APPS 2018

ASIA PACIFIC PERFORATING SYMPOSIUM

Successful Use of API Section-IV Testing to Select Between Zinc and Steel Case Shaped-Charges in a Dual-Zone Cased-Hole Gravel Pack Tubing-Conveyed-Perforating Operation for a Gas Well: Case Study

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AUTHORS: Mandeep Kuldeep Singh and Josh Lavery, Halliburton

AGENDA

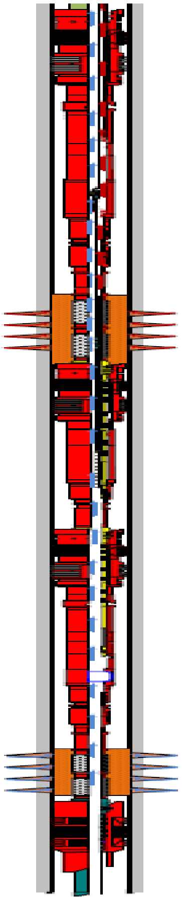
- Design Drivers
- Charge Selection
- Shot Testing—Parameters
- Shot Testing Results—Charge Performance
- Shot Testing Results—Flow Performance
- Outcomes and Field Application

Design Drivers

- Well type: dual-zone cased-hole gravel pack
  - Large distance between zones: ~200 m—2 ea. runs
  - Large casing diameter: 10 3/4 in.—larger clearance
  - Intermediate completions valves between zones—debris risk
  - Vertical
  - Entry hole diameter (EHD) criteria from operator: 1.0 in.
  - Gas well—overbalance, shoot, and retrieve perforation with retrievable packer

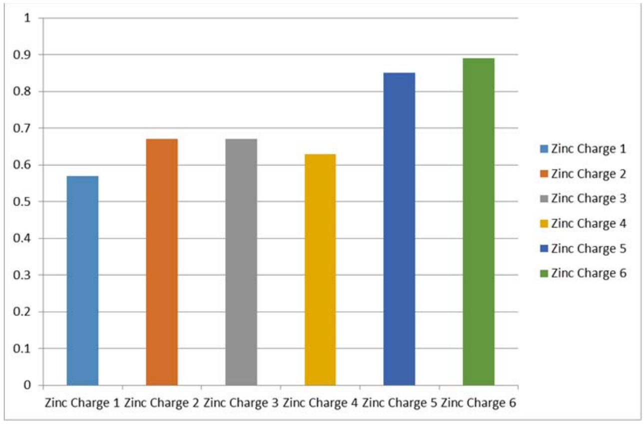
- Lower zone
  - Open sump—no additional risk
  - Largest EHD big hole charge—more effective gravel pack, better production

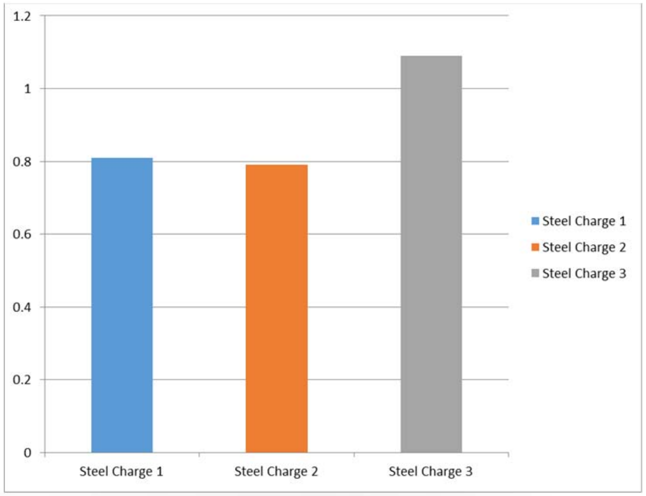
- Upper zone
  - Sump packer with plug set—to stop debris going farther downhole
  - Risk of debris sitting on plug—unable to pull plug
  - Perforating close to sump, 3 m—high shock (pressure) loading on sump packer



Charge Selection

- Initial screening for best charge performed using perforation simulation software
- Best zinc and steel charge used in testing
- Bottom zone selection
  - No debris risk—steel charge
  - Conduct testing to validate charge performance with expected dynamic underbalance
- Top zone selection
  - Debris—major concern
  - Steel vs. zinc—shot testing
    - Shot performance
    - Perforation cleanup for zinc
    - Sump packer shock loading
    - Debris consideration
  - Evaluate sump packer shock loading for zinc





Shot Testing—Parameters

- Actual rock parameters (sandstone)
  - Top zone
    - Permeability: up to 4000 md; average 600 md
    - Porosity: 17 to 18%
    - Unconfined compressive strength (UCS): average ~6,000 psi
  - Bottom zone
    - Permeability: up to 1000 md
    - Porosity: 22%
    - UCS: average ~4,000 psi

Analog rock selected: outcrop Bentheimer sandstone selected for both zones

- Test gun details to match actual
- Wellbore details based on ideal centralization

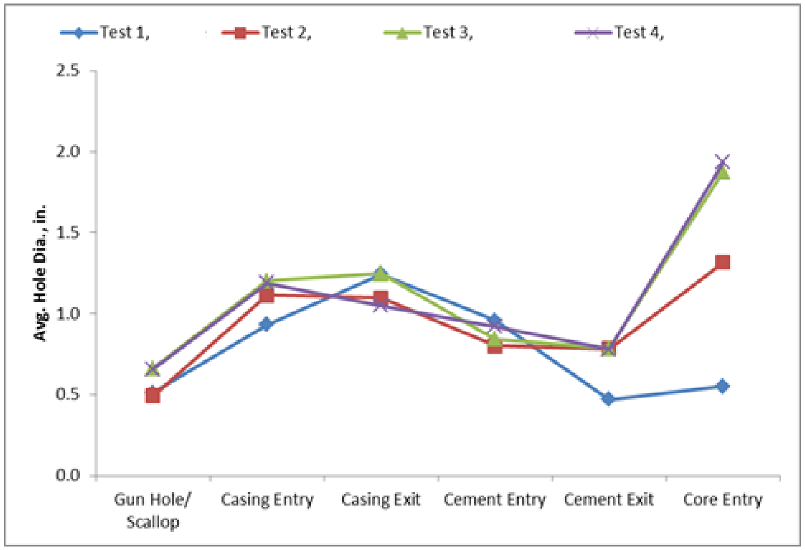
Analog Rock Properties

Measured Analog Core Properties†	Dry Bulk Density, g/cm^3	1.99	1.99	1.98	1.98
	Saturation Fluid	N2	N2	N2	N2
	Saturation, % PV	100	100	100	100
	Porosity, % BV	24.6	24.8	25.1	24.9
	Scratch A UCS, psi	3,990	3,953	3,798	3,822
	Scratch B UCS, psi	3,624	4,473	4,031	4,111
	Absolute Permeability, md	2,338	2,149	2,744	2,271

Shot Testing Results—Charge Performance

- Testing plan
  - Temperature
    - Shoot 1 ea. at ambient
    - Shoot 1 ea. at 257°F
  - Inject odorless mineral spirits (OMS)—simulate gravel packing
  - Flow with N_2—simulate gas flow

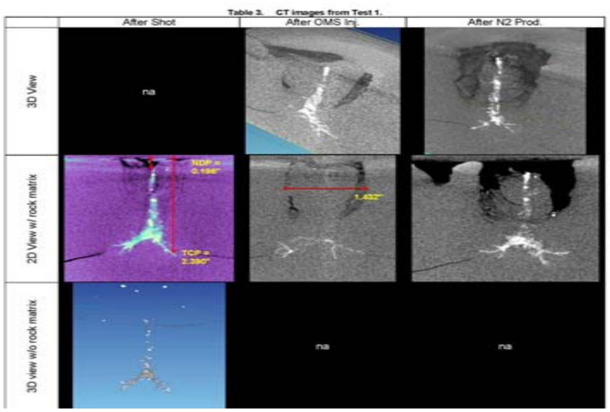
- Results
  - Both charge performances met operator requirements
  - Identified dynamic underbalance could potentially clean up zinc perforations
  - Smallest EHD through cement
  - <u>Zinc performance qualified for operator requirements</u>

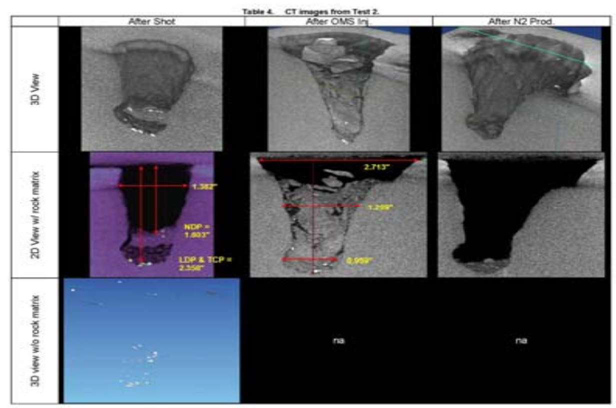


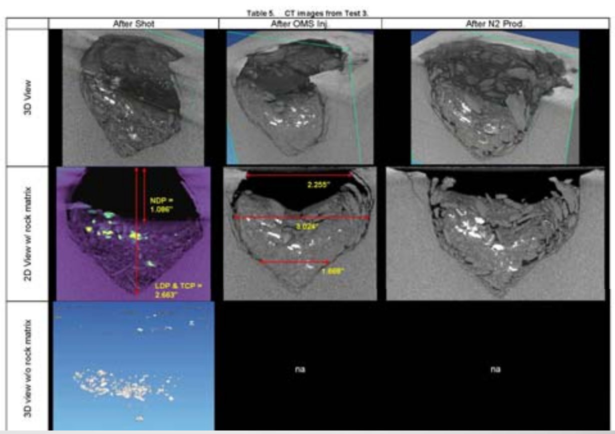
Actual Dynamic Underbalance During Testing

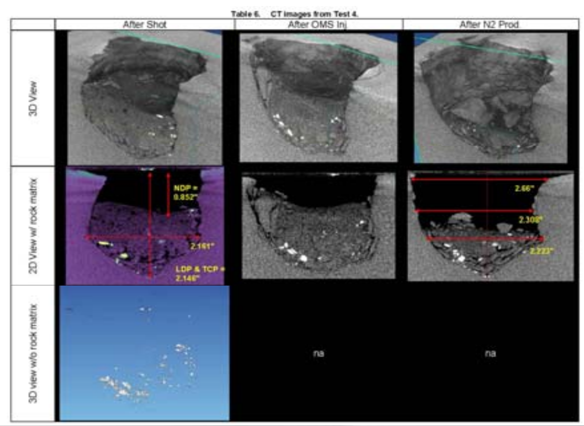
Minimum Wellbore Pressure Reached, psi	3,592	3,757	4,163	3,656
Observed Peak DOB(+)/DUB(-), psi	-708	-543	-337	-844

Shot Testing Results—Charge Performance







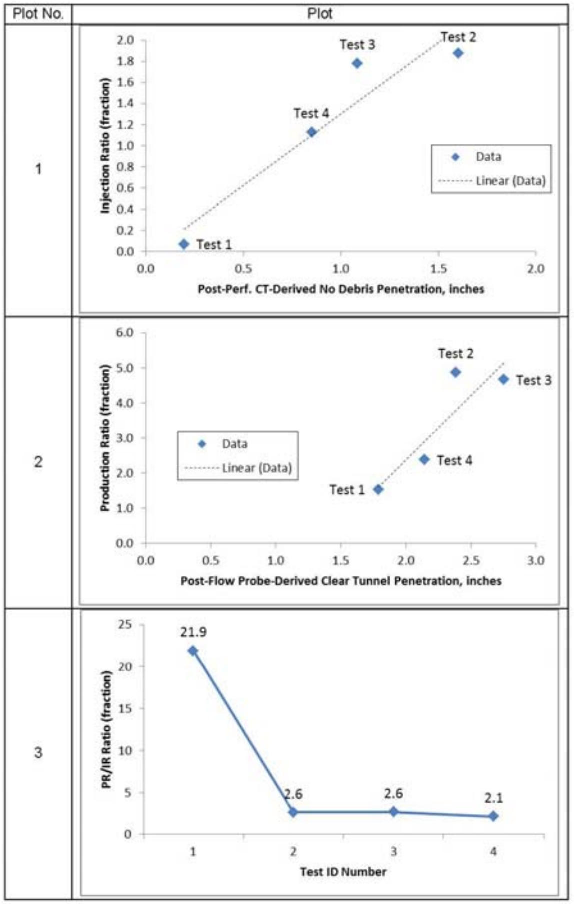


Shot Testing—Flow Performance

- Outcomes
  - Zinc performance met operator requirement—enabled option to use zinc charge
  - Zinc vs. steel performance in terms of injection/production was highly similar: zinc has a lower debris advantage
  - Zinc perforation clean-up—Dynamic Underbalance shown to be able to clean up perforation
  - Implemented a delayed Dynamic Underbalance surge event

	Post-shot Flow	1) Injectivity Index, (R.cm^3-cp)/(atm-s)	1.86 → 0.80 (start to end)	13.96	17.95	10.98
		1) Injection Ratio (to Restr.-Face RI)	0.17 → 0.07 (start to end)	1.88	1.78	1.13
		2) Productivity Index, (R.cm^3-cp)/(atm-s)	17.03	36.12	47.10	23.14
		2) Production Ratio (to Restr.-Face RI)	1.53	4.86	4.67	2.37

Table 10. Plots summarizing correlations between post-shot flow performance as a function of penetration and flow direction.

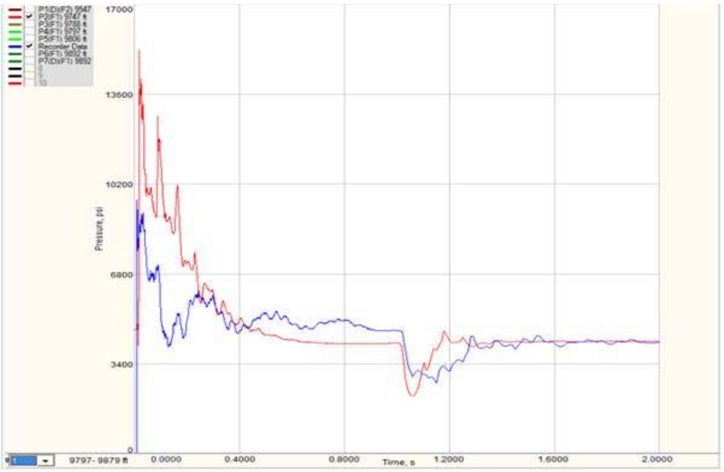


Outcomes and Field Application

- Outcomes
  - Zinc performance met operator requirements
  - Similar zinc vs. steel flow performance
  - Zinc charge provided lower debris advantage
  - Zinc perforations clean-up —Dynamic underbalance shown to be able to fluidize the debris created during the Zinc perforation event

- Field application
  - Zinc charge used for top zone and steel charge for bottom zone
  - Implemented a delayed Dynamic Underbalance surge event—fast gauges verified
  - Well successfully gravel packed—injection rates achieved
  - Loss rates and production rates met operator expectations
  - Debris was cleaned using wellbore cleanup tools
  - Well successfully perforated, gravel packed, and completed

Fast Gauge Data for Delayed Dynamic Underbalance



Red line—fast gauge data
Blue line—simulated data

Debris Recovered from Well

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QUESTIONS?
THANK YOU!

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