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Field Application Study of Zinc Based, Low Debris Perforating Charges

IPS 16-26

POSTER PRESENTATION

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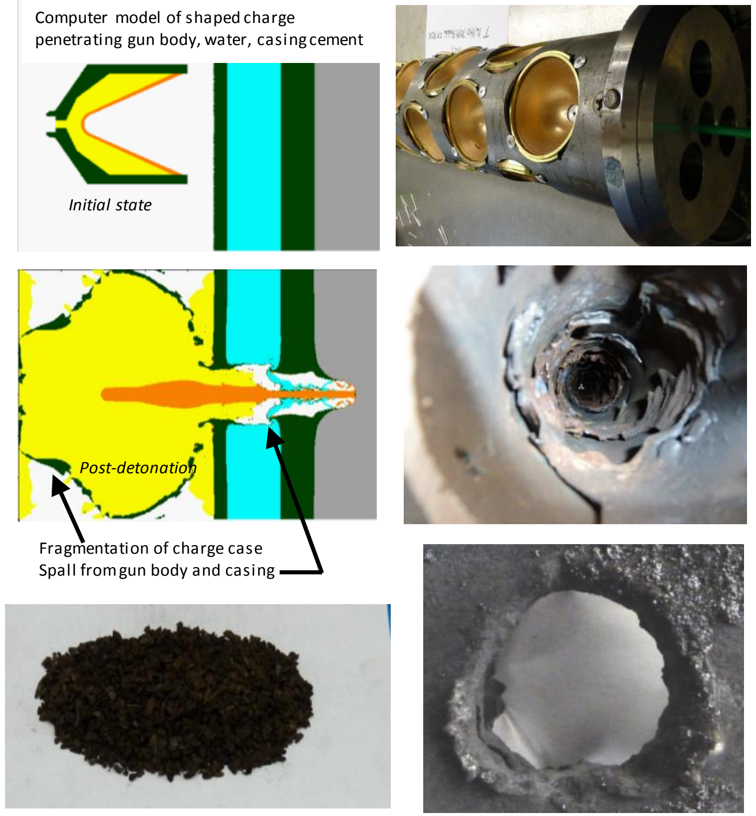
Solution Statement

- All perforating operations create some amount of debris.
- Low Debris perforating techniques and systems have been developed within the industry.
- One method developed and widely deployed within the industry that has proven successful is the use of zinc-cased perforating charges.
- Limitations to using zinc charges have been identified in previous studies.
- A proposed process for successful system selection, implementation, and clean-up techniques of perforating debris is presented in this paper.
- As with any technology, if using Zinc cased charges, they must be applied properly to realize their full benefit.

Perforating Debris - Review

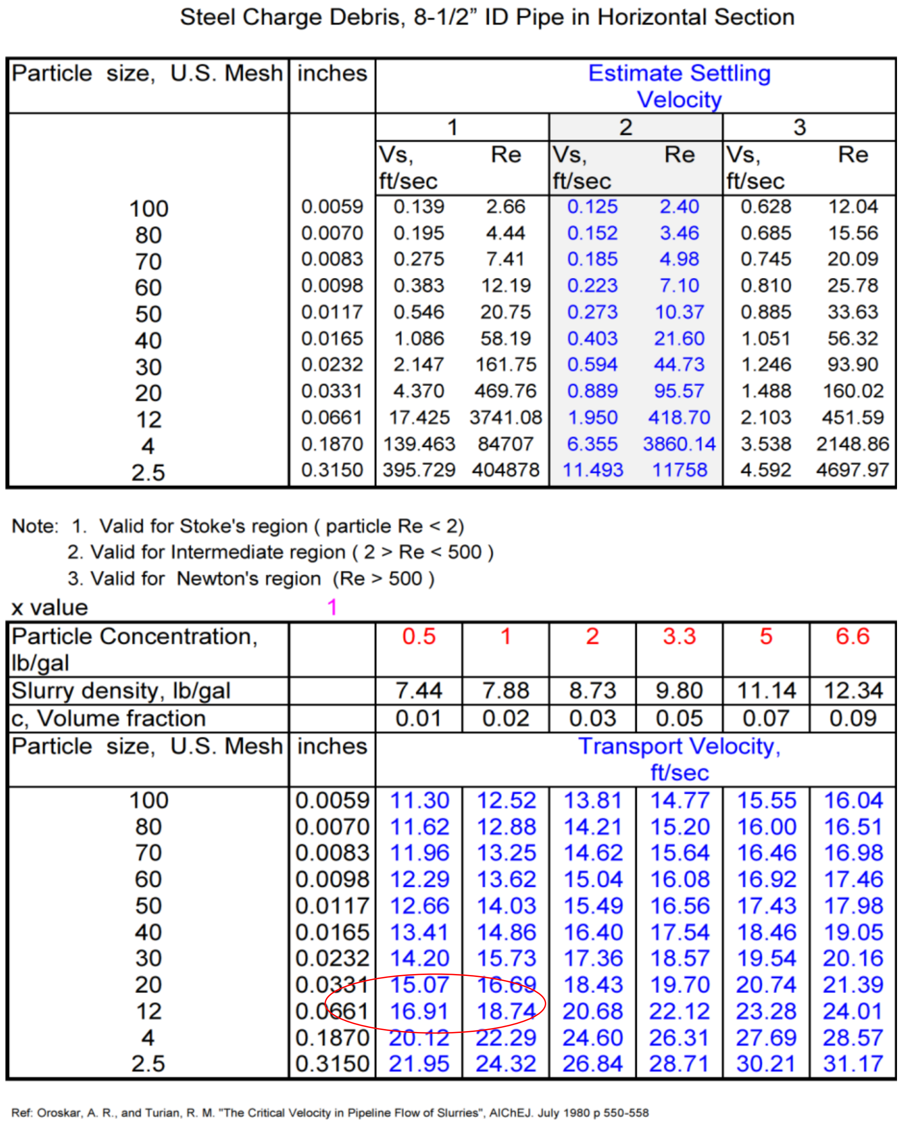
- All perforating operations produce some amounts of debris
- Sources of perforating debris include:
  - Charge Case and Liner fragments
  - Charge tube (strip, holder) fragments
  - Hollow carrier spall/burrs
  - Casing spall/burrs
  - Internal gun components
- Debris can
  - Can cause downhole restrictions
  - Choke downhole hardware
  - Limit wellbore access
  - Plug perforations
- ***Mitigation or elimination of debris is important for life of the well***

Damaged Seal Assembly from perforating debris



Shaped charge case fragmenting in computer simulation (upper and center left), charge tube before and after detonation (upper and center right), example debris (lower left), and interior of shot casing (lower right)

Debris Particle Transport



Steel Charge Debris, 8-1/2” ID Pipe in Horizontal Section

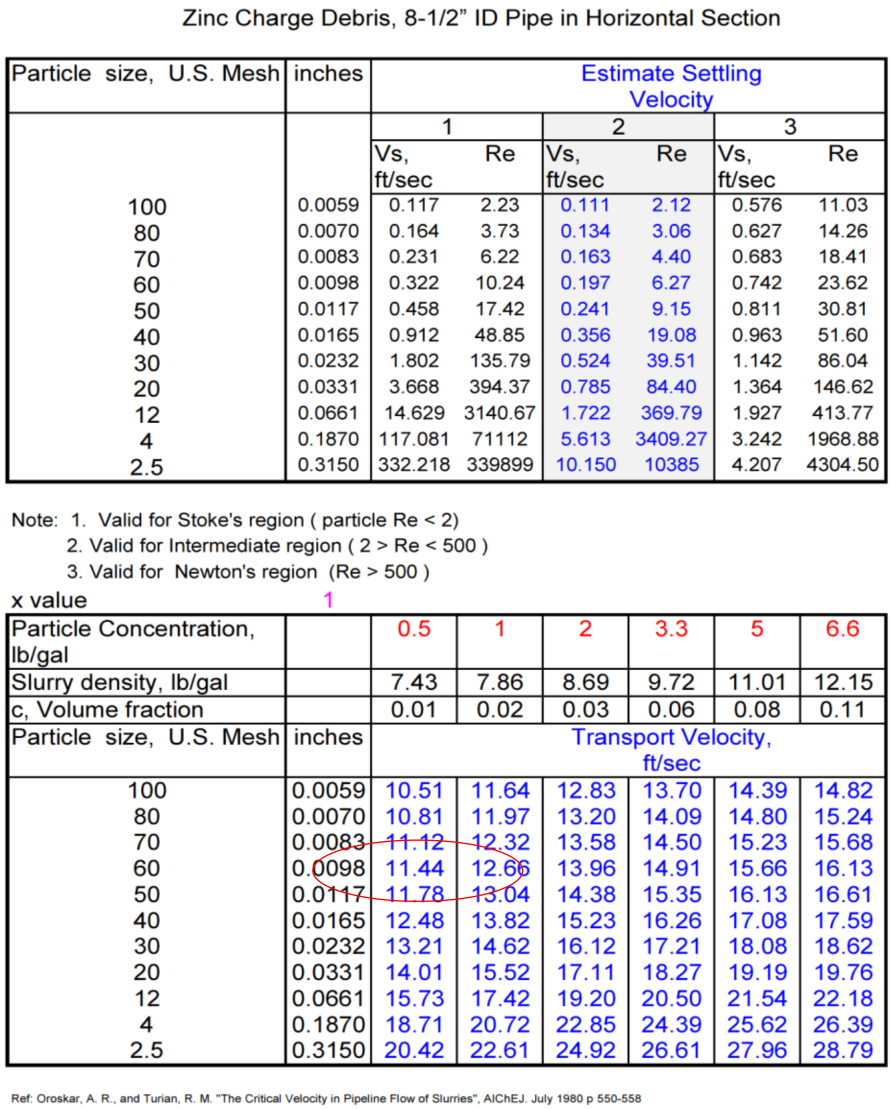
Particle size, U.S. Mesh	inches	Estimate Settling Velocity					
		1		2		3	
		Vs, ft/sec	Re	Vs, ft/sec	Re	Vs, ft/sec	Re
100	0.0059	0.139	2.66	0.125	2.40	0.628	12.04
80	0.0070	0.195	4.44	0.152	3.46	0.685	15.56
70	0.0083	0.275	7.41	0.185	4.98	0.745	20.09
60	0.0098	0.383	12.19	0.223	7.10	0.810	25.78
50	0.0117	0.546	20.75	0.273	10.37	0.885	33.63
40	0.0165	1.086	58.19	0.403	21.60	1.051	56.32
30	0.0232	2.147	161.75	0.594	44.73	1.246	93.90
20	0.0331	4.370	469.76	0.889	95.57	1.488	160.02
12	0.0661	17.425	3741.08	1.950	418.70	2.103	451.59
4	0.1870	139.463	84707	6.355	3860.14	3.538	2148.86
2.5	0.3150	395.729	404878	11.493	11758	4.592	4697.97

Note: 1. Valid for Stoke's region (particle Re < 2)
2. Valid for Intermediate region (2 > Re < 500)
3. Valid for Newton's region (Re > 500)

x value 1

Particle Concentration, lb/gal		0.5	1	2	3.3	5	6.6
Slurry density, lb/gal		7.44	7.88	8.73	9.80	11.14	12.34
c, Volume fraction		0.01	0.02	0.03	0.05	0.07	0.09
Particle size, U.S. Mesh	inches	Transport Velocity, ft/sec					
100	0.0059	11.30	12.52	13.81	14.77	15.55	16.04
80	0.0070	11.62	12.88	14.21	15.20	16.00	16.51
70	0.0083	11.96	13.25	14.62	15.64	16.46	16.98
60	0.0098	12.29	13.62	15.04	16.08	16.92	17.46
50	0.0117	12.66	14.03	15.49	16.56	17.43	17.98
40	0.0165	13.41	14.86	16.40	17.54	18.46	19.05
30	0.0232	14.20	15.73	17.36	18.57	19.54	20.16
20	0.0331	15.07	16.69	18.43	19.70	20.74	21.39
12	0.0661	16.91	18.74	20.68	22.12	23.28	24.01
4	0.1870	20.12	22.29	24.60	26.31	27.69	28.57
2.5	0.3150	21.95	24.32	26.84	28.71	30.21	31.17

Ref: Oroskar, A. R., and Turian, R. M. "The Critical Velocity in Pipeline Flow of Slurries", AIChEJ. July 1980 p 550-558



Zinc Charge Debris, 8-1/2” ID Pipe in Horizontal Section

Particle size, U.S. Mesh	inches	Estimate Settling Velocity					
		1		2		3	
		Vs, ft/sec	Re	Vs, ft/sec	Re	Vs, ft/sec	Re
100	0.0059	0.117	2.23	0.111	2.12	0.576	11.03
80	0.0070	0.164	3.73	0.134	3.06	0.627	14.26
70	0.0083	0.231	6.22	0.163	4.40	0.683	18.41
60	0.0098	0.322	10.24	0.197	6.27	0.742	23.62
50	0.0117	0.458	17.42	0.241	9.15	0.811	30.81
40	0.0165	0.912	48.85	0.356	19.08	0.963	51.60
30	0.0232	1.802	135.79	0.524	39.51	1.142	86.04
20	0.0331	3.668	394.37	0.785	84.40	1.364	146.62
12	0.0661	14.629	3140.67	1.722	369.79	1.927	413.77
4	0.1870	117.081	71112	5.613	3409.27	3.242	1968.88
2.5	0.3150	332.218	339899	10.150	10385	4.207	4304.50

Note: 1. Valid for Stoke's region (particle Re < 2)
2. Valid for Intermediate region (2 > Re < 500)
3. Valid for Newton's region (Re > 500)

x value 1

Particle Concentration, lb/gal		0.5	1	2	3.3	5	6.6
Slurry density, lb/gal		7.43	7.86	8.69	9.72	11.01	12.15
c, Volume fraction		0.01	0.02	0.03	0.06	0.08	0.11
Particle size, U.S. Mesh	inches	Transport Velocity, ft/sec					
100	0.0059	10.51	11.64	12.83	13.70	14.39	14.82
80	0.0070	10.81	11.97	13.20	14.09	14.80	15.24
70	0.0083	11.12	12.32	13.58	14.50	15.23	15.68
60	0.0098	11.44	12.66	13.96	14.91	15.66	16.13
50	0.0117	11.78	13.04	14.38	15.35	16.13	16.61
40	0.0165	12.48	13.82	15.23	16.26	17.08	17.59
30	0.0232	13.21	14.62	16.12	17.21	18.08	18.62
20	0.0331	14.01	15.52	17.11	18.27	19.19	19.76
12	0.0661	15.73	17.42	19.20	20.50	21.54	22.18
4	0.1870	18.71	20.72	22.85	24.39	25.62	26.39
2.5	0.3150	20.42	22.61	24.92	26.61	27.96	28.79

Ref: Oroskar, A. R., and Turian, R. M. "The Critical Velocity in Pipeline Flow of Slurries", AIChEJ. July 1980 p 550-558

Particle Transport calculations used to plan for debris removal requirements.

Using D50 from steel debris characterization:

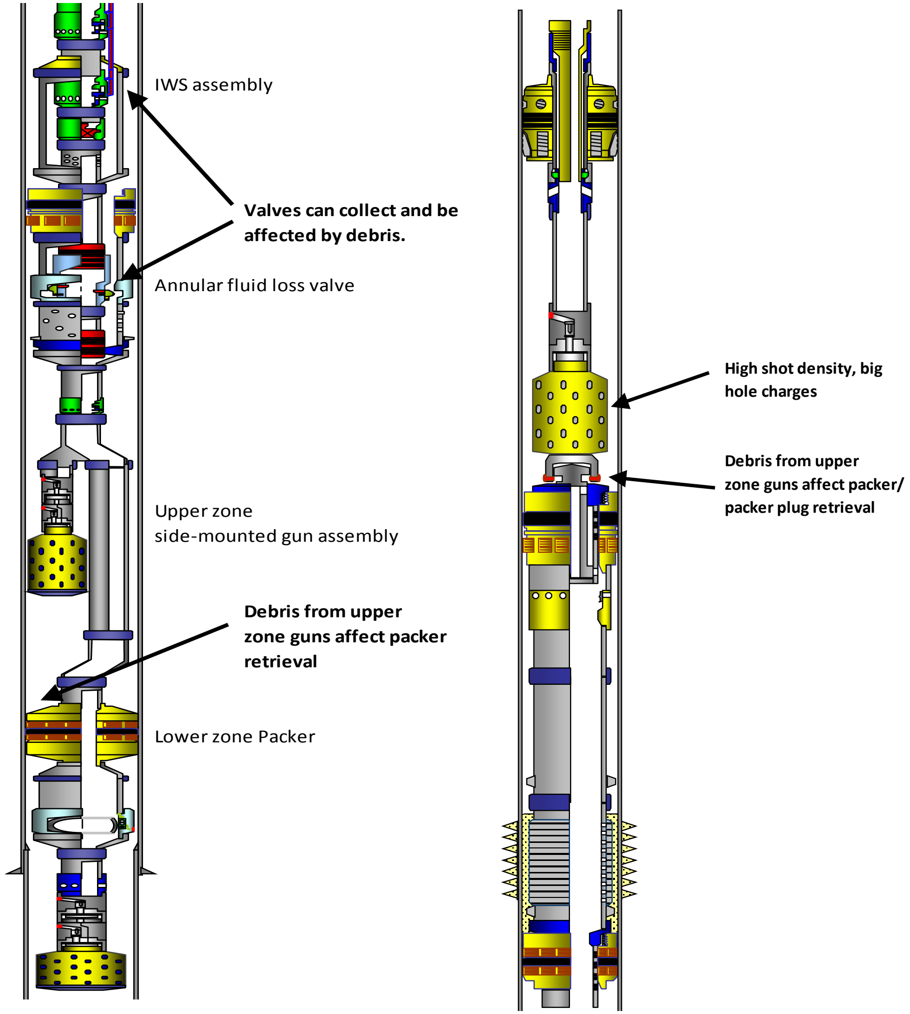
- Assume particle size: US Mesh 12
- Removal at 0.5 PPG concentration requires ~***16.9*** ft/sec transport velocity

Using D50 from zinc debris characterization:

- Assume particle size: US Mesh 60
- Removal at 0.5 PPG concentration requires ~***11.5*** ft/sec transport velocity.

Perforating Debris – Completion Concerns

- The nature (size) of perforating debris can have a significant impact on completion operations
- Steel debris may require higher transport velocities. Settling of debris within valves, sleeves and horizontal sections can occur.
- Frac Pack/ Sand Control wells concerns of debris settling around packer plugs and above production packers.
- NPT for perforating debris related issues can be significant



Plugging of Perforation Tunnels

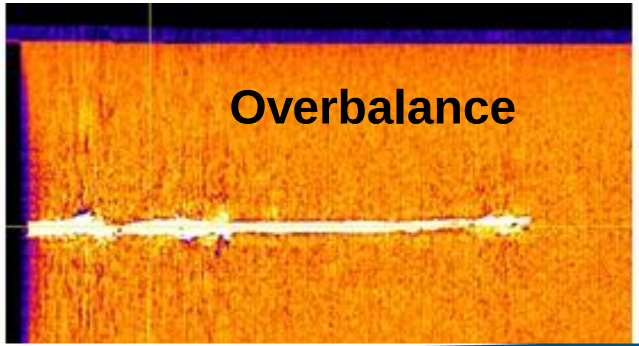
- Potential for damage to perforating tunnels from zinc debris exists, but there are techniques to eliminate these effects and create a clean perforation.

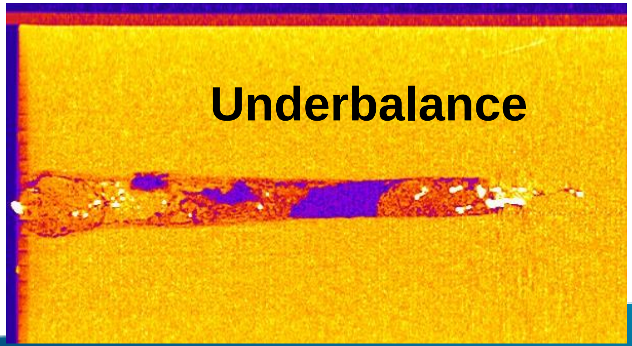
- Test conducted using two different well conditions, for a “natural completion” scenario (not stimulated or FracPack):
  - Overbalance with standard gun volume
  - Underbalance with maximum gun volume

- Deep Penetrating shaped charges

- Results demonstrated that optimizing (or maximizing) underbalance was critical for tunnel cleanup and enhancing productivity.

Wellbore fluid	Confining (psi)	Pore (psi)	Wellbore (psi)	Gun volume (cc)	Penetration (in)	PR
NaBr	**9300**	**6000**	**6250 (OB)**	**330**	**9.44** **13.81**	**0.15** **0.69**
NaBr	**9300**	**6000**	**5500 (UB)**	**660**	**10.31** **10.63**	**1.20** **1.85**

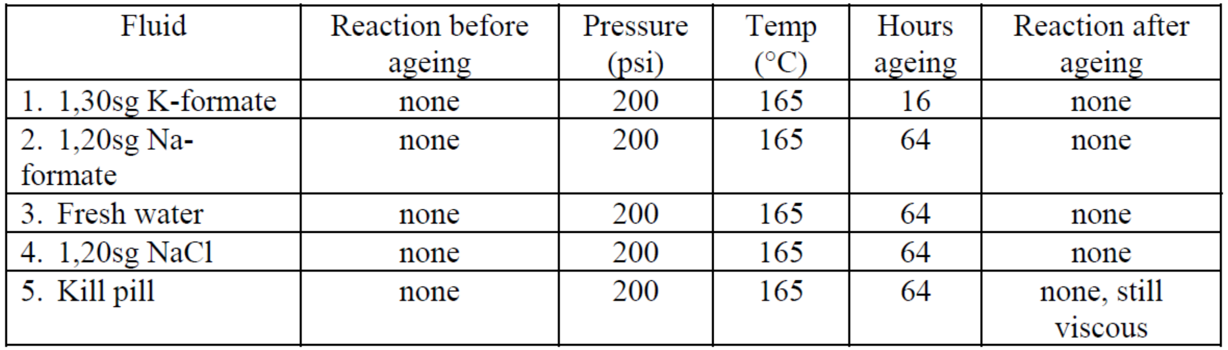




Fluids Compatibility

Solubility Testing

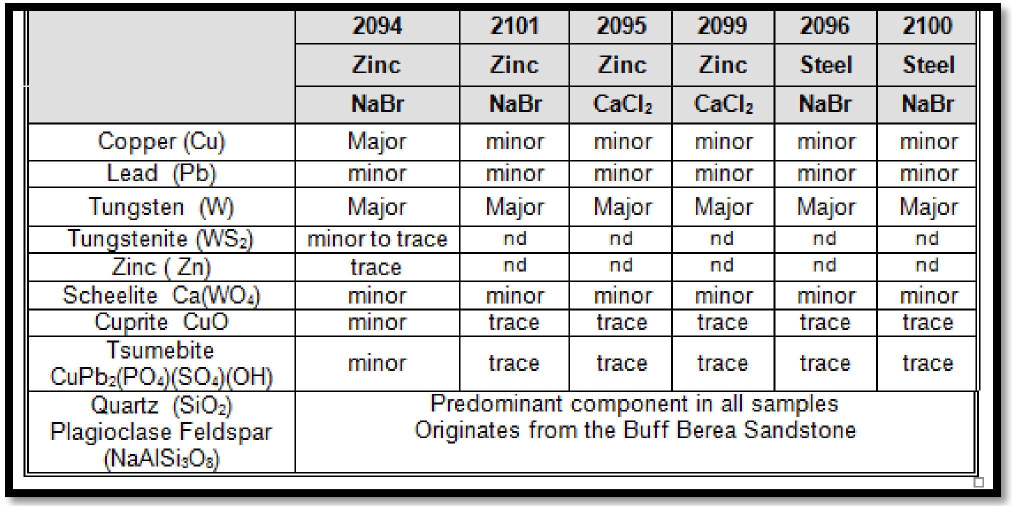
- ➢ The potential for interaction between zinc charge debris and CaCl completion fluid in certain conditions has been covered in previous papers by others (Javora et al for example).
- ➢ To expand the understanding, testing was conducted on a selection of fluids to examine chemical reaction phenomena that may occur due to the interaction with zinc debris.
- ➢ The tests were conducted at 165^{o}C for 16-64 hours with the objective of checking for reactions between debris and fluid.
- ➢ No reactions between the fluids and the zinc debris were observed.



Fluid	Reaction before ageing	Pressure (psi)	Temp (°C)	Hours ageing	Reaction after ageing
1. 1,30sg K-formate	none	200	165	16	none
2. 1,20sg Na-formate	none	200	165	64	none
3. Fresh water	none	200	165	64	none
4. 1,20sg NaCl	none	200	165	64	none
5. Kill pill	none	200	165	64	none, still viscous

Mineralogy

- ➢ Interpreted minerals and their relative abundance are shown in the following table along with interpreted sources.
- ➢ The mineralogical analysis indicated that the perforating debris was mostly composed of quartz (from the Buff Berea core) along with charge material (tungsten, lead and copper), with minor traces of precipitates (Cuprite, Tsumebite, Scheelite).



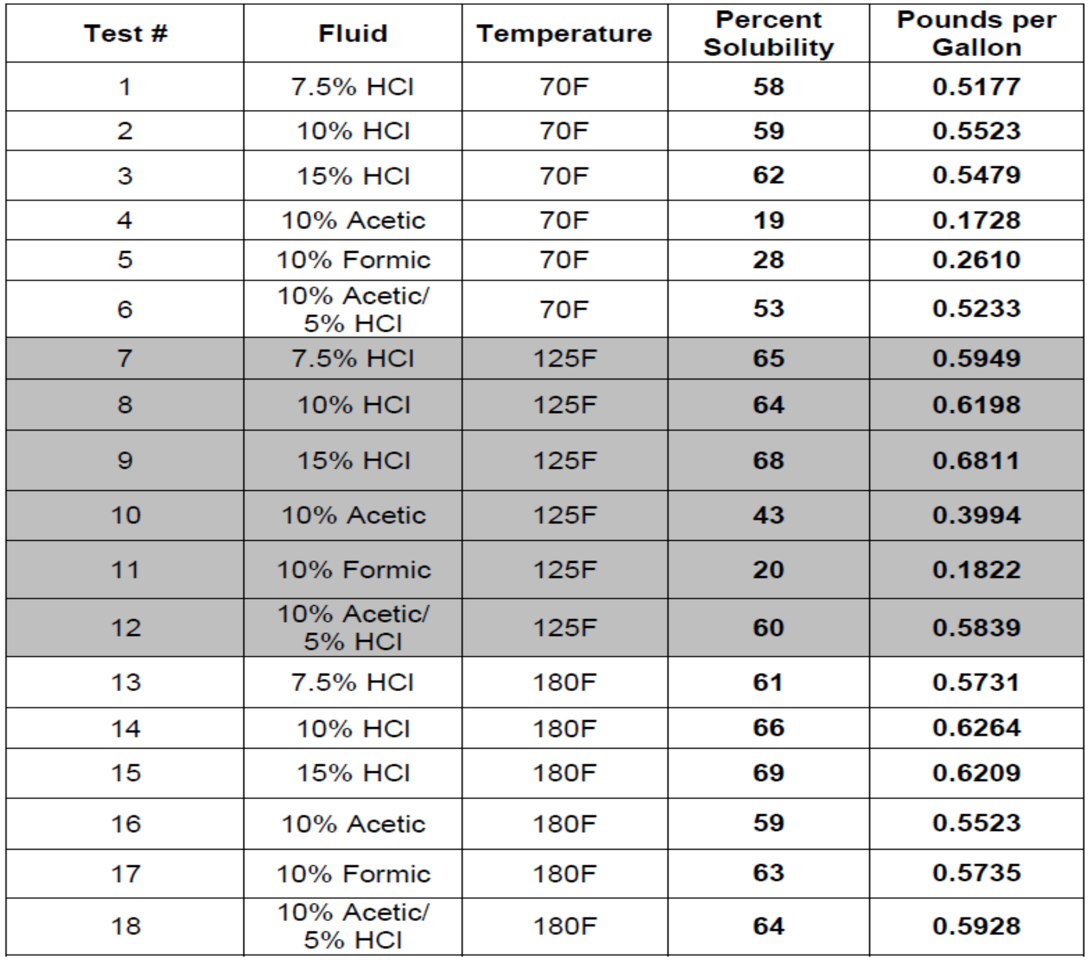
	2094	2101	2095	2099	2096	2100
	Zinc	Zinc	Zinc	Zinc	Steel	Steel
	NaBr	NaBr	$CaCl_2$	$CaCl_2$	NaBr	NaBr
Copper (Cu)	Major	minor	minor	minor	minor	minor
Lead (Pb)	minor	minor	minor	minor	minor	minor
Tungsten (W)	Major	Major	Major	Major	Major	Major
Tungstenite (WS_2)	minor to trace	nd	nd	nd	nd	nd
Zinc (Zn)	trace	nd	nd	nd	nd	nd
Scheelite $Ca(WO_4)$	minor	minor	minor	minor	minor	minor
Cuprite CuO	minor	trace	trace	trace	trace	trace
Tsumebite $CuPb_2(PO_4)(SO_4)(OH)$	minor	trace	trace	trace	trace	trace
Quartz (SiO_2) Plagioclase Feldspar ($NaAlSi_3O_8$)	Predominant component in all samples Originates from the Buff Berea Sandstone					

Acid Solubility and Remediation

- With overbalanced shot conditions, fine nature of the zinc debris can allow the particles to be carried into the perforation tunnels by fluid losses, potentially impairing the perforation

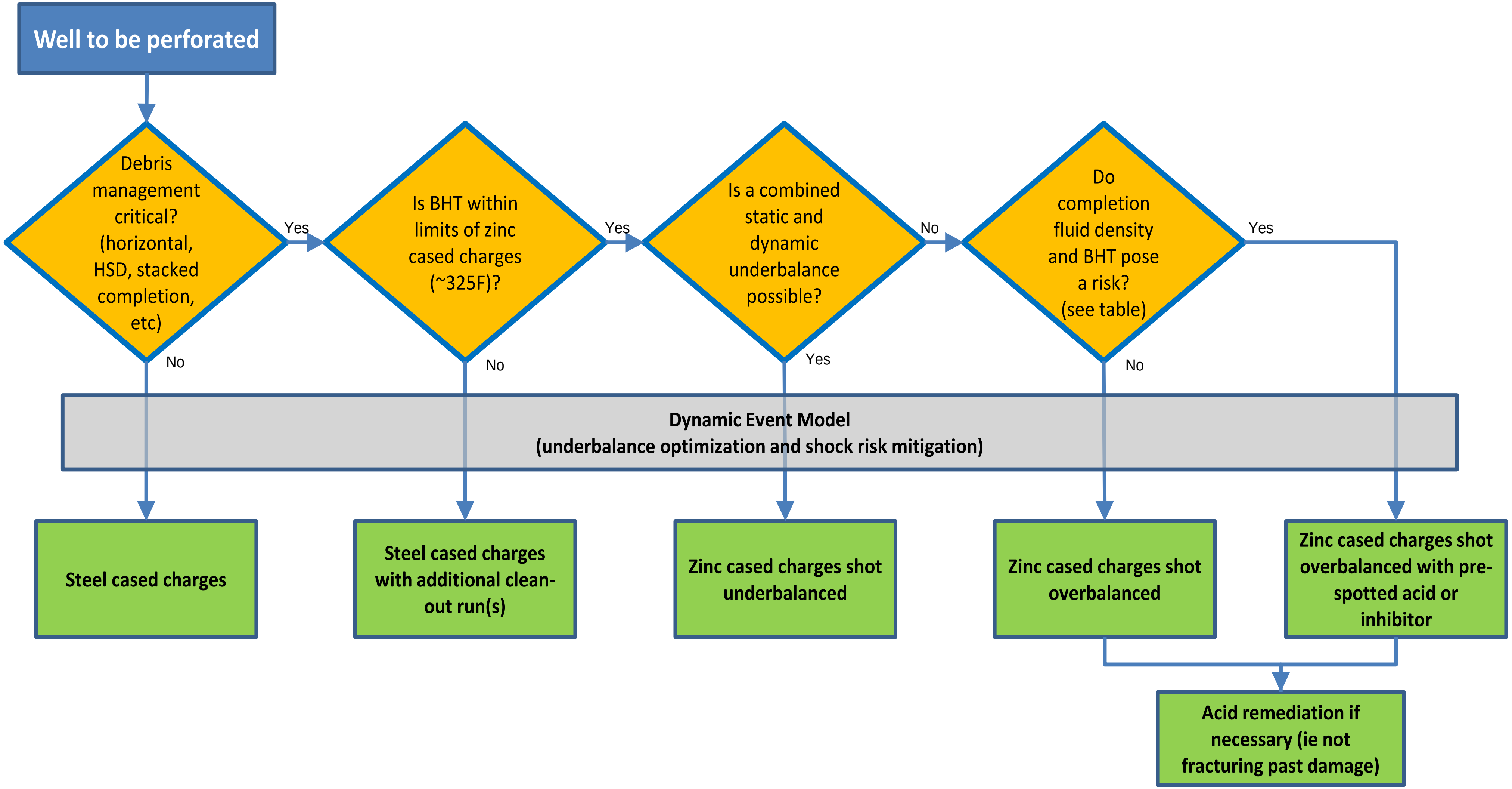
- Zinc particulates are remediated with the use of acid

- 15% HCl had the highest solubility on the solids at all temperatures



Test #	Fluid	Temperature	Percent Solubility	Pounds per Gallon
1	7.5% HCl	70F	**58**	**0.5177**
2	10% HCl	70F	**59**	**0.5523**
3	15% HCl	70F	**62**	**0.5479**
4	10% Acetic	70F	**19**	**0.1728**
5	10% Formic	70F	**28**	**0.2610**
6	10% Acetic/ 5% HCl	70F	**53**	**0.5233**
7	7.5% HCl	125F	**65**	**0.5949**
8	10% HCl	125F	**64**	**0.6198**
9	15% HCl	125F	**68**	**0.6811**
10	10% Acetic	125F	**43**	**0.3994**
11	10% Formic	125F	**20**	**0.1822**
12	10% Acetic/ 5% HCl	125F	**60**	**0.5839**
13	7.5% HCl	180F	**61**	**0.5731**
14	10% HCl	180F	**66**	**0.6264**
15	15% HCl	180F	**69**	**0.6209**
16	10% Acetic	180F	**59**	**0.5523**
17	10% Formic	180F	**63**	**0.5735**
18	10% Acetic/ 5% HCl	180F	**64**	**0.5928**

Perforating Debris - Proposed Completion Selection



Field Examples

Case	Type	Charge Type	Well Type	Deviation	BHT, F	Fluid Type	Underbalance
1	Shoot and Pull TCP	Zinc Big Hole	Gravel Pack Oil Producer	24°	Est 150	8.8# Filtered Sea Water	700 psi UB
2	Shoot and Pull TCP	Zinc Deep Penetrator	Salt Water Disposal Well	0°	105	9.0# Lease Salt Water	300 psi UB
3	Shoot and Drop TCP	Zinc Deep Penetrator	Natural Completion Gas Well	35°	240	11.6# CaCl2	1,500 psi UB
4a	Shoot and Pull TCP	Zinc Big Hole	DW Frac Pack Oil Producer, Lower Zone	54°	195	12.7 # CaCl2/CaBr	200 psi Overbalanced
4b	Shoot and Pull TCP	Zinc Big Hole	DW Frac Pack Oil Producer, Upper Zone	54°	185	13.0 # CaCl2/CaBr	200 psi Overbalanced

Conclusions

- Perforating debris can create mechanical risks during completion operations, and formation damage risk during production.
- Understanding not only the amount of debris, but the nature of the debris is critical to decision making for the perforated completion.
- Debris particle size dictates the ability or effectiveness to remove (circulate/flow) debris from the well.
- Sometimes the potential risk associated with NPT due to steel debris may counter any performance advantage of steel over zinc charges.
- The fine nature of zinc debris makes it critical to properly design the job through use of perforation clean-up techniques, completion fluid selection, potential use of acids/inhibitors, and operational recommended practices to ensure successful application and realize the benefits of using zinc-cased charges.

QUESTIONS? THANK YOU!