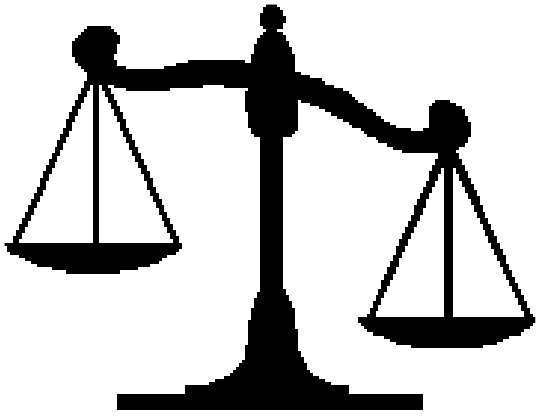
Completion Brine Challenges for HTHP Applications

BAKER HUGHES

Presentation Overview

1. **Brine Fluids & Properties**
2. **Displacement of Drilling Fluid**
3. **Brine Compatibility**
4. **Fluid Loss Control**
5. **Packer Fluids**
6. **Safety**



Presentation Overview

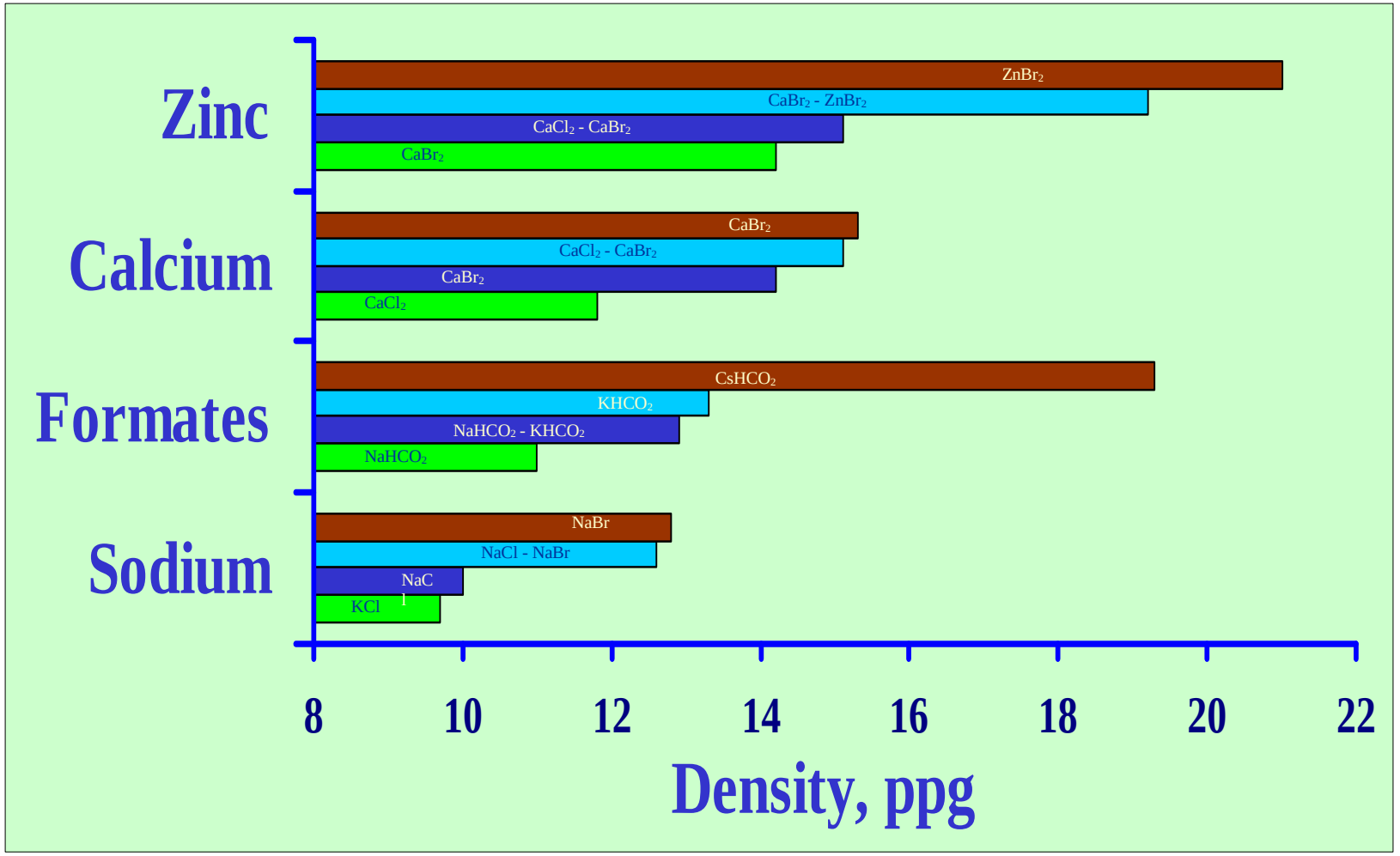
6. Safety

Very important topic

Detailed considerations required

Subject for another discussion

Completion and Workover Brine



Are Crystallization Temperatures Important ?

Completion & Workover Fluids

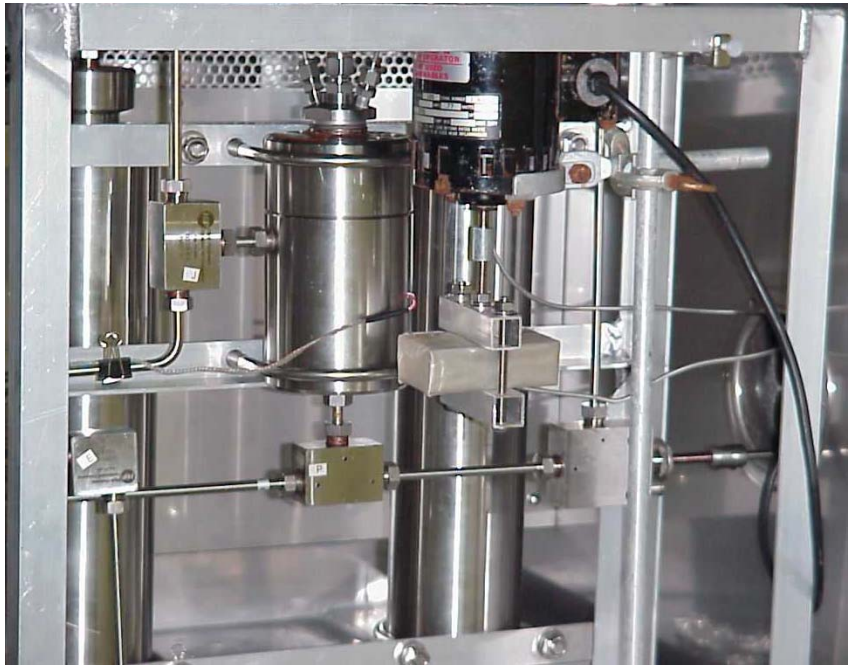
Density (ppg)*	$CaCl_2$ (wt %)	$CaBr_2$ (wt %)	TCT (^{O}F/^{O}C)	
*1.50 g/cc				
12.5	34.40	10.80	60	15.6
12.5	32.20	13.13	44	6.7
12.5	22.84	20.55	15	-9.4
12.5	00.00	41.55	-33	-36.1

PCT Testing Apparatus

Environmental Chamber

Temperature to - 40°F

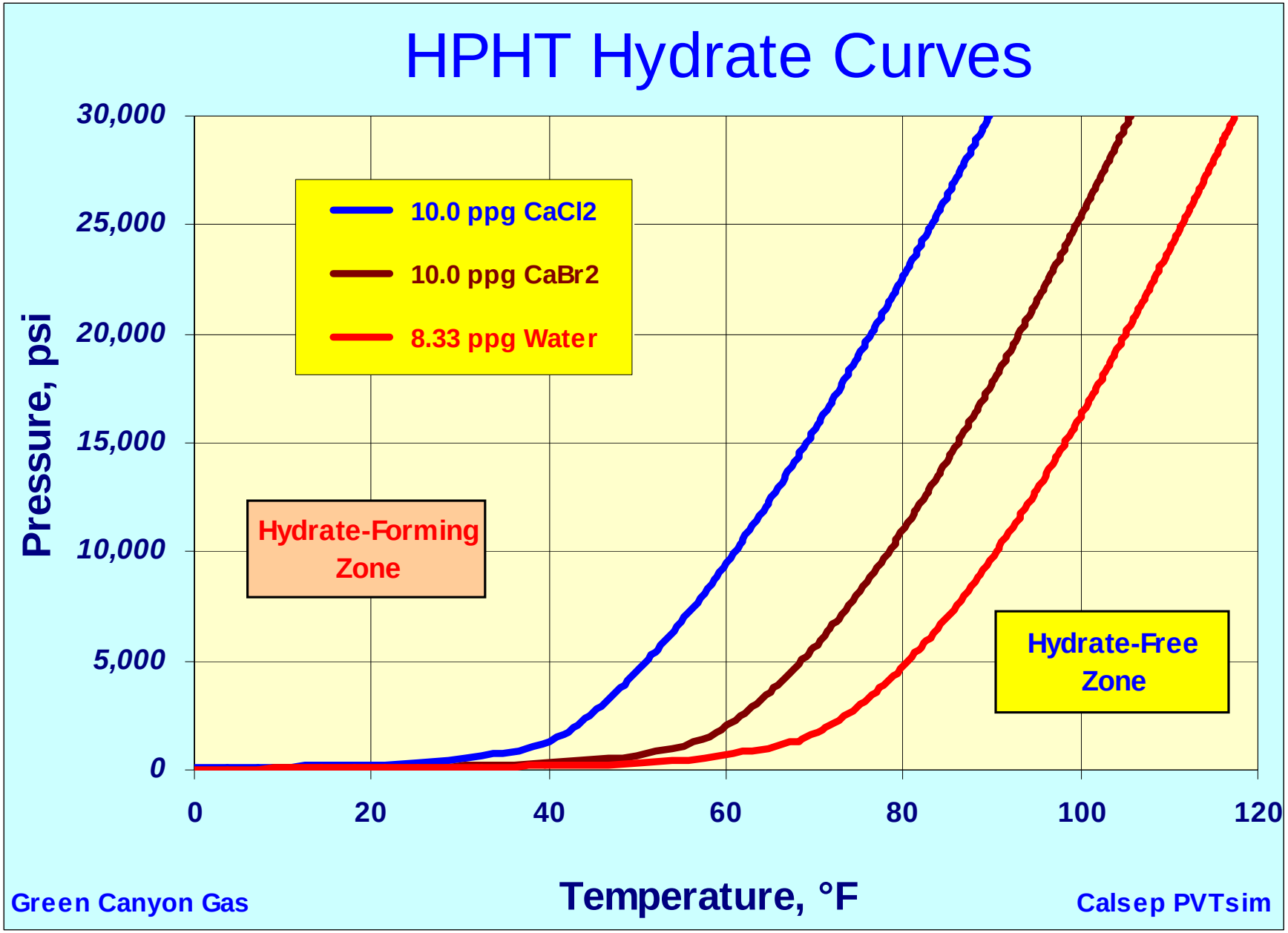
- Dual Piston Pumps
- Rated 20,000+ psi



Optical View Cell

Rated to 20,000 psi

HPHT Hydrate Curves



PCT *versus* Hydrate Potential

Density (ppg)* *1.50 g/cc	$CaCl_2$ (wt %)	$CaBr_2$ (wt %)	TCT (^{O}F	^{O}C)
12.5	34.40	10.80	60	15.6
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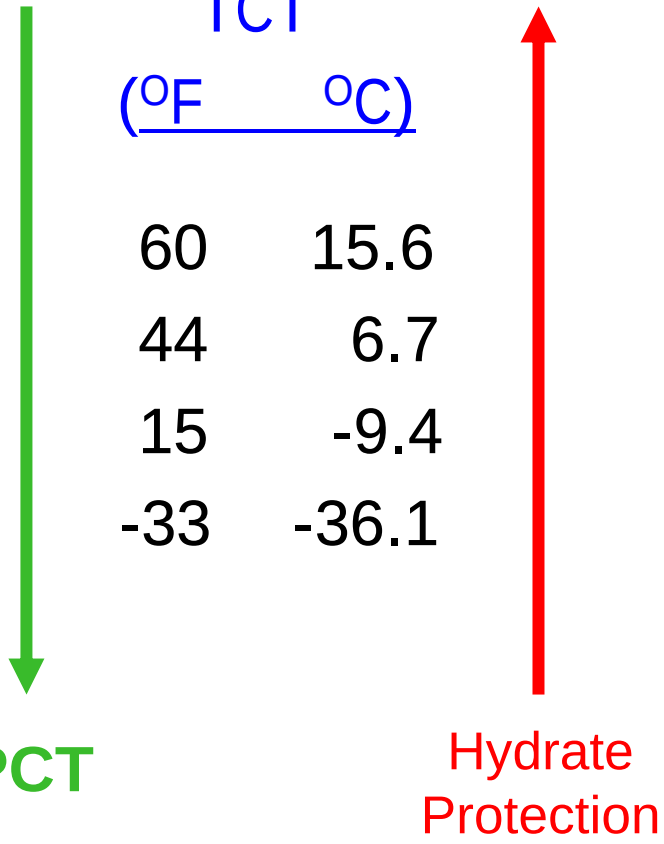


Density Correction Calculation

$$D_{(C)} = D_{(M)} * [1 + V_e (T_{(M)} - T_{(C)})]$$

$D_{(M)}$ = 16.4 ppg @ 85^{O}F $D_{(C)}$ = ? @ 60^{O}F $V_{(e)} = 2.52 * 10^{-4}$

$$D_{(60)} = 16.4 * [1 + 2.52 * 10^{-4} (85 - 60)]$$

$$D_{(60)} = 16.4 * [1.0063] = 16.5 \text{ ppg}$$

V_e (* 10^4)	Density (ppg)	Brine
2.80	12.0	NaBr
2.39	11.5	$CaCl_2$
2.50	15.0	$CaBr_2/CaCl_2$
2.54	17.5	$ZnBr_2/CaBr_2/CaCl_2$
2.71	18.5	$ZnBr_2/CaBr_2/CaCl_2$
2.78	19.0	$ZnBr_2/CaBr_2/CaCl_2$

Wellbore Pressure Profile

Well Parameters

18,000 TVD, feet
370 BHT, °F
16,000 BHP, psi
300 Overbalance, psi
70 Surface Temperature, °F

Surface Density Required, ppg = ?
Average Brine Density, ppg = ?
Bottom Hole Density, ppg = ?

Wellbore Pressure Profile

Depth - ft	Temp - °F	Density - ppg	Δp - psi	Total - psi
0	70.0	17.52	0.0	0
720	82.0	17.48	654.0	654
1,440	94.0	17.45	652.8	1,307
2,160	106.0	17.42	651.6	1,958
2,880	118.0	17.39	650.4	2,609
3,600	130.0	17.36	649.2	3,258
4,320	142.0	17.32	648.0	3,906
5,040	154.0	17.29	646.8	4,553
5,760	166.0	17.26	645.6	5,198
6,480	178.0	17.23	644.4	5,843
7,200	190.0	17.20	643.3	6,486
7,920	202.0	17.17	642.1	7,128
8,640	214.0	17.13	640.9	7,769
9,360	226.0	17.10	639.7	8,409
10,080	238.0	17.07	638.5	9,047
10,800	250.0	17.04	637.3	9,684
11,520	262.0	17.01	636.1	10,320
12,240	274.0	16.97	634.9	10,955
12,960	286.0	16.94	633.7	11,589
13,680	298.0	16.91	632.5	12,221
14,400	310.0	16.88	631.2	12,853
15,120	322.0	16.84	630.0	13,483
15,840	334.0	16.81	628.8	14,112
16,560	346.0	16.78	627.6	14,739
17,280	358.0	16.75	626.4	15,366
18,000	370.0	16.71	625.2	15,991

Hydrostatic Pressure at 18,000 feet
15,991 psi

Average Fluid Density in Wellbore
17.10 ppg

Surface Density at 70°F
17.52 ppg (17.5)

Density at 60°F
17.56 ppg (17.6)

Wellbore Pressure Profile

Zero *vs* 300 psi Overbalance

Hydrostatic Pressure at 18,000 feet **15,991 psi**	**Hydrostatic Pressure at 18,000 feet** **16,291 psi**
Average Fluid Density in Wellbore **17.10 ppg**	**Average Fluid Density in Wellbore** **17.42 ppg**
Surface Density at 70°F **17.52 ppg (17.5)**	**Surface Density at 70°F** **17.84 ppg (17.8)**
Density at 60°F **17.56 ppg (17.6)**	**Density at 60°F** **17.89 ppg (17.9)**

Temperature - Pressure Factors

12,000 psi from 76°F to 345°F — 827 bars from 24°C to 174°C [1]

198°F from 2,000 psi to 12,000 psi — 92°C from 138 bars to 827 bars [1]

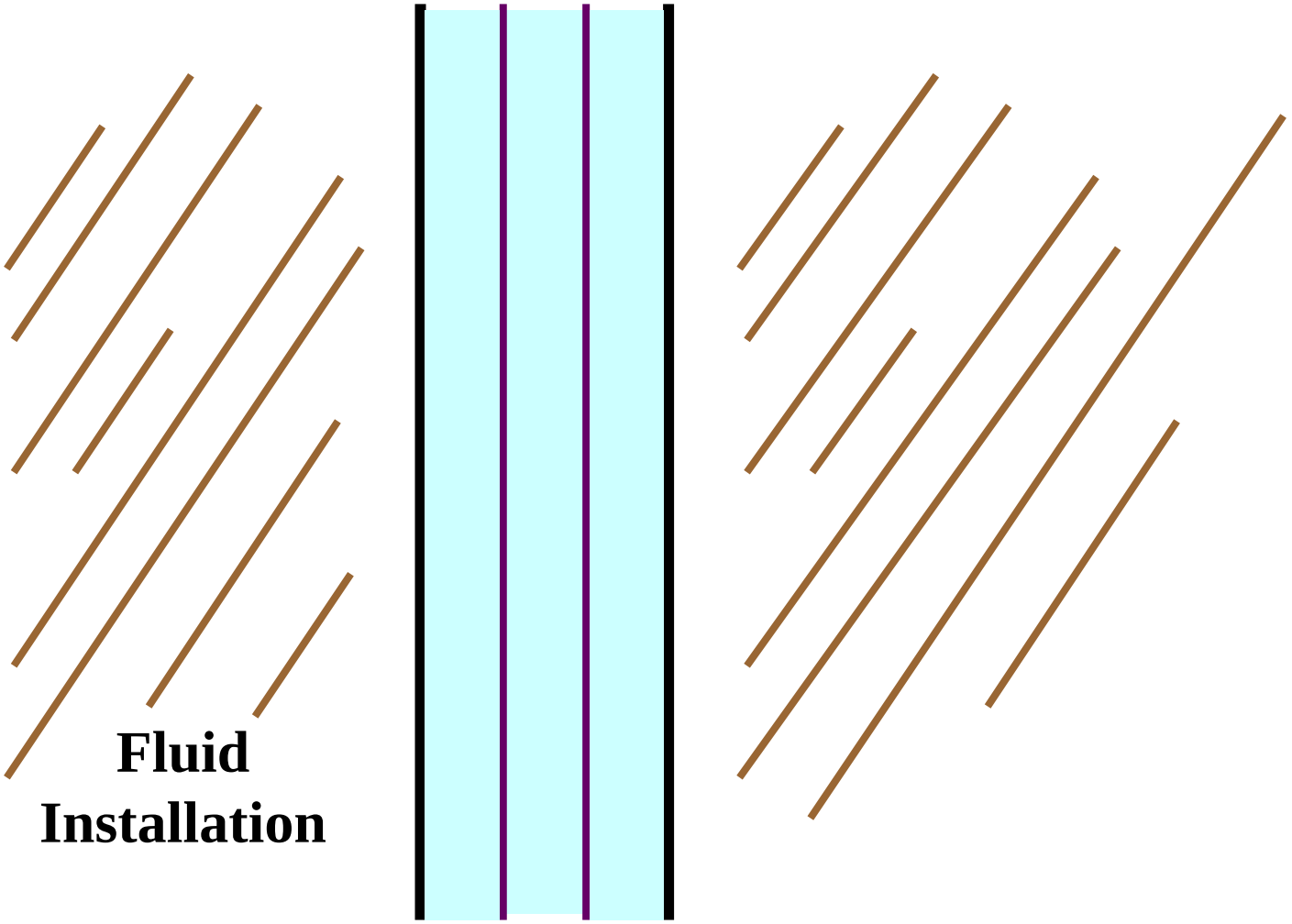
Brine	Density (lb/gal)	Expansion Factors		Compressibility Factors	
		$a * 10^4$ vol/vol/°F	A lb/gal/100°F	$b * 10^6$ vol/vol/psi	B lb/gal/1000 psi
NaCl	9.42	2.54	0.24	1.98	0.019
$CaCl_2$	11.45	2.39	0.27	1.50	0.017
NaBr	12.48	2.67	0.33	1.67	0.021
$CaBr_2$	14.30	2.33	0.33	1.53	0.022
Three Salt [2]	16.01	2.27	0.36	1.39	0.022
Two Salt [3]	19.27	2.54	0.48	1.64	0.031

[1] SPE 12490 Krook & Boyce

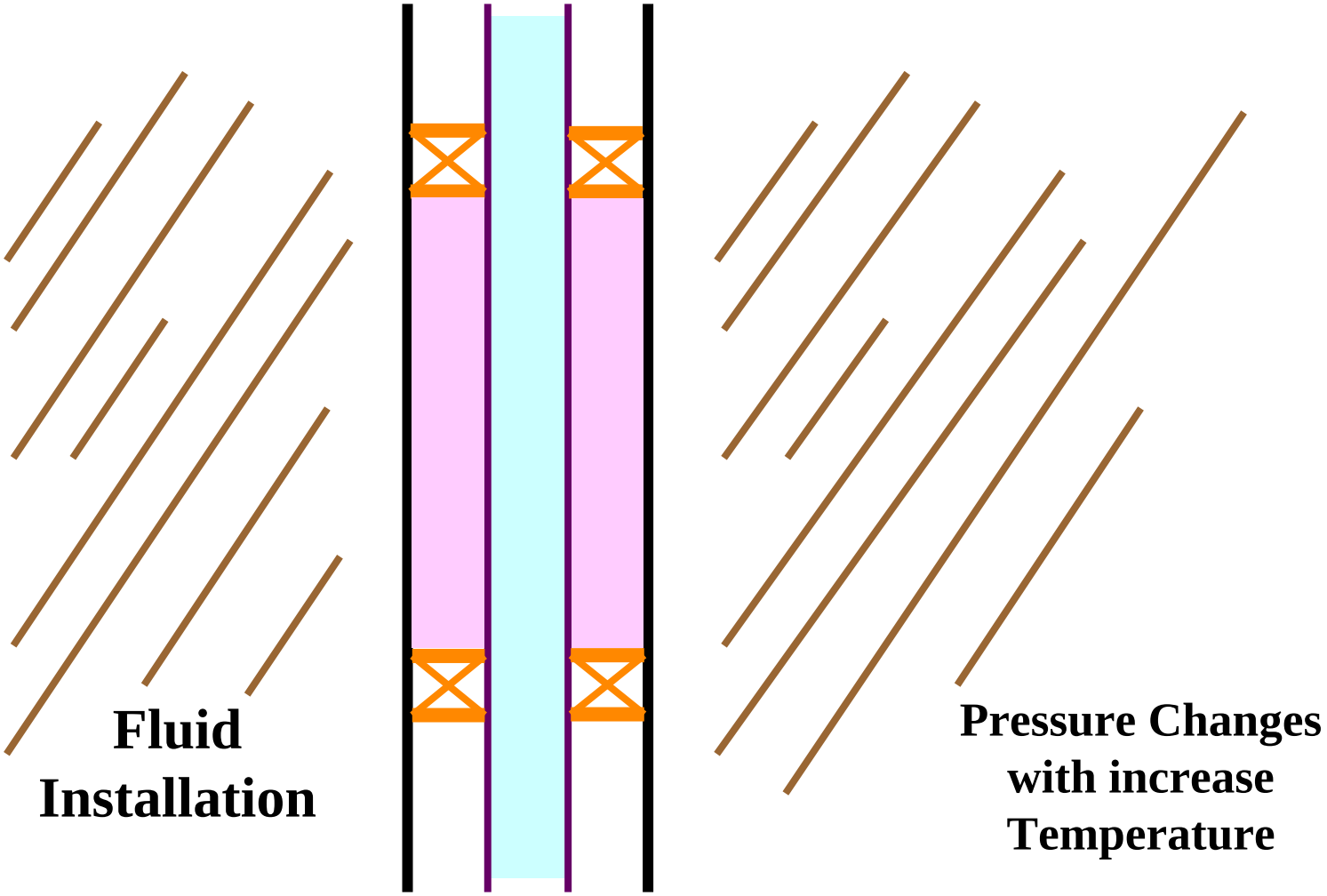
[2] Three Salt = $ZnBr_2/CaBr_2/CaCl_2$

[3] Two Salt = $ZnBr_2/CaBr_2$

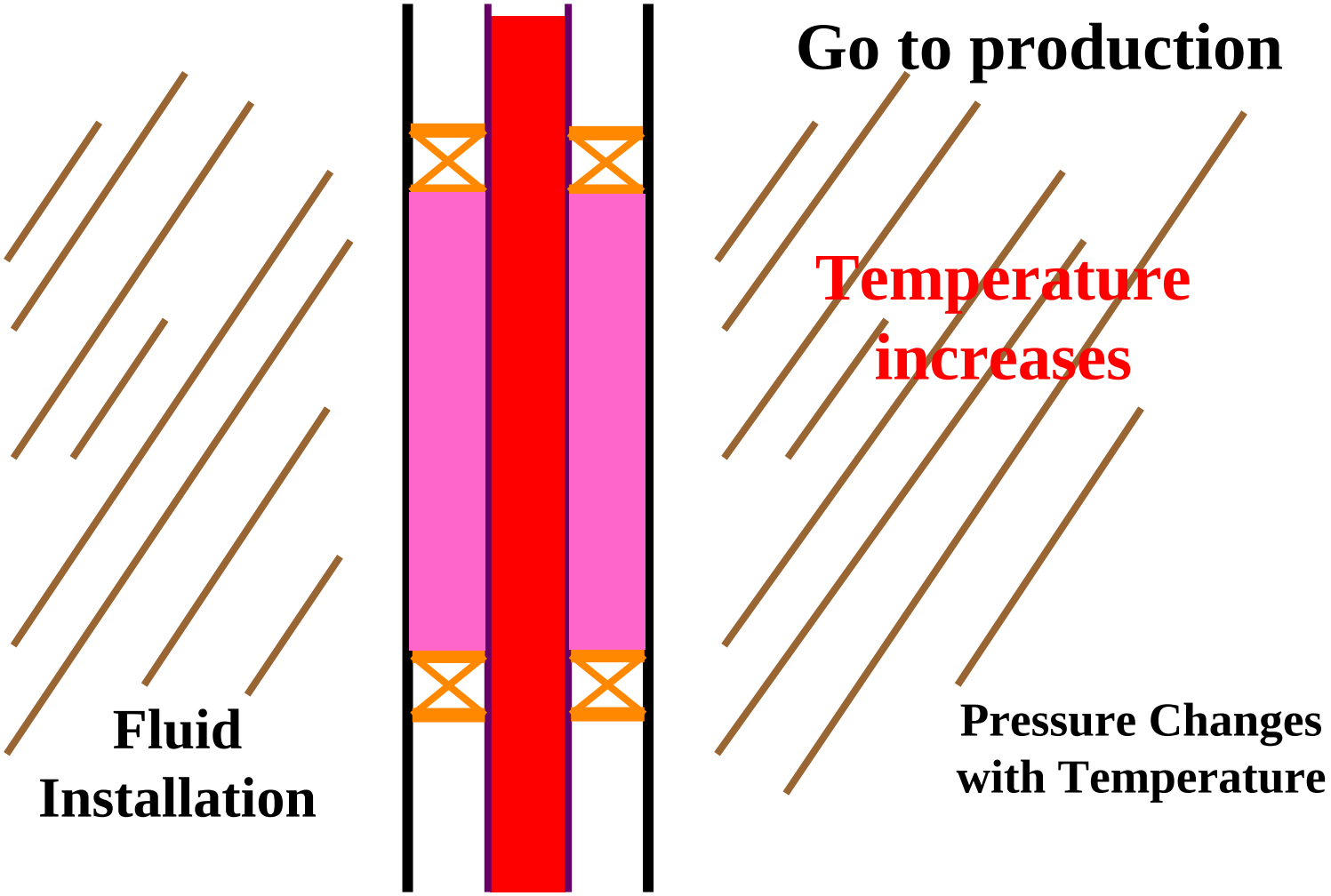
Trapped Annular Fluid



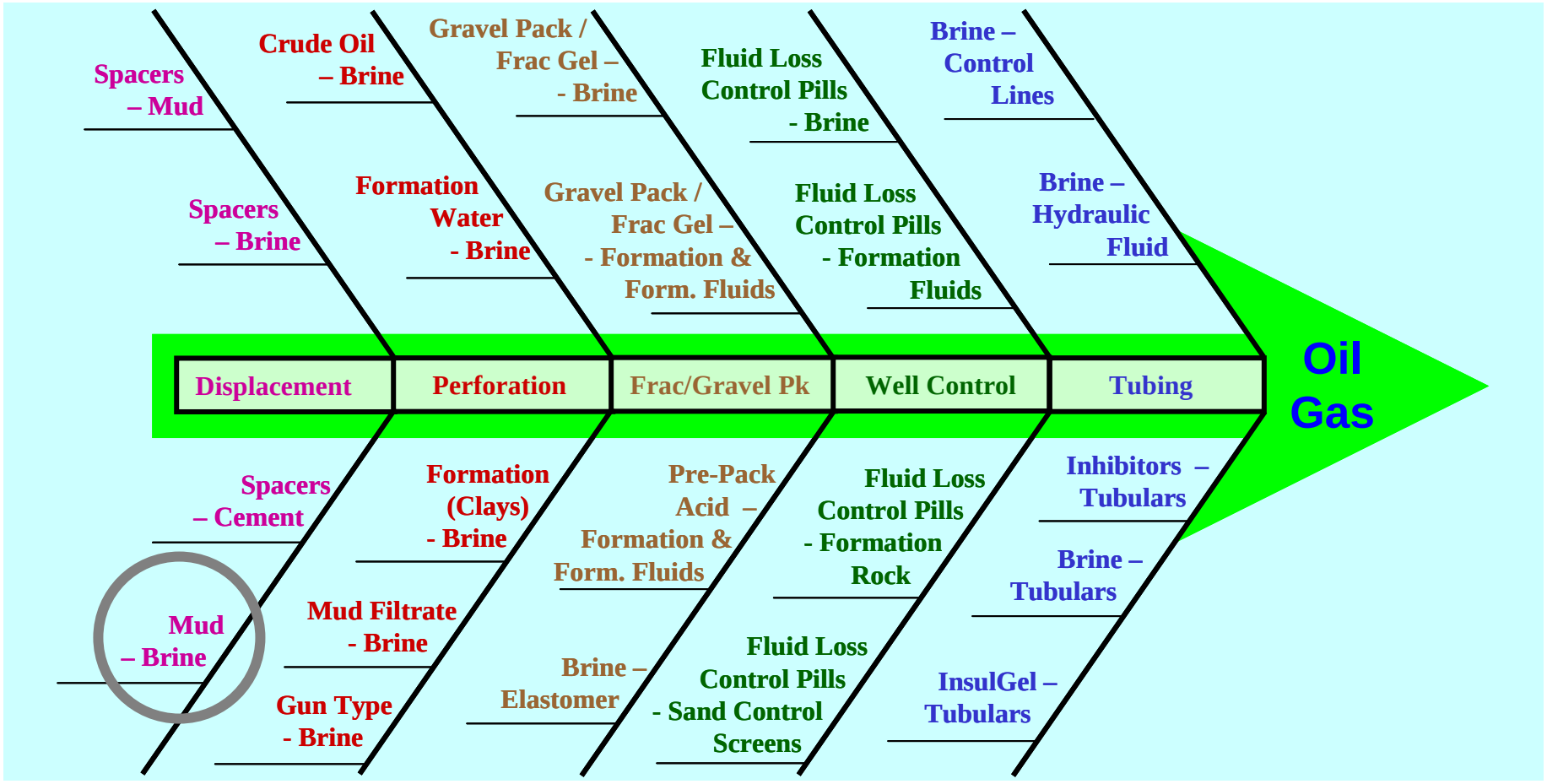
Trapped Annular Fluid



Trapped Annular Fluid



Fishbone Diagram



After Syed Ali, Chevron

CLEANUP (TM) - Input Window

File Calculate Utilities Table Language Help

General
Operation
Survey
Pore/Frac
Wellbore
Pipe
Native fluids
Pumping fluids
Open hole OP
Deep water I
Deep water II

Operation:

○ **Conventional**

Flow direction:
- ◉ Forward
- ○ Reverse

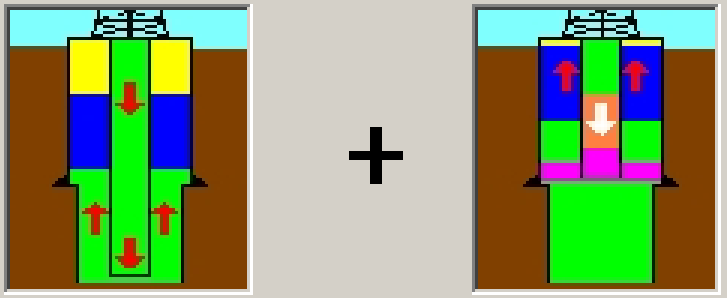
Back pressure:
- ◉ No back pressure
- ○ Manual input
- ○ Automatically calculated (no free-fall)
- ○ Well control, mantain BH p. [...]

Depth	0.	(ft)
Desired mini. press.	0	(psi)

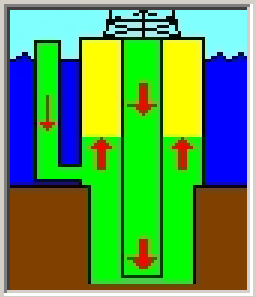
	Job Time (min)	Back Pressure (psi)
1	0.0	0
2		
3		
4		
5		
6		

Insert Delete Clear all

◉ **Open hole completion**



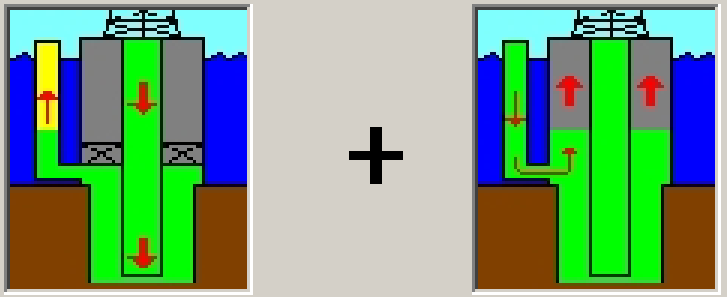
○ **Deep water operations - operation 1**



For deep water applications:

Riser MD	2000.	(ft)
Choke line ID	2.000	(in)
Kill line ID	2.000	(in)
Boost line ID	5.000	(in)

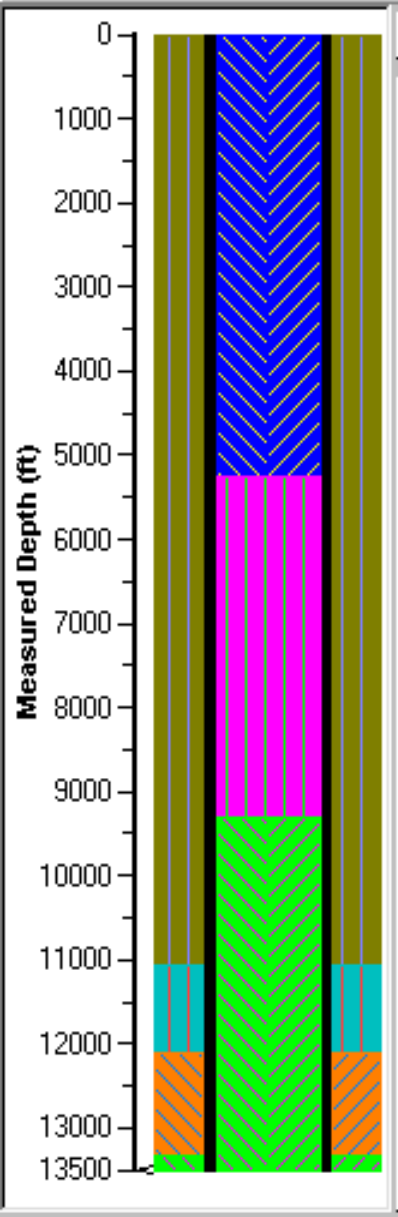
○ **Deep water operations - operation 2**



C:\Gefei\Open Hole Completion Case.DP3 12:21 PM

CLEANUP (TM) - Displacement Simulation

Close Wellbore Table



55.8 (min)

Summary | Press profiles | Rates | Pump P | ECD @ TD | ECD @ Zone

Simulation speed:

(•) Slow ( ) Medium ( ) Fast

Key output:

Parameters	Value	Unit
Elapsed time	55.8	(min)
Fluid Vol.	159.0	(bbl)
Pump stroke #	795	
Rate in	4.00	(bpm)
Rate out	4.00	(bpm)
Pump Press	6266	(psi)
Choke Press	0	(psi)
Pump HP	614.	(HP)
Hydrostatic p. @ 13500.(ft	11193	(psi)
Total p. @ 13500.(ft)	11779	(psi)
ECD @ 13500.(ft)	16.78	(ppg)
Hydrostatic p. @ 13500.(ft	11193	(psi)
Total p. @ 13500.(ft)	11779	(psi)
ECD @ 13500.(ft)	16.78	(ppg)
Free fall	0.	(ft)
Trace Fluid	-11065.	(ft)

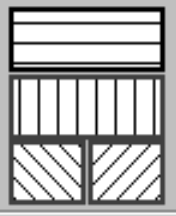
Flow pattern display:

[x] Show flow pattern

Plug flow

Laminar flow

Turbulent flow



	Fluid	Density (ppg)	Vol. in (bbl)	Edge (ft)
1	16.8 WBM	16.80	N/A	- 0
2	17.0 Barite Spa	17.00	25.0	-11065.
3	Spacer I (Caus	8.40	30.0	-12100.
4	Spacer II WW	8.40	35.0	-13340.
5	Spacer III Vis	8.50	30.0	9304.
6	10.0 Packer Fl	10.00	39.0	5262.
7	Free fall	N/A	N/A	N/A

Displacement Considerations

Displacement Spacers

Size and weight of each spacer

Depth of well & circulation time

Spacer effective at BHT ?

Effective when contaminated with mud ?

How much mud contamination can be tolerated ?

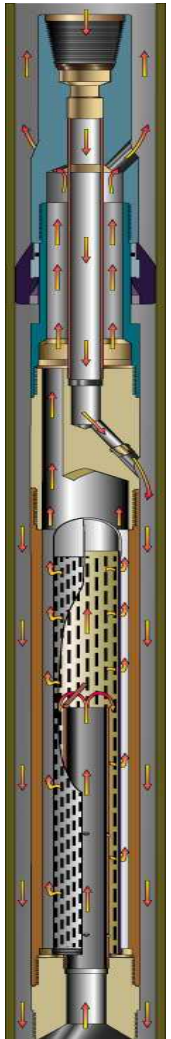
Weighted Displacement System *Field Example*

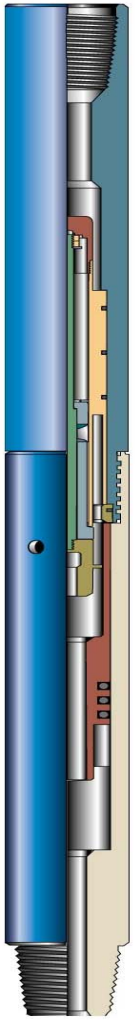
Spacer	Volume, bbl	Comments
Base Oil	75	Separate mud from cleaning fluids
17.5 ppg Barite	50	Barrier spacer, offset density of base oil
12.0 ppg Barite	300	Improve hydraulics (563 bbl WS, 5-7/8"x4-1/2"), cost for SOBM or WBM
12.0 ppg HD-WCF Type 1	125	Based on $CaBr_2$ Brine
12.0 ppg HD-WCF Type 2	125	Based on $CaBr_2$ Brine
12.0 ppg Viscous Pill	100	Separate spacer train from the 10.5 ppg $CaBr_2$ completion brine
Brine		10.5 ppg $CaBr_2$ completion brine

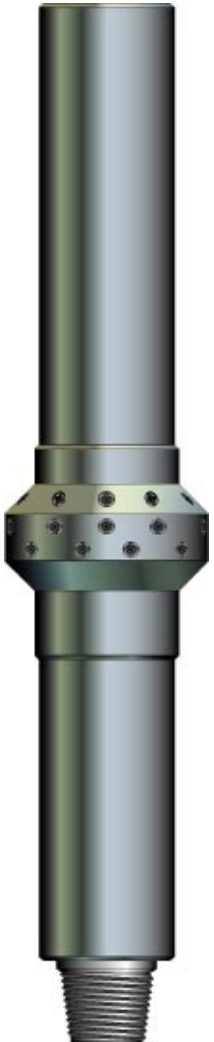
SPE 99158

Wellbore Cleaning Tools

Enhancements to clean wellbores

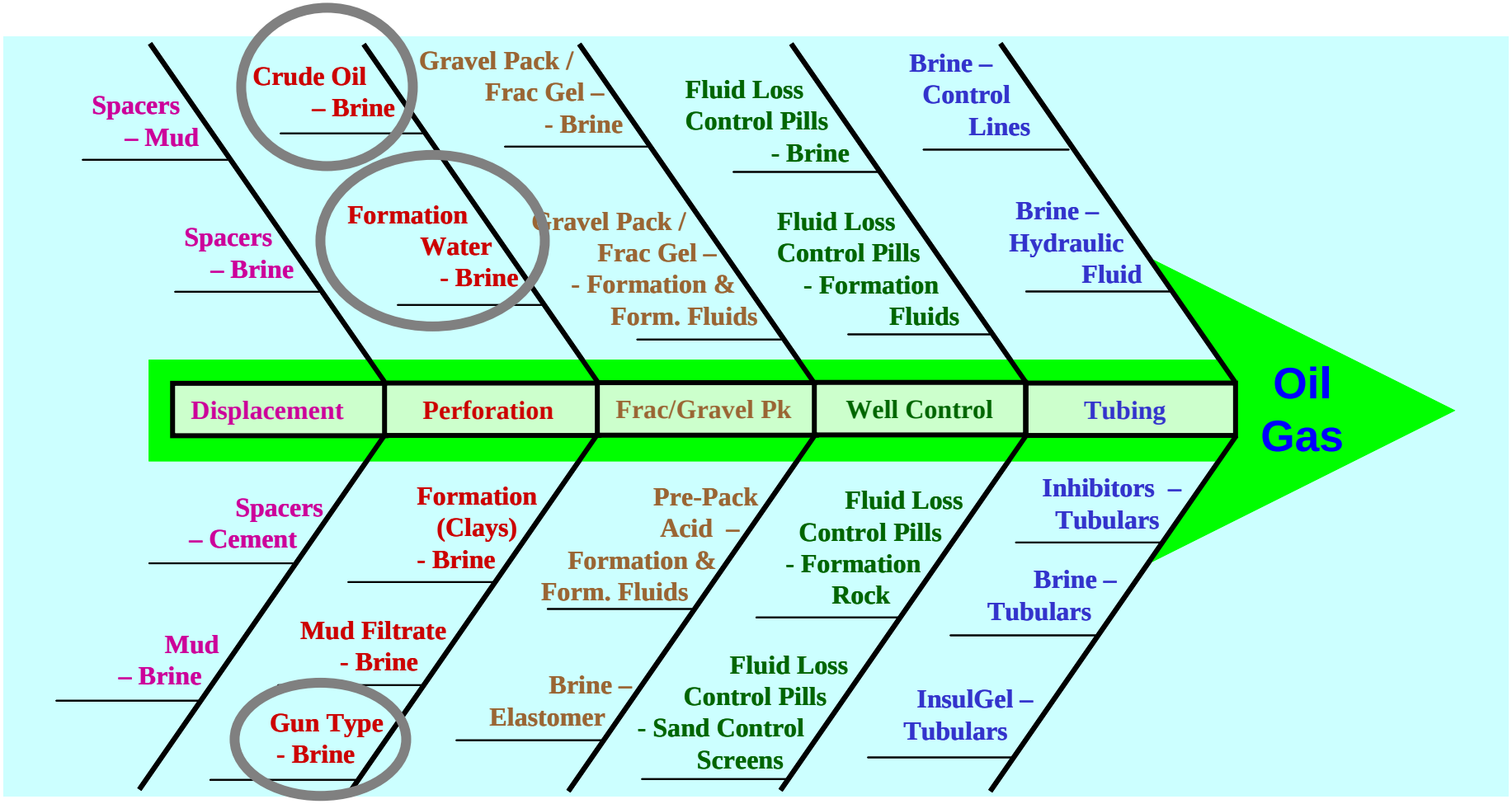






Surface Filtration Equipment

Fishbone Matrix



After Syed Ali, Chevron

Formation Oil Compatibility

Surfactants in High Density Brine

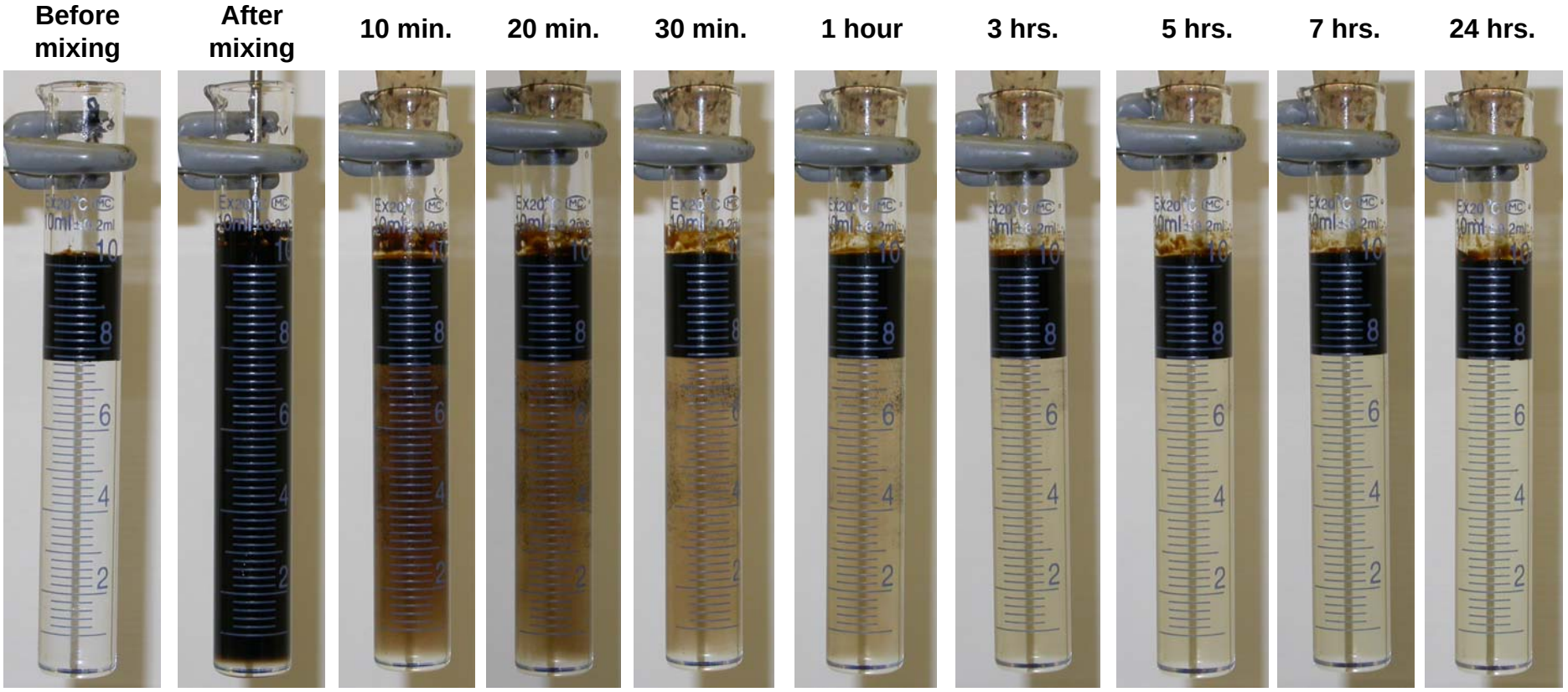
Blank Surf 1 Surf 2 Surf 3 Surf 4 Surf 5 Surf 6 HyPerm NoMul

Non-Emulsifying Surfactant Technology

Mini Oil-Compatibility Test Method

Crude Oils (6-15% wax & 4-14% asphaltene) / 15.4ppg Brine

(inhibited + non-emulsifier) @ 180ºF



Formation Water Compatibility

15.4 ppg Cesium Formate Optimized Formulation #2 Formation Water @ 70°F	Significant amount of settled solids	Significant amount of settled solids	Clear
15.4 ppg Cesium Formate Optimized Formulation #2 Formation Water @ 180°F	Significant amount of settled solids	Significant amount of settled solids	Clear
15.6 ppg Zinc-Based Brine Formation Water @ 70°F	Clear	Clear	Clear
15.6 ppg Zinc-Based Brine Formation Water @ 180°F	Clear	Clear	Clear

Principle Characteristics	Concentration, mg/L
Chloride	147,000
Bi-Carbonate	470
Sulfate	200
Sodium	90,600
Potassium	500
Calcium	8,930
Magnesium	1,500
Barium	208
Strontium	215
pH	7.33

SPE 103209

Downhole Debris

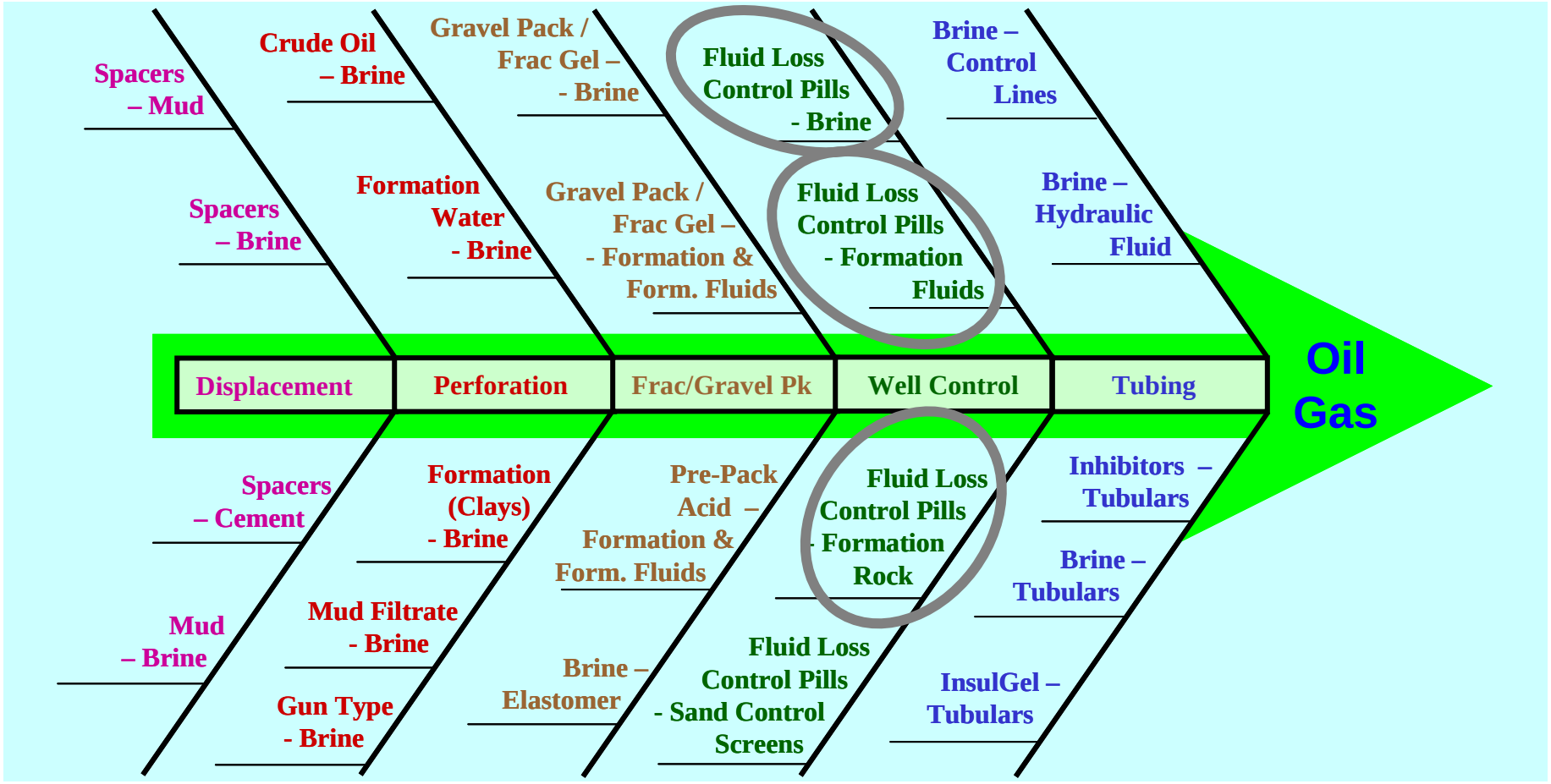
Case History #4

Packer Plug
Retrieval Tool

SPE 112479

$$Zn_5(OH)_8Br_2 \cdot H_2O$$

Fishbone Matrix



After Syed Ali, Chevron

Darcy's Law: Linear Flow

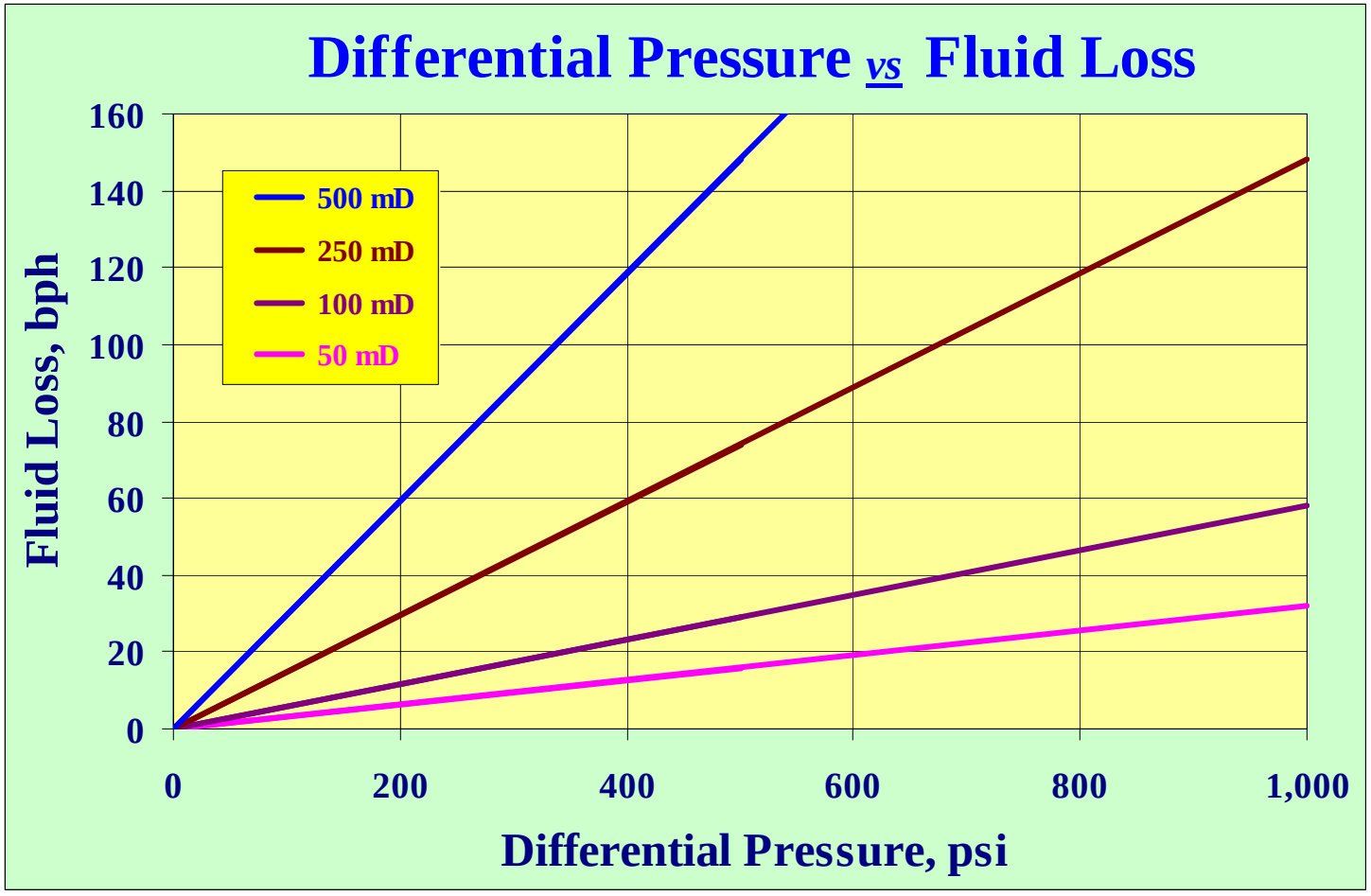
$$Q = [\, K\, A\, (p_e - p_{wf}) \,] \,/\, [\, \mu\, L \,]$$

Where:

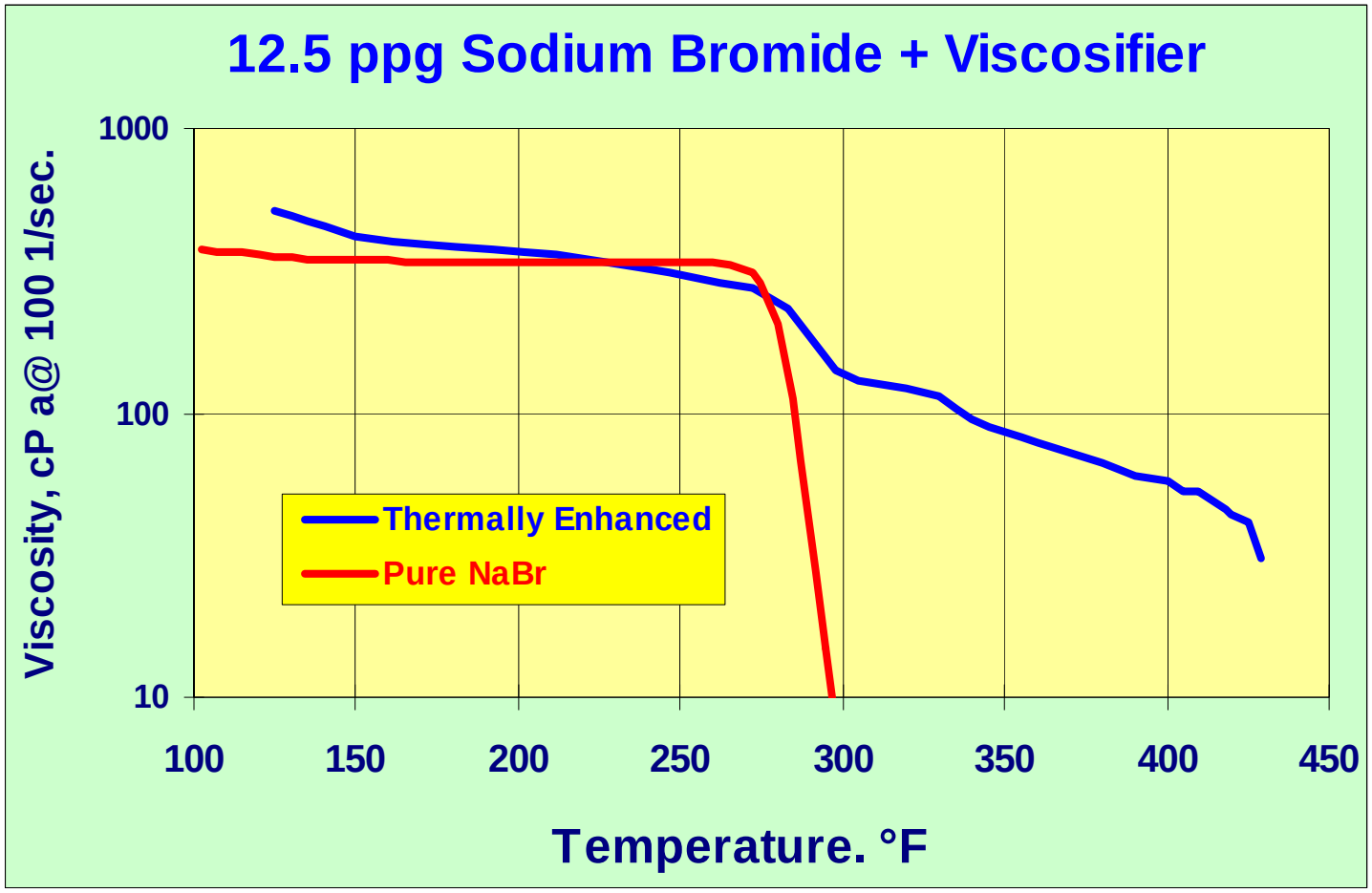
Q = Production rate in liters/sec
K = Permeability, mD
P_e = Reservoir pressure, atm
P_{wf} = Flowing wellbore pressure, atm
μ = Viscosity in cP
A = Surface area in cm^2
L = Length in cm

Radial Flow: $Q = 7.082\, K\, H\, (P_e - P_{wf}) \,/\, [\beta\, \mu\, (\ln (r_e/r_w)) + S]$

Effect of Differential Pressure



Non-Cross-Linked Solids-Free Fluid Loss Control Pills



Sized Solid FLC Materials

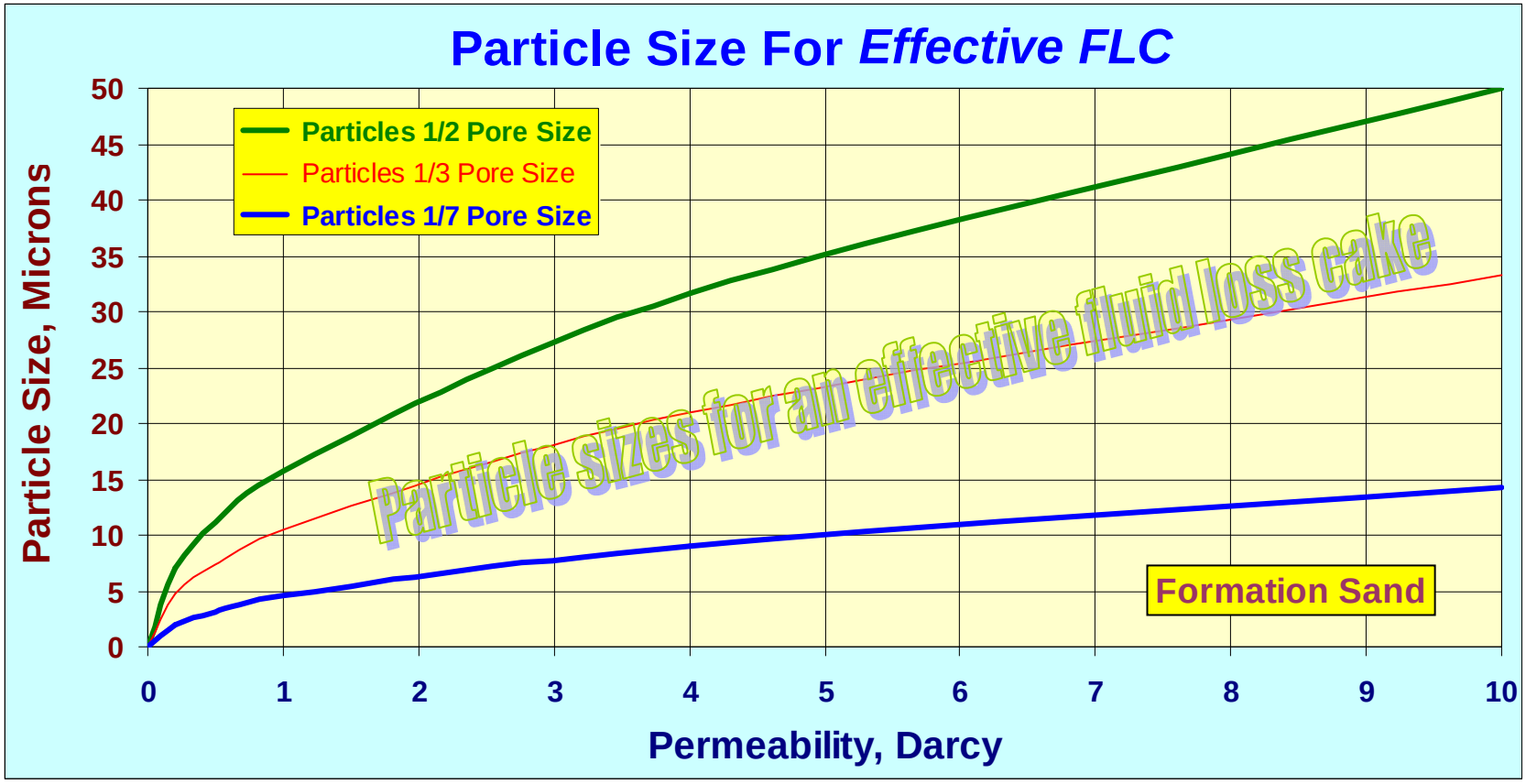
Calcium Carbonate, $CaCO_3$

Salt, NaCl

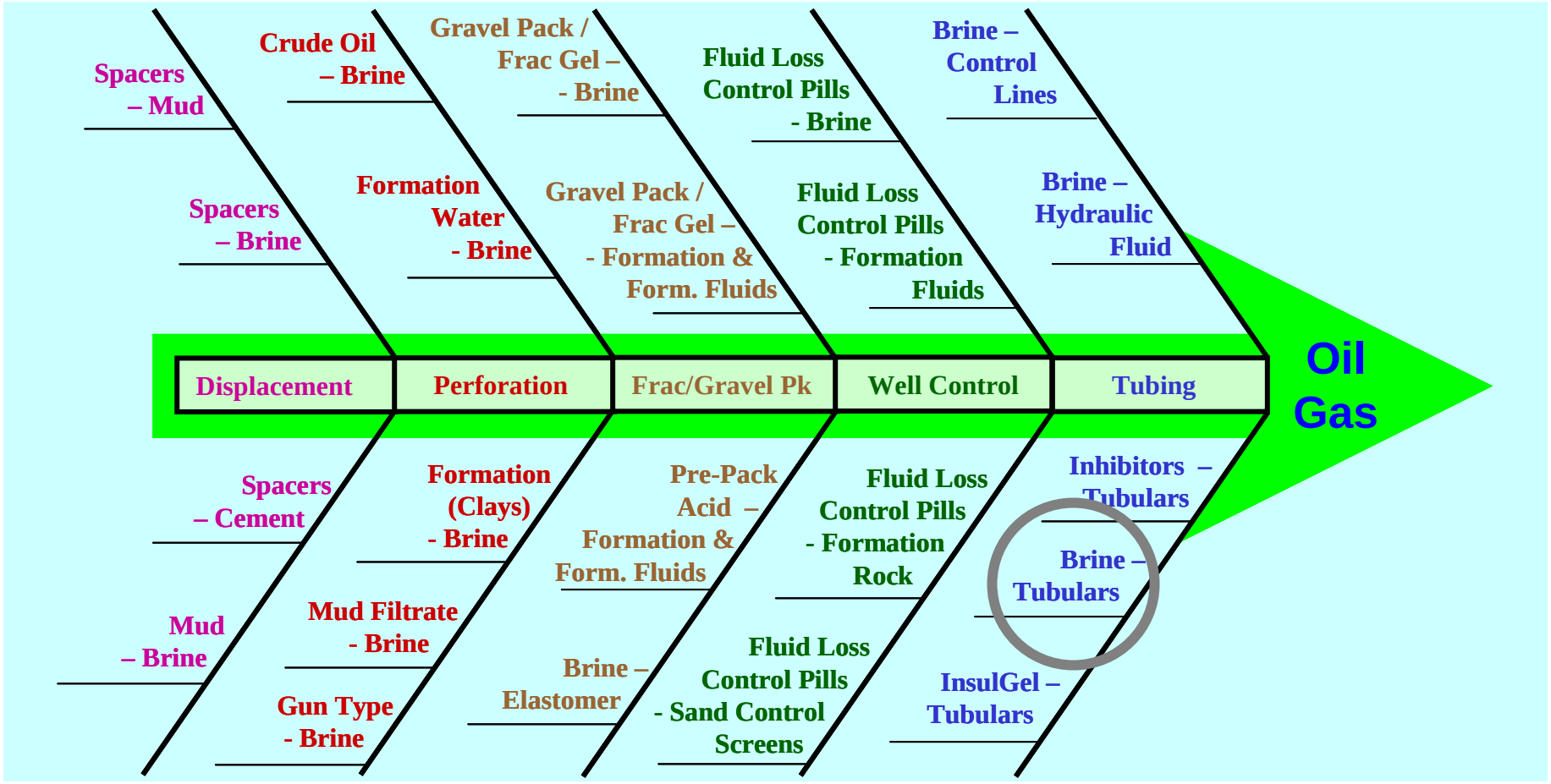
Oil Soluble Resins

Solid Bridging Materials

Against Formations



Fishbone Matrix



After Syed Ali, Chevron

Brine Corrosion Rates

N-80 Steel, 30 Days, MPY, No Inhibitor

Brine Type	Density (ppg)	70°F	150°F	250°F	300°F	350°F
NaCl	10.0	0.5	1.5	0.2	0.1	0.1
NaCl/NaBr	11.2	0.4	0.7	0.1	0.1	0.1
NaBr	12.4	0.3	0.4	0.1	0.1	0.1
$CaCl_2$	11.6	0.1	0.2	0.7	0.9	1.9
$CaCl_2/CaBr_2$	13.6	0.3	0.9	1.6	1.6	3.0
$CaCl_2/CaBr_2$	15.1	0.1	0.5	2.4	2.9	6.6

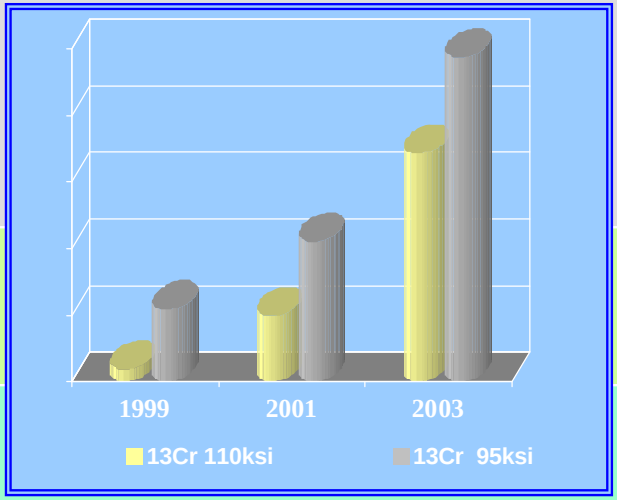
Corrosion Data, Zinc Based Brines

N-80 Steel, MPY, Inhibited with NaSCN

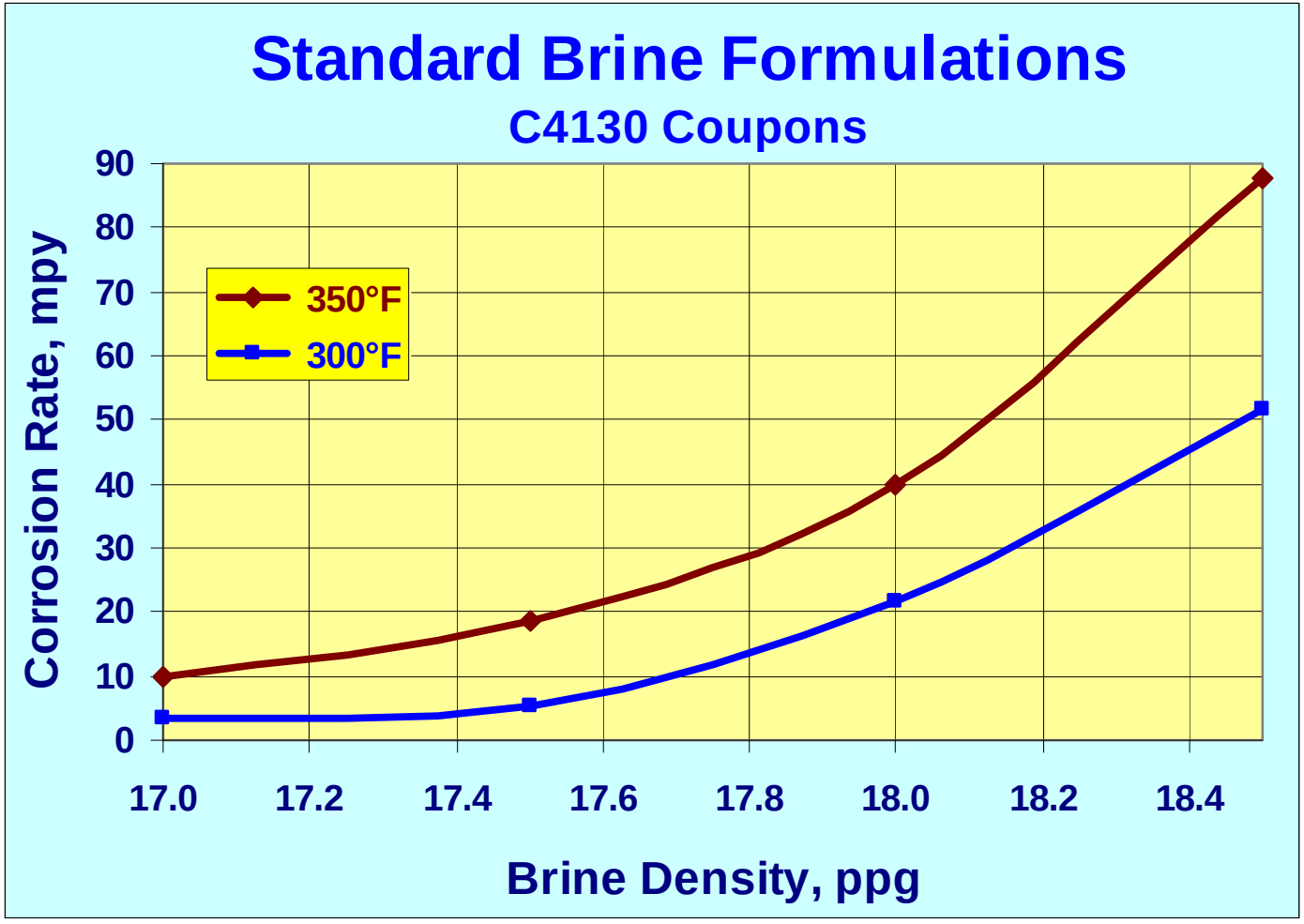
HyCal III Density (ppg)	250°F 30 Days	350°F 30 Days	400°F 180 Days
15.5	1.9	7.1	1.6
16.5	1.2	7.6	3.1
17.5	5.3	7.9	5.7
18.5	2.4	9.9	6.2

Casing & Tubular Applications

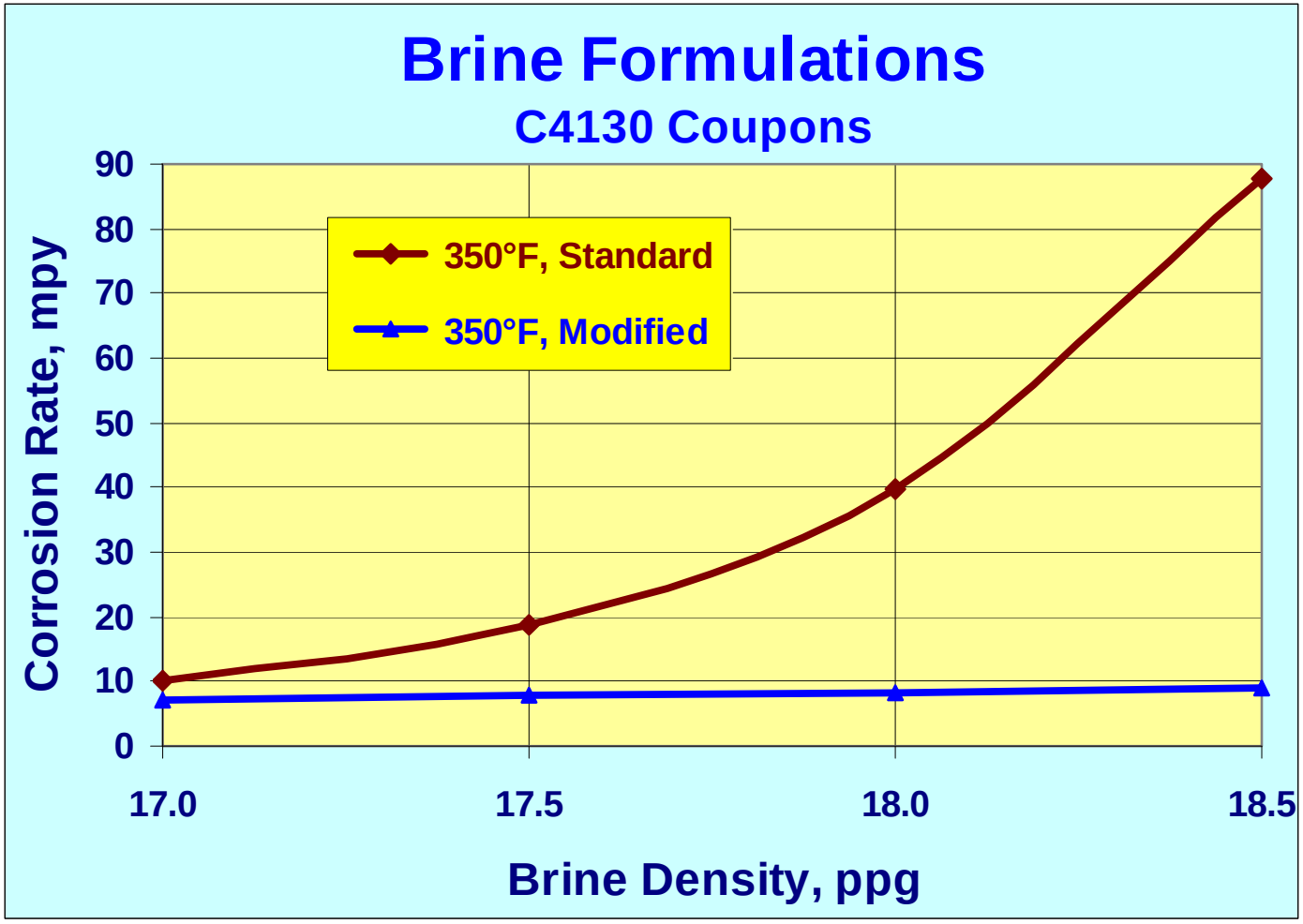
Mild Environment	J-55 N-80 P-110
SSC concerns (medium PSI & temp.)	L-80 C-90
SSC concerns (high PSI & temp.)	C-100 C-110
Wet CO_2	13% Chrome **&** 0-5% Ni **&** 0-2% Mo
Wet CO_2 & little H_2S	22-25% Chrome **&** 5-7% Ni **&** ~3% Mo
More Corrosive Environments	16-25% Chrome **&** 35-60% Ni **&** 3-16% Mo



Standard Uninhibited Zinc-Based Brines



Advancement for Zinc-Based Brines



Iron Pillar

On the outskirts of Delhi, this 7.3 meter high pillar was forged from a great number of hammered billets over 1,600 years ago.

It is 6.5 tons of 99.72% pure iron.

48 cm diameter tapers to 29 cm at the top.

It shows no sign of corrosion.

Iron Pillar

“Misawite", a compound of iron, oxygen and hydrogen, forms the protective shield.

Protective film has grown just one-twentieth of a millimeter thick.

Questions