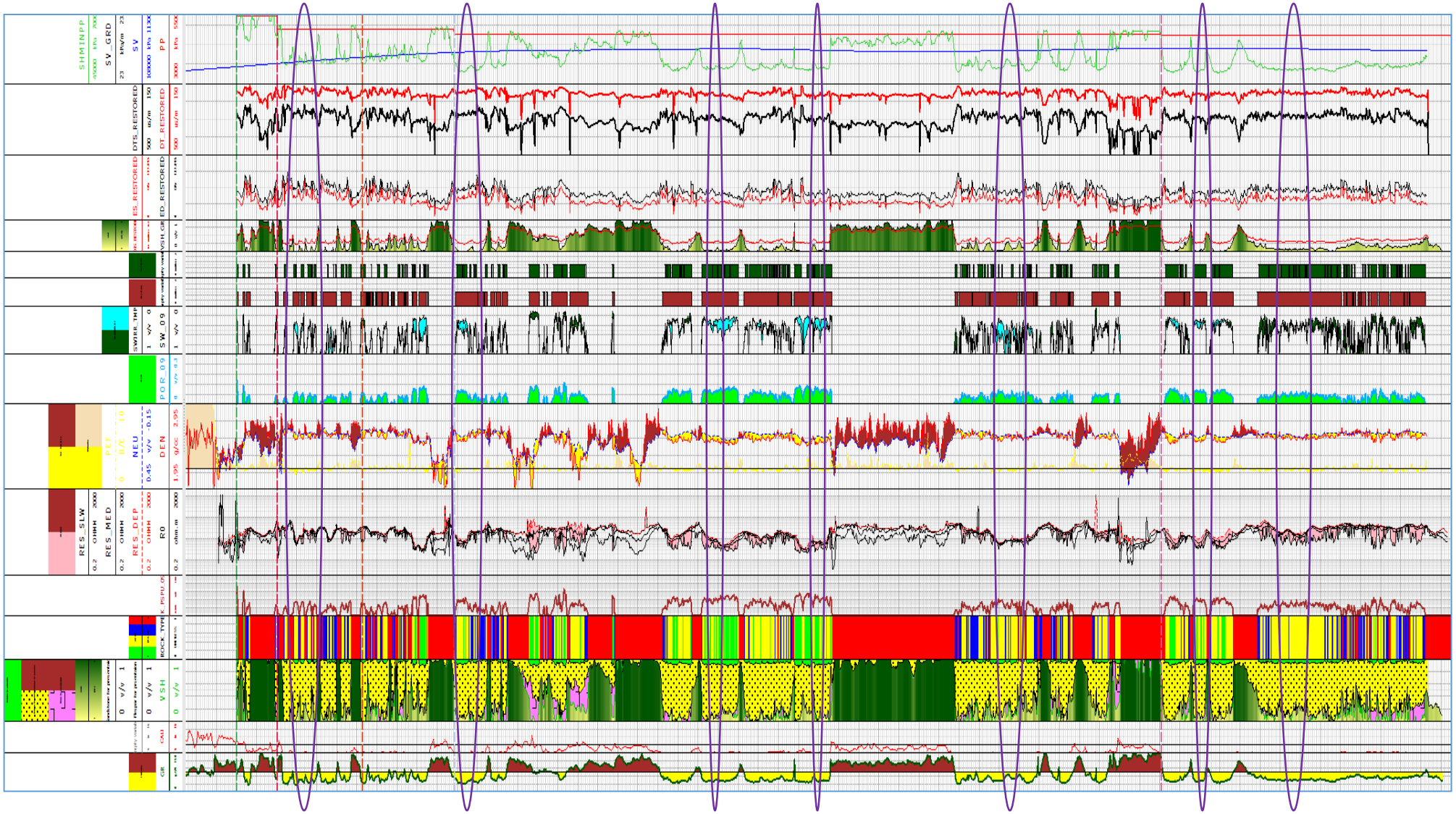


Oman Horizontal Well Case Study

- Deep sandstone, gas well at 200-400 Bar and 138 degC.
- 4.5” monobore with multiple-stages cross-linked gel fracturing.
- Heterogeneous formation and multiple 0.9m guns per stage, shooting on same spot require accurate realtime correlation.

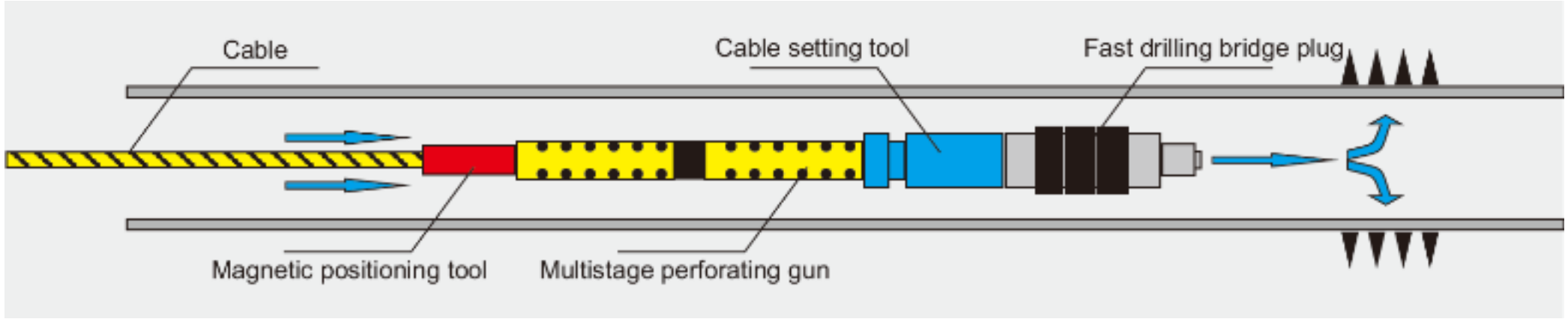


Heterogeneous Formation



Conveyance Option-1: Pump-down

- Globally popular : Relatively cheaper and efficient.
- Requires overflush right after pumping main fracturing.
- Then, more fluid into fracture during pump-down operations.
- Real-time correlation.
- Multiple guns with addressable-switches



Conveyance Option-1: Pump-down

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- Multiple guns with addressable-switches

	Pump-down
Overflush required	Yes
Convey plug and multiple guns in tandem	Yes
Higher pumping rate that enables hole cleanout	n/a
Real time correlation for accurate positioning	Yes

Conveyance Option-2: Tractor

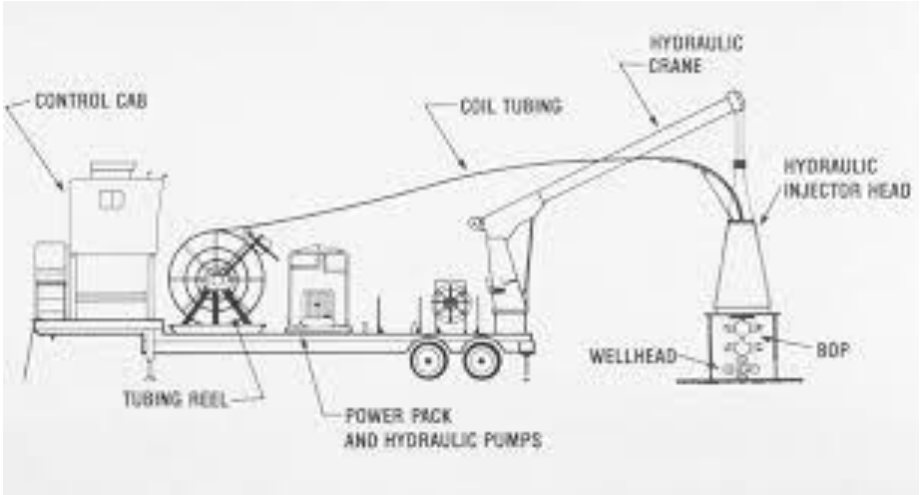
- Needs cleaner wellbore.
- Overflush and/or with CT cleanout
- Real-time correlation.
- Multiple guns with addressable-switches

	Pump-down	Tractor
Overflush required	Yes	Yes
Convey plug and multiple guns in tandem	Yes	Yes
Higher pumping rate that enables hole cleanout	n/a	n/a
Real time correlation for accurate positioning	Yes	Yes

Conveyance Option-3: Conventional Coiled Tubing

- More robust with some proppant leftover in wellbore. Greater pushing force and circulation while conveying guns
- CT at wellsite can perform hole cleanout trip.
- Poor depth accuracy. Additional run for correlation may also be needed.
- Limited number of guns per run.

	Pump-down	Tractor	Conventional CT
Overflush required	Yes	Yes	No
Convey plug and multiple guns in tandem	Yes	Yes	No
Higher pumping rate that enables hole cleanout	n/a	n/a	Yes
Real time correlation for accurate positioning	Yes	Yes	No



Conveyance Option-4: Coiled Tubing with Electric Wireline

- More robust with some proppant leftover in wellbore. Greater pushing force and limited circulation while conveying guns
- Real-time correlation.
- Multiple guns with addressable-switches
- Limited pumping rate and milling capability. Efficiency affected when swapping to conventional coil.

	Pump-down	Tractor	Conventional CT	CT with wireline
Overflush required	Yes	Yes	No	No
Convey plug and multiple guns in tandem	Yes	Yes	No	Yes
Higher pumping rate that enables hole cleanout	n/a	n/a	Yes	No
Real time correlation for accurate positioning	Yes	Yes	No	Yes

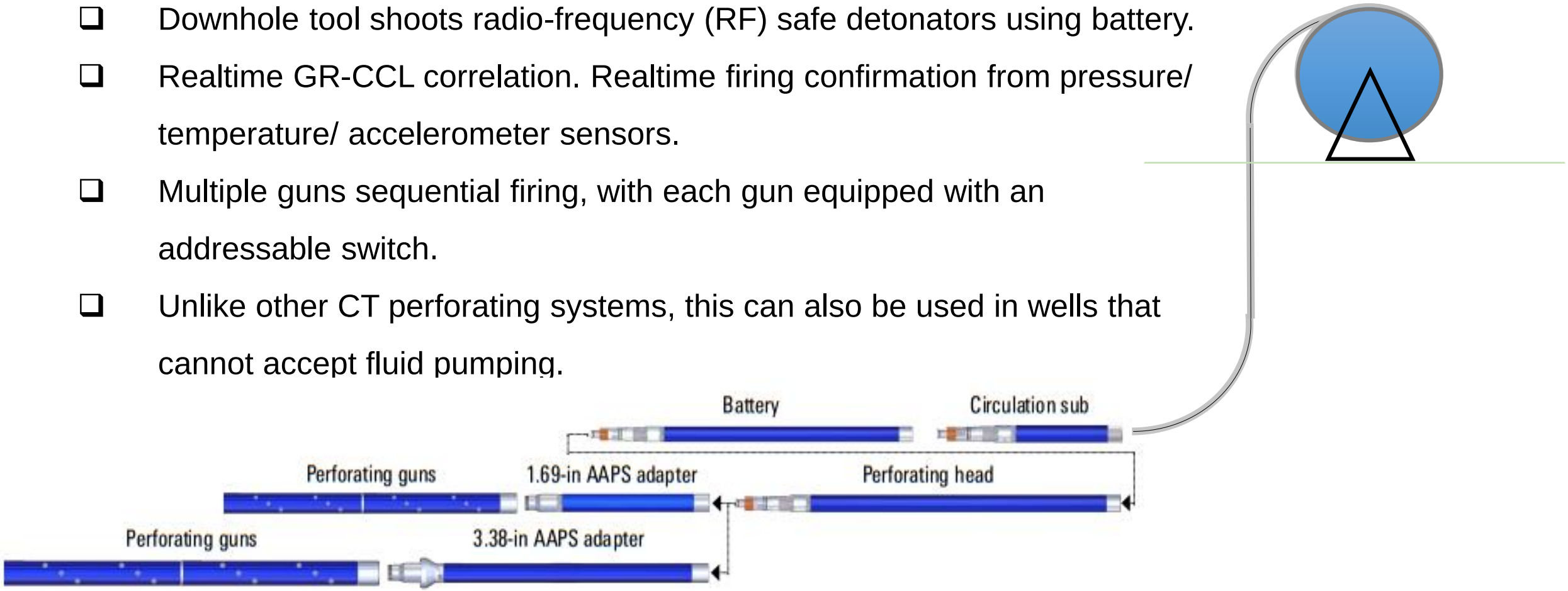
Fibre Optic Based Coiled Tubing Selective Perforating

- CT with fibre-optics
- Optic based selective firing head system
- Better pumping rate at 2 bbl/min and milling capability.
- Better efficiency and avoids overflushing

	Pump-down	Tractor	Conventional CT	CT with wireline	CT with fibre-optic and selective perforating
Overflush required	Yes	Yes	No	No	No
Convey plug and multiple guns in tandem	Yes	Yes	No	Yes	Yes
Higher pumping rate that enables hole cleanout	n/a	n/a	Yes	No	Yes
Real time correlation for accurate positioning	Yes	Yes	No	Yes	Yes

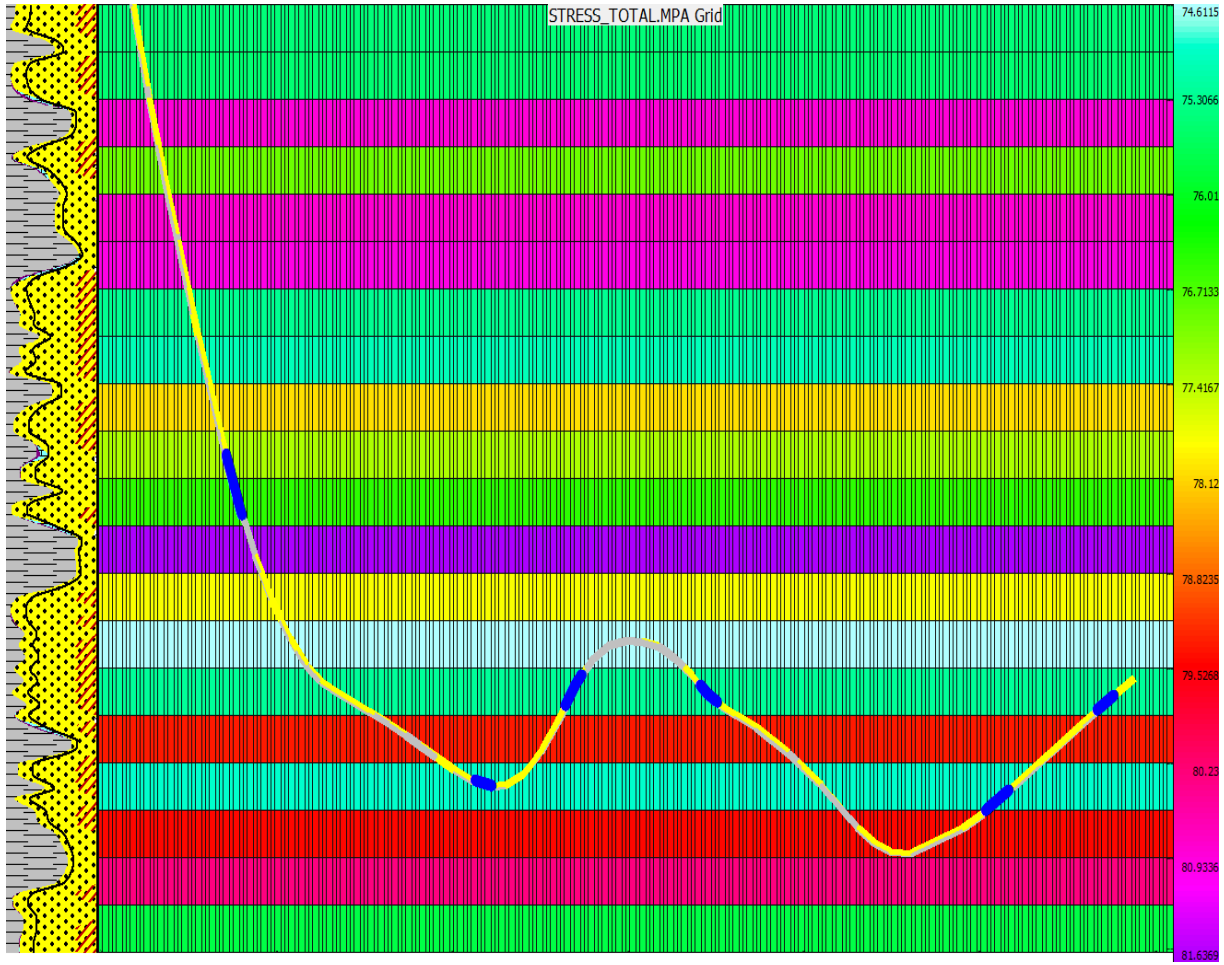
Optic Based Selective Perforating System

- Surface to downhole communication/ control using fibre optics
- Downhole tool shoots radio-frequency (RF) safe detonators using battery.
- Realtime GR-CCL correlation. Realtime firing confirmation from pressure/ temperature/ accelerometer sensors.
- Multiple guns sequential firing, with each gun equipped with an addressable switch.
- Unlike other CT perforating systems, this can also be used in wells that cannot accept fluid pumping.



Oman Horizontal Well Case Study

- Deep sandstone, gas well at 200-400 Bar and 138 degC.
- 4.5” monobore with multiple-stages cross-linked gel fracturing.
- Heterogenous formation and multiple 0.9m guns per stage, shooting on same spot require accurate realtime correlation.
- Fibre-optic based system selected to:
  - Avoid overflushing
  - Multiple guns accurate correlation
  - Efficient hole cleanout

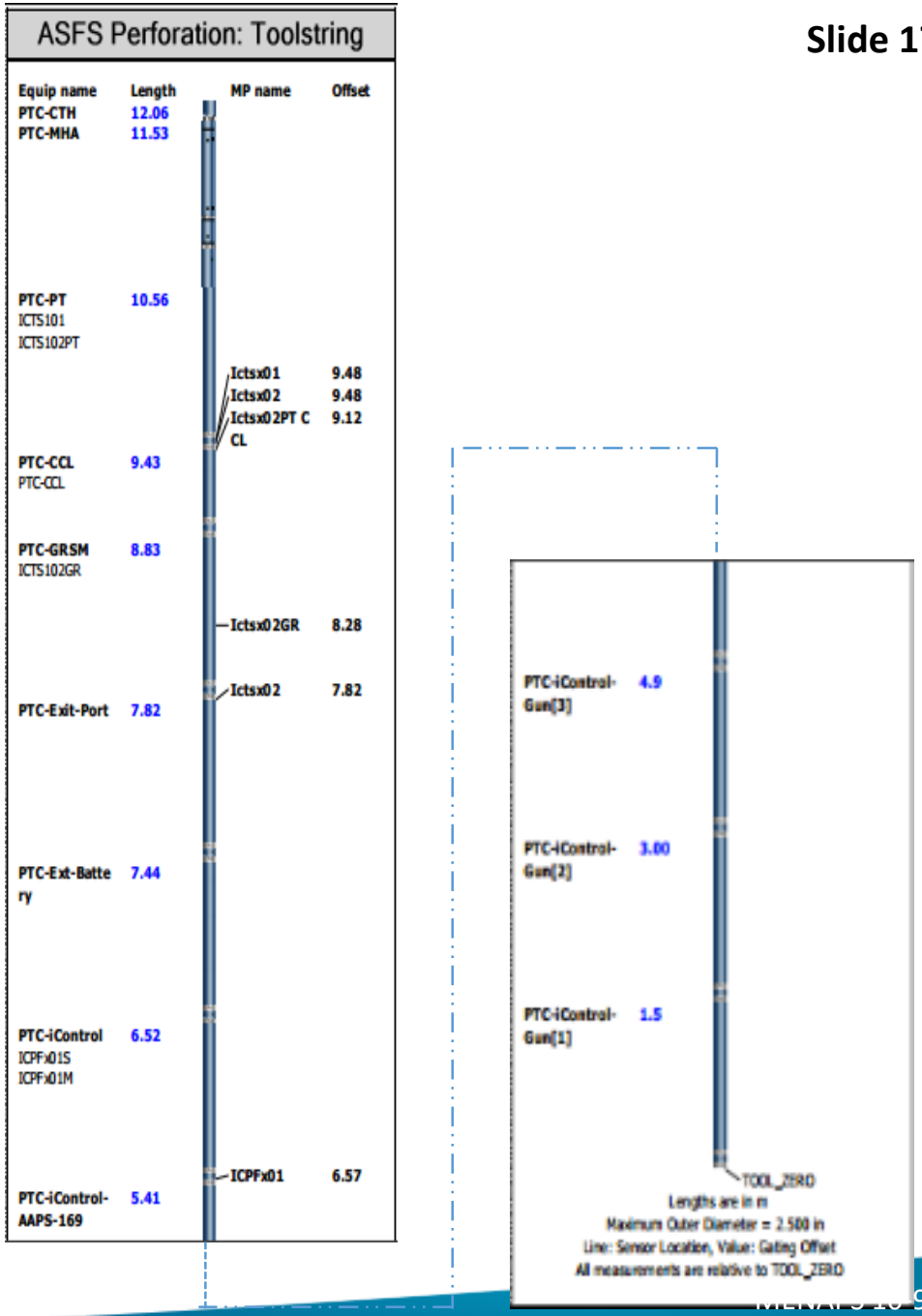


Oman Horizontal Well Case Study

- Operation performed with the system involving:
  - Plug setting

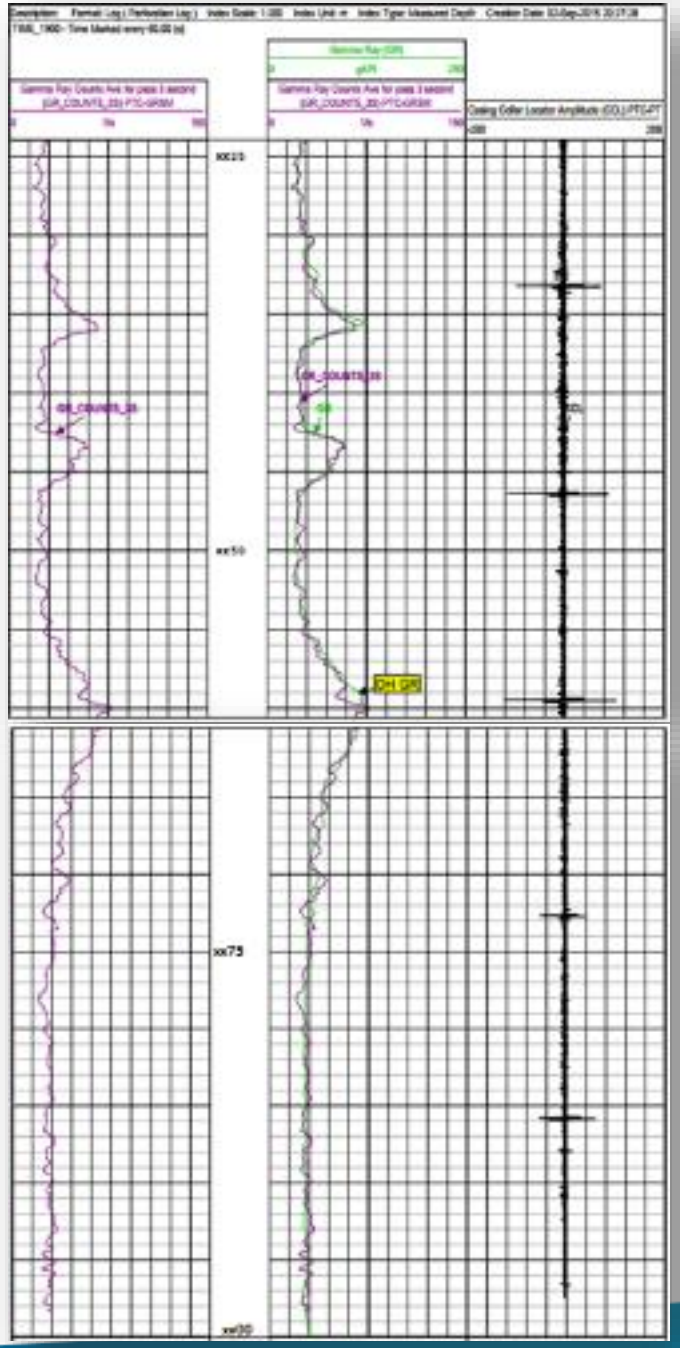
Oman Horizontal Well Case Study

- Operation performed with the system involving:
  - Plug setting
  - Perforating multiple guns



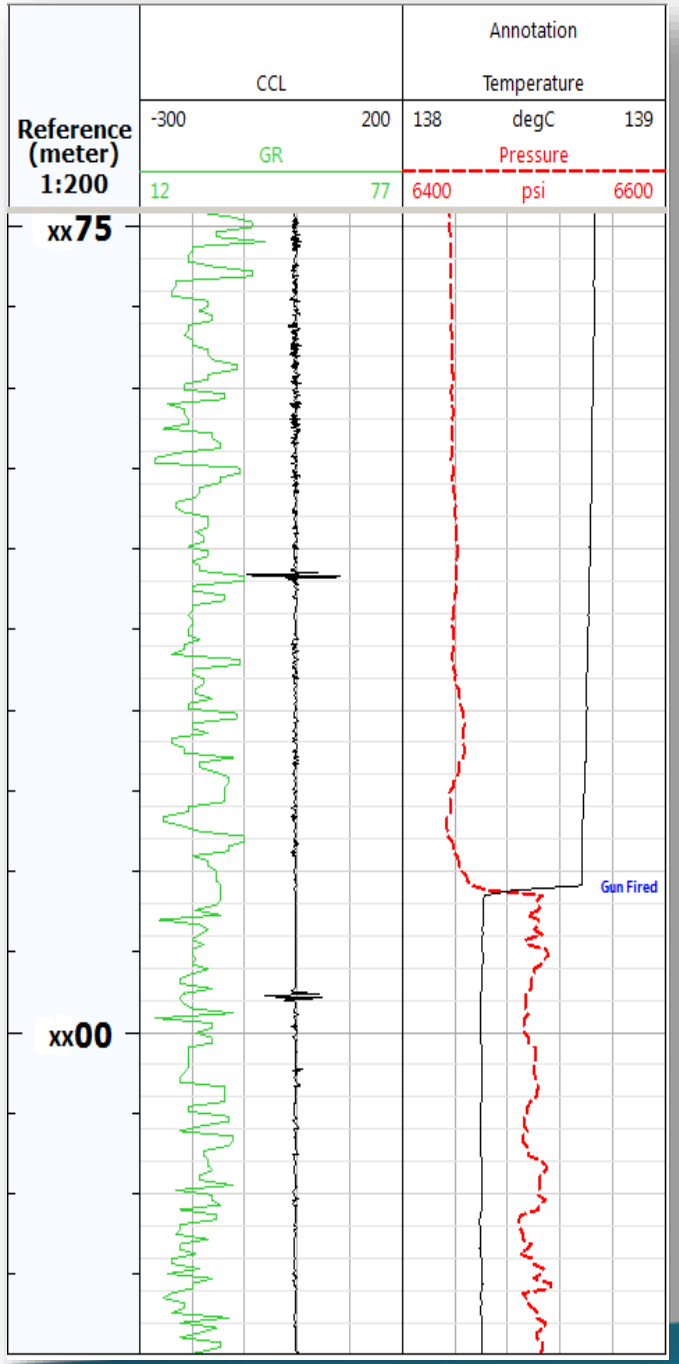
Oman Horizontal Well Case Study

- Operation performed with the system involving:
  - Plug setting
  - Perforating multiple guns
    - Realtime GR-CCL correlation



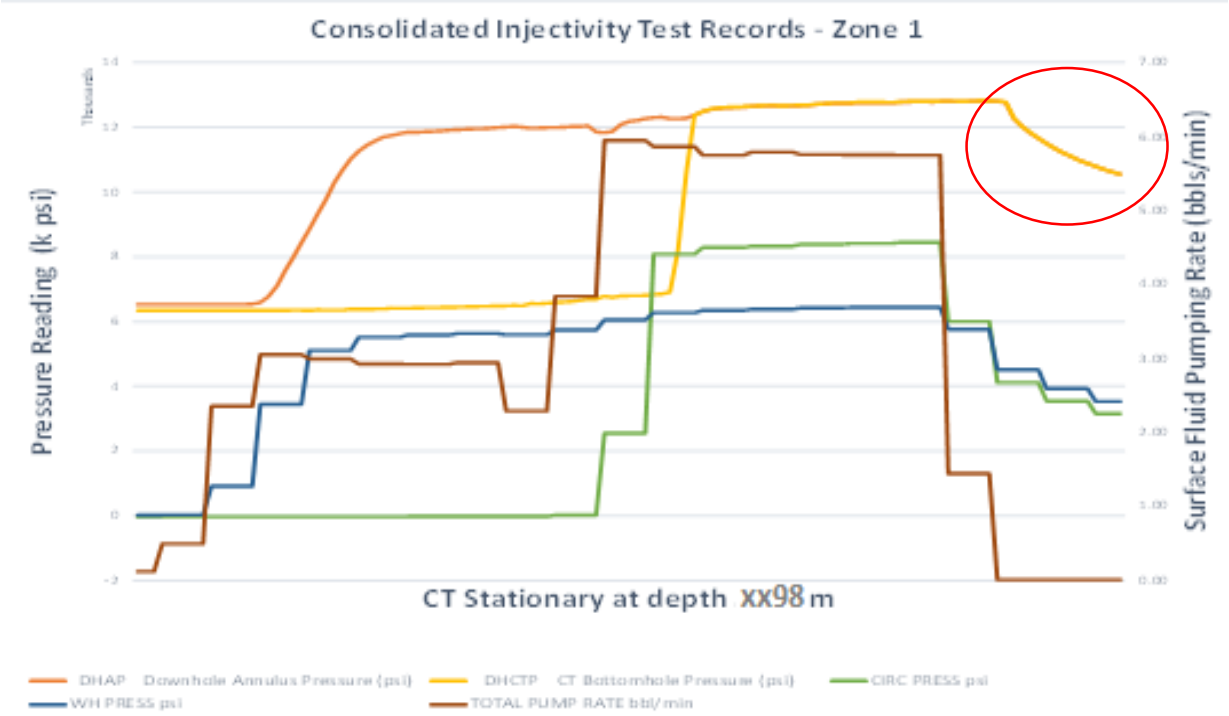
Oman Horizontal Well Case Study

- Operation performed with the system involving:
  - Plug setting
  - Perforating multiple guns
    - Realtime GR-CCL correlation
    - Perforation confirmation from the switches and Pressure/ Temperature sensors



Oman Horizontal Well Case Study

- Operation performed with the system involving:
  - Plug setting
  - Perforating multiple guns
  - Injectivity and pressure decline tests
  - Hole cleanout
  - Plug milling



Conclusion

- Successful multiple stages operations with accurate correlations of multiple short guns.

Run	Perforation Guns	Result
Run 1	Three sets of 0.9-m guns	All three guns fired sequentially successfully
Run 2	Three sets of 0.9-m guns	All three guns fired sequentially successfully
Run 3	Three sets of 0.9-m guns	All three guns fired sequentially successfully
Run 4	Three sets of 0.9-m guns	Only gun-2 fired and could not fire gun-1 and gun-3 due to tool communication error. Repeat of two guns performed.
Run 5a	Three sets of 0.9-m guns	All three guns fired sequentially successfully
Run 5b	One set of 3-m gun	Gun fired successfully after tool communication error while running in hole.
Run 6	Three sets of 0.9-m guns	All three guns fired sequentially successfully

- Overflushing avoided.
- Hole cleaning and plug milling with the same coil meet some of the expectation due to pumping rate limitation 2 bpm maximum rate on a 2” CTU
- Software and electronics communication was an issue that cause to pull out of hole several times
- Possible future expansion scope of application to include distributed temperature sensing (DTS)

QUESTIONS?
THANK YOU!