AADE Houston Chapter Fluids Management Group Meeting

October 11, 2006

Update on Formate Fluids and Field Applications

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Specialty Fluids

Most abundant source of Pollucite, containing around 15 – 22% Cesium Oxide is found at Bernic Lake, Manitoba, Canada

- *Pollucite:-*
- *Originally discovered: 1846 - San Piero, Campo, Elba, Livorno Province, Tuscany, Italy*
- *Named after* Pollux*, a figure from Greek mythology, brother of Castor, for its common association with "Castorite" (petalite)*
- *Chemical makeup:* $Cs_{0.7}Na_{0.2}Rb_{0.04}Al_{0.9}Si_{2.1}O_6 \cdot (H_20)$
- *Found in many places including:*
  - Bikita, Masvingo, Zimbabwe
  - Shigar Mine, Skardu, Pakistan
  - Varuträsk, Västerbotten, Sweden
  - Kunar Province, Afghanistan
  - Oxford, Maine, USA
  - Ray Mica Mine, North Carolina, USA

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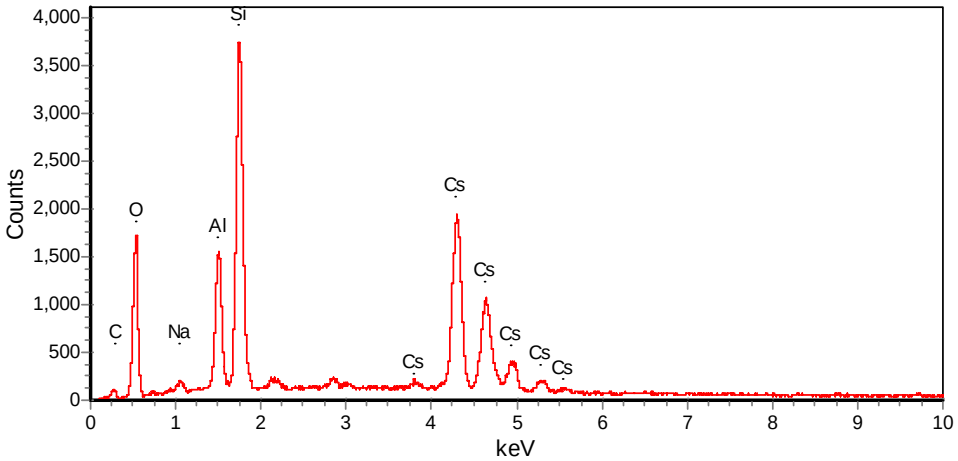
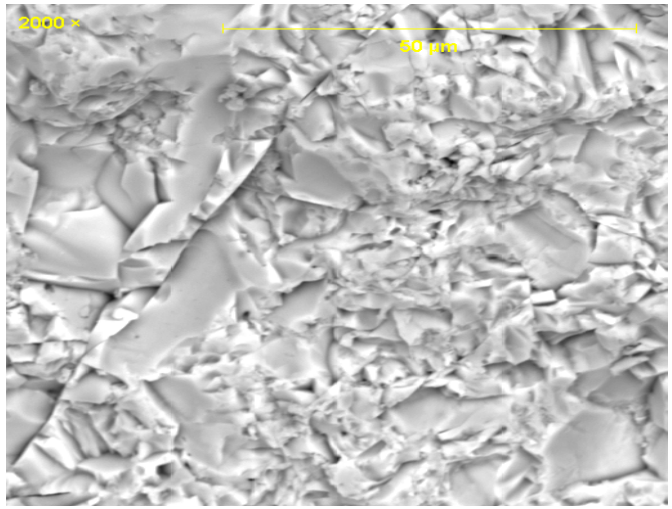
Specialty Fluids

Converting Cesium Oxide to Cesium Formate





- *Pollucite mineral is classified as a Pegmatite, a class of old volcanic hard rock where specialized machinery is used in the mining process.*
- *Pollucite is first mined by blasting and crushing. The crushed pollucite is then milled at surface.*
- *Cesium oxide is then extracted by digestion in sulphuric acid to form a cesium alum.*

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Specialty Fluids

Converting Cesium Oxide to Cesium Formate

- Cesium Alum is used as the base to manufacture the alkali metal salt - Cesium Formate - which has a saturation density of 2.3
- Cesium Formate is a high density, thermally stable, environmentally friendly heavy fluid used for:
  - Drilling, completing and workovers of high pressure high temperature (HPHT) oil and gas wells
  - Safely overcoming the hydrostatic pressure while drilling, completing, suspending or workovers
  - Minimizing formation damage while drilling to optimize productivity of hydrocarbons

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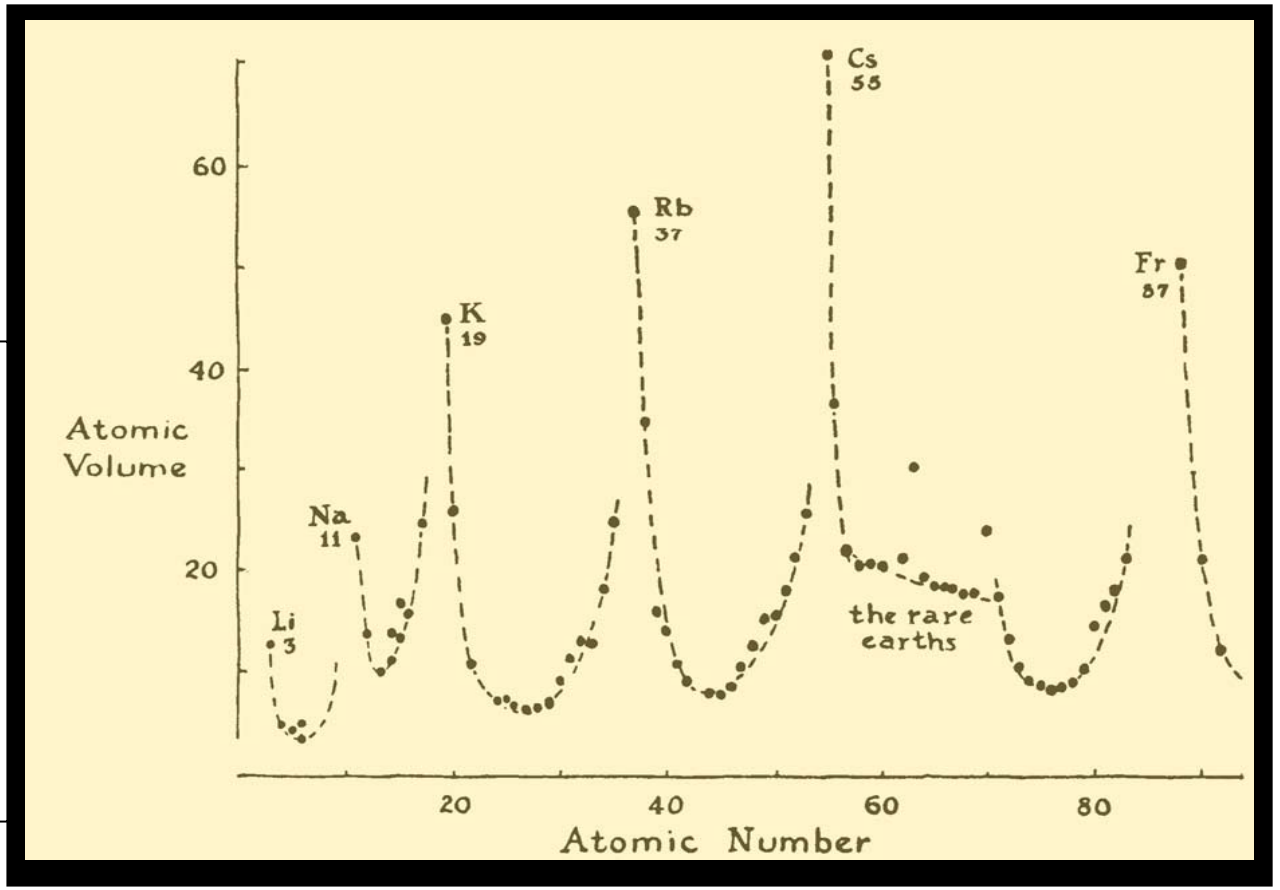
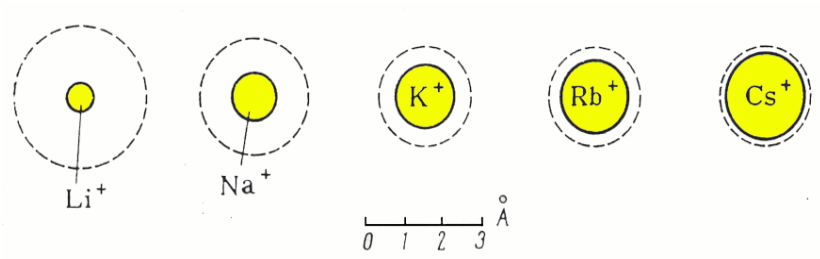
Specialty Fluids

Monovalent Ion Series

- *Li = Lithium*
- ***Na = Sodium***
- ***K = Potassium***
- *Rb = Rubidium*
- ***Cs = Cesium***
- *Fr = Francium*





= Hydration layer around ion

N.B. hydration layer decreases with increasing atomic number of ion

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Monovalent Ion Organic Alkali Metal Salts (Formate)

Cs+ / K+ / Na+

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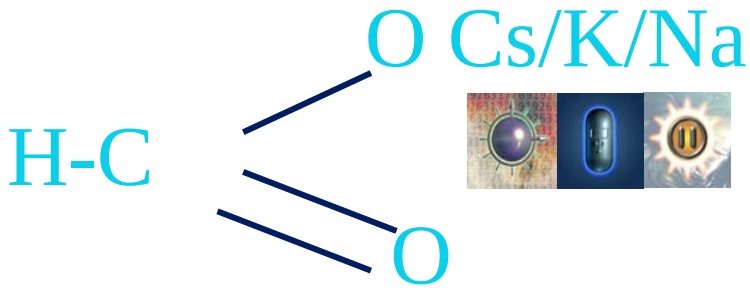
Specialty Fluids

Basic Properties and Attributes of Formate Fluids

Formate fluids and Cabot Specialty Fluids have an excellent HS&E record

- ***Saturated formate fluids:***
  - ***Na Formate 45% 10.8 ppg***
  - ***K Formate 75% 13.1 ppg***
  - ***Cs Formate 80% 19.2 ppg***
- ***Saturated formate fluids are polar ionic fluids***
  - ***Inherently low viscosity***
  - ***Biodegradable***
  - ***Environmentally benign***
  - ***Non-Toxic***
  - ***Non-Corrosive***
  - ***Non-Damaging***
  - ***Safe to handle, pH 9.0 – 10.5***
  - ***Protect polymers***
  - ***Reclaimable and recyclable***



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Specialty Fluids

Differences in basic properties between Formates and Halides

- ***Formates***
  - ***Monovalent***
  - ***Organic***
  - ***Bufferable***
  - ***More alkaline (pH 8 – 11)***
  - ***Densities up to 19.2 ppg***
  - ***Applicable to higher temperatures***
  - ***Solubility of polymers***
  - ***Biodegradable***
  - ***Less corrosive (wider AOE)***
  - ***Simple drill-in fluids***

- ***Halides***
  - ***Divalent***
  - ***Inorganic***
  - ***Unbufferable***
  - ***More acidic (pH 3 – 6)***
  - ***Densities up to 19.2 ppg***
  - ***Less applicable at higher temperatures***
  - ***Polymers less soluble***
  - ***Non-biodegradable***
  - ***More corrosive (Lesser AOE)***
  - ***Difficult to formulate drill-in fluids***

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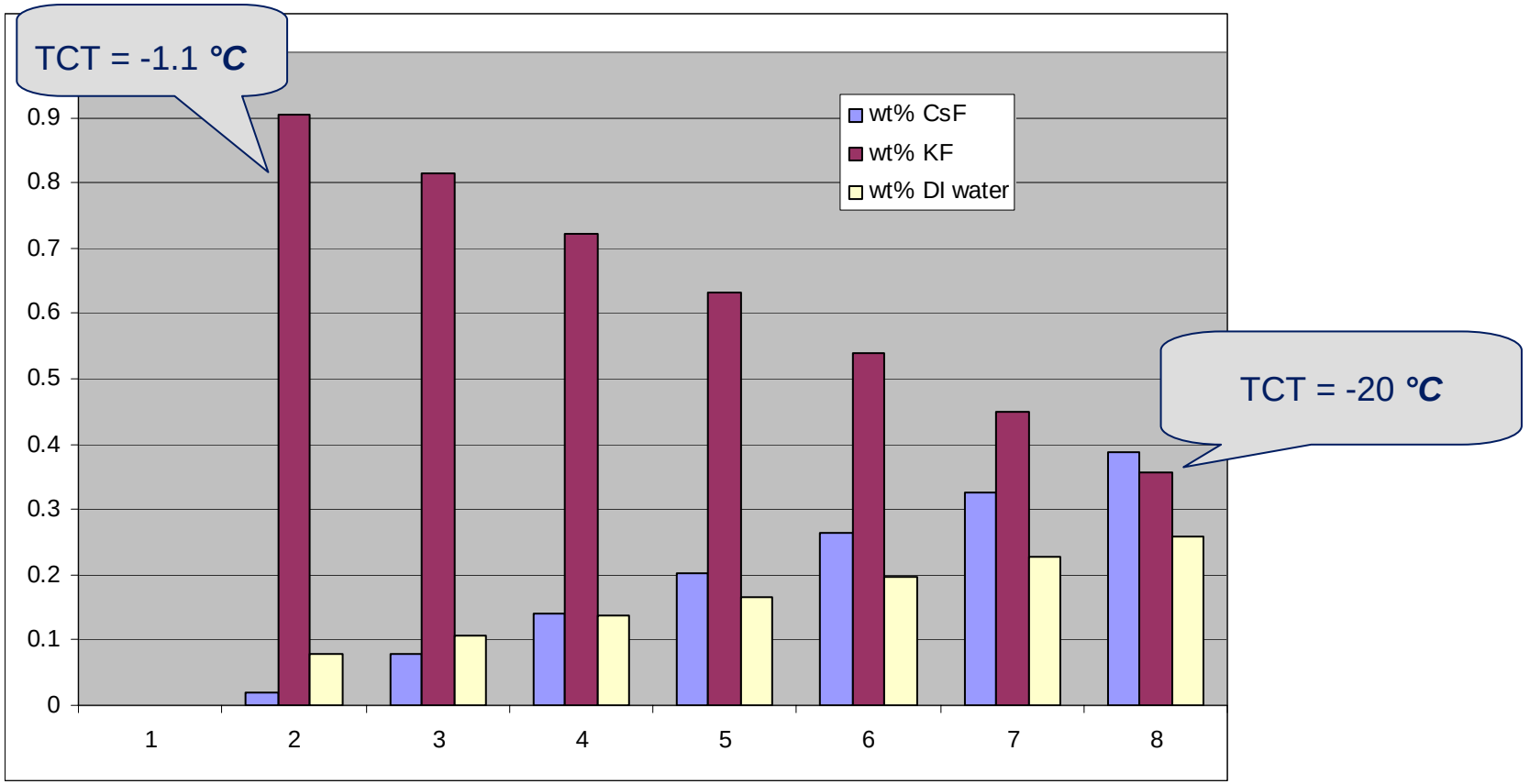
Specialty Fluids

Typical formulation of Base Formate Fluid (1.52 s.g.) with Optimization of Crystallization Temperature and Pressure



Cs Formate = 2.2 s.g, K Formate = 1.57 s.g., H_20 = 1.0 s.g

{RULE-of-THUMB for PCT: 1.0 °F per 1000 psi}

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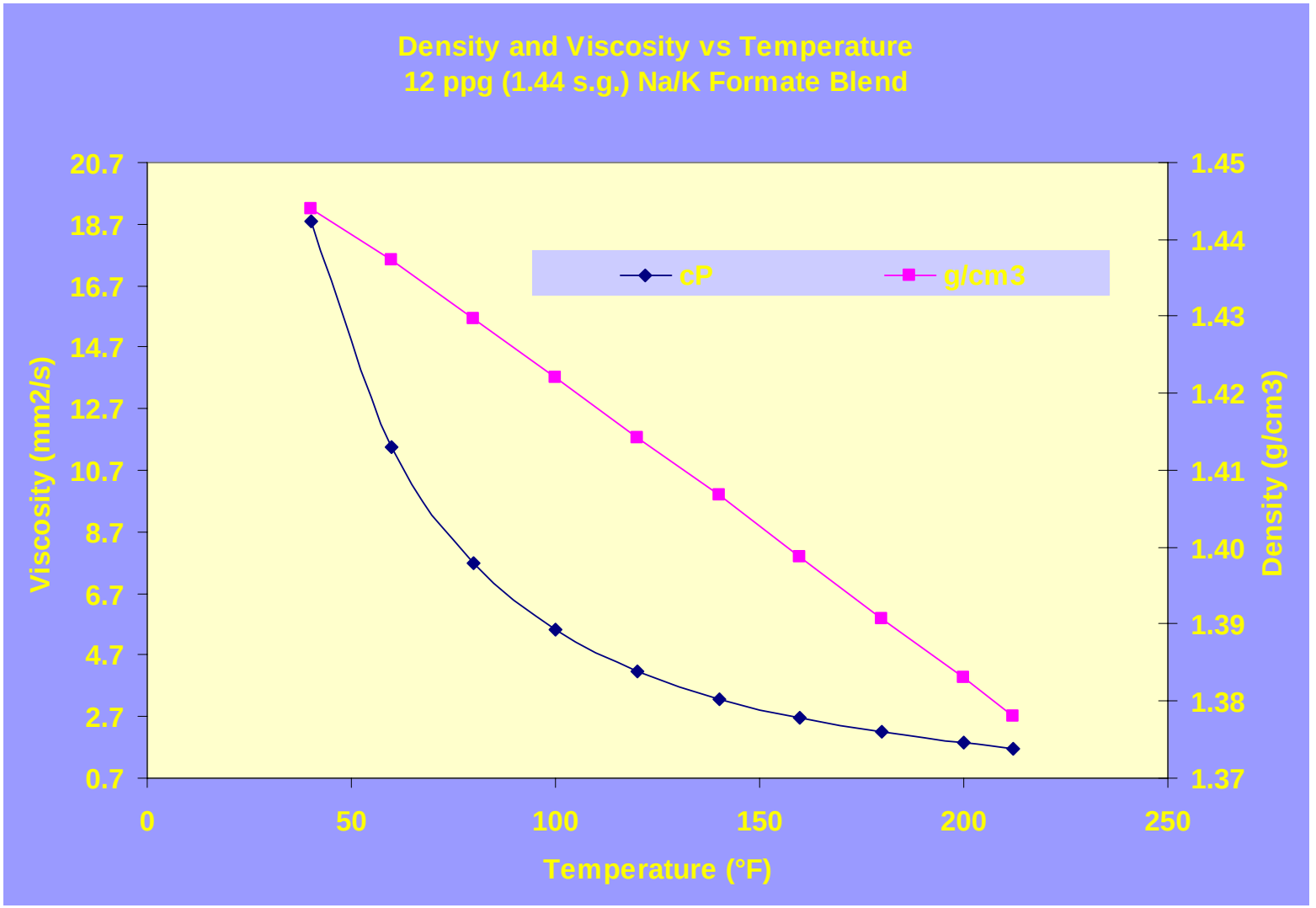
Rheology of Formate Base Fluids



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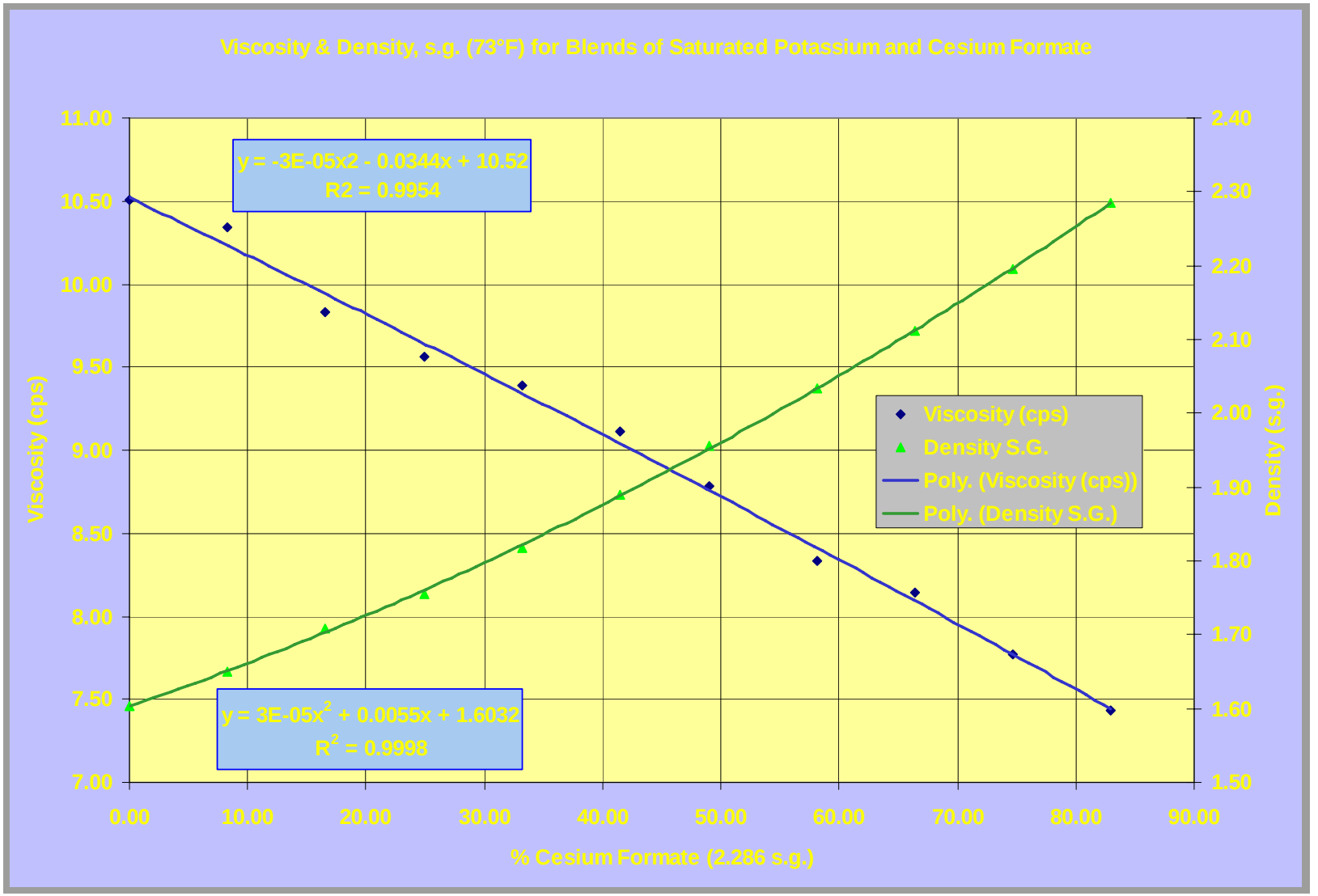
Rheology of Formate Base Fluids



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Specialty Fluids

Cesium Acetate applicable as XHPHT Fluid ?

- *Cesium Acetate behaves similarly to Cesium Formate but stable to higher temperatures.*
  - *Cesium Acetate tested to 600°F in titanium cell with no degradation observed*
  - *Eutectic blending with K Acetate for saturated fluid over similar density range*
  - *Buffered pH for control and maintenance with carbonate/bicarbonate*
  - *Low solids drill-in fluids formulated with synthetic high temperature stable polymers for rheology and fluid loss*
  - *Non-damaging as completion fluid*
  - *Non-corrosive to C-276 type and titanium tubulars*
  - *Resistant to CO2 and H2S in similar manner as formate based fluids*
  - *Passivating film formation with carbon steel and CO2*
  - *High productivity as with Cesium Formate based fluids*

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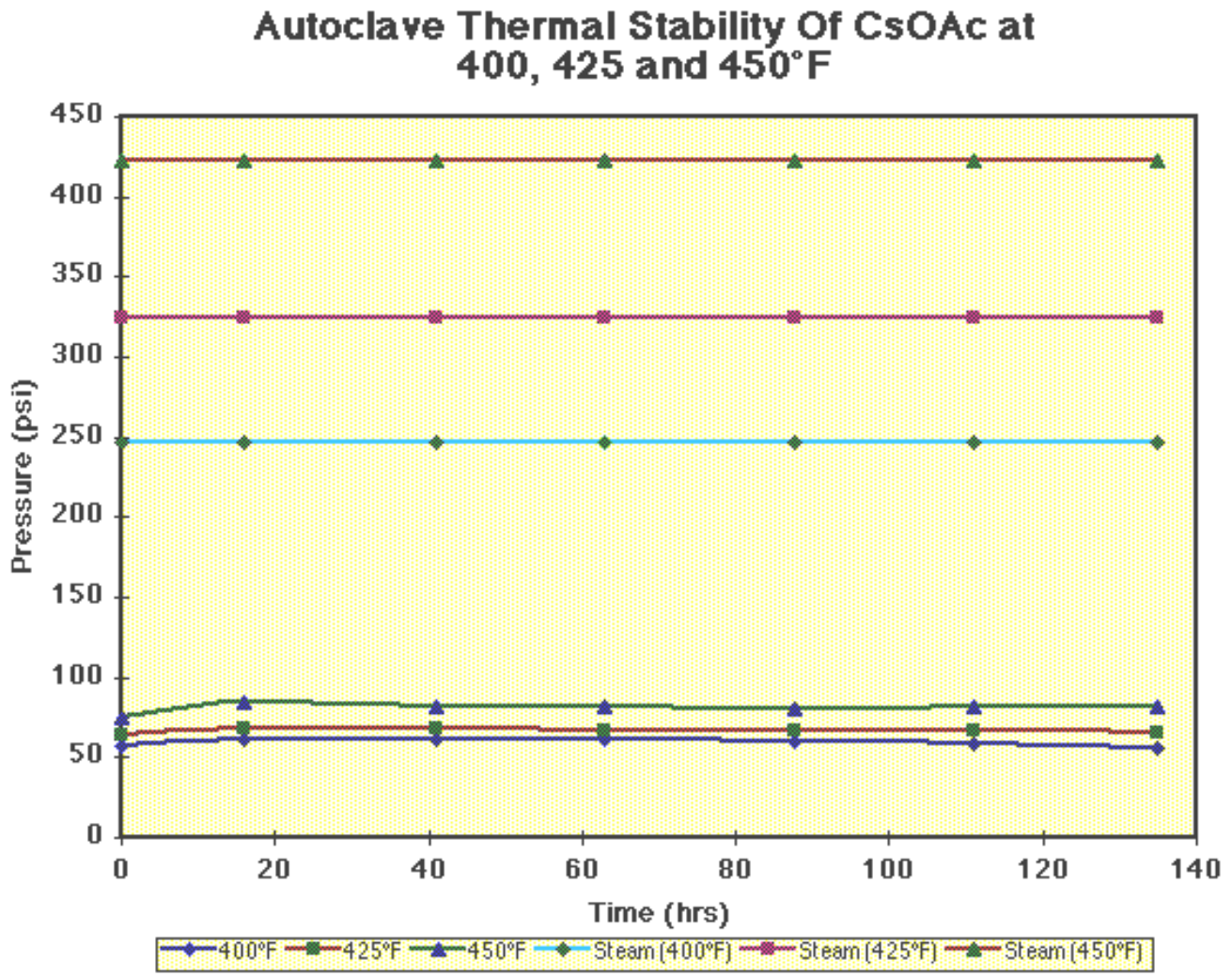
Specialty Fluids

Autoclave pressure build-up of Cesium acetate compared to steam pressure



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Specialty Fluids

Reduced Risk of Common Drilling Hazards

Improved well control:

- ***Reduced Risk of Stuck Pipe - Differential and Mechanical***
- ***Barite Sag Eliminated - i.e. very low solids content***
- ***Excellent Shale Inhibition/Stabilization***
- ***Reduced Risk of Tool/ Pump Failures***
- ***Thermal Equilibrium Reached Quickly - Reduces Flow-Check Time***
- ***Easier Kick Detection and Well Kill***
- ***High Dissociation Constant gives Excellent Hydrate Inhibition***
- ***Cleaner Completions***
- ***All of the above result in Reduced Rig Spread Costs***

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Specialty Fluids

Formulating a Formate-Based Reservoir Drill-In Fluid

Very stable fluids can be made using commonly available oilfield additives

Na/K Formate Drilling/Drill-In Formulation

Density 10.8 ppg (Na + K Formate)

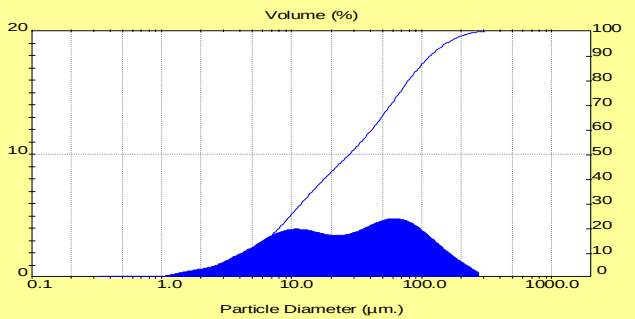
Viscosifier - 1.0 lb/bbl

FL-1 0.5 lb/bbl

FL-2 1.5 lb/bbl

Soluble Carbonate/Bicarbonate * as pH buffer (4 - 10 lb/bbl)

$CaCO_3$ - 15 lb/bbl (PSD is pore throat matched to porosity)



Monovalent formate fluids are alkaline buffered pH 10.0 – 10.5 to enhance fluid stability, mitigate influx of acid gases and to minimize corrosion

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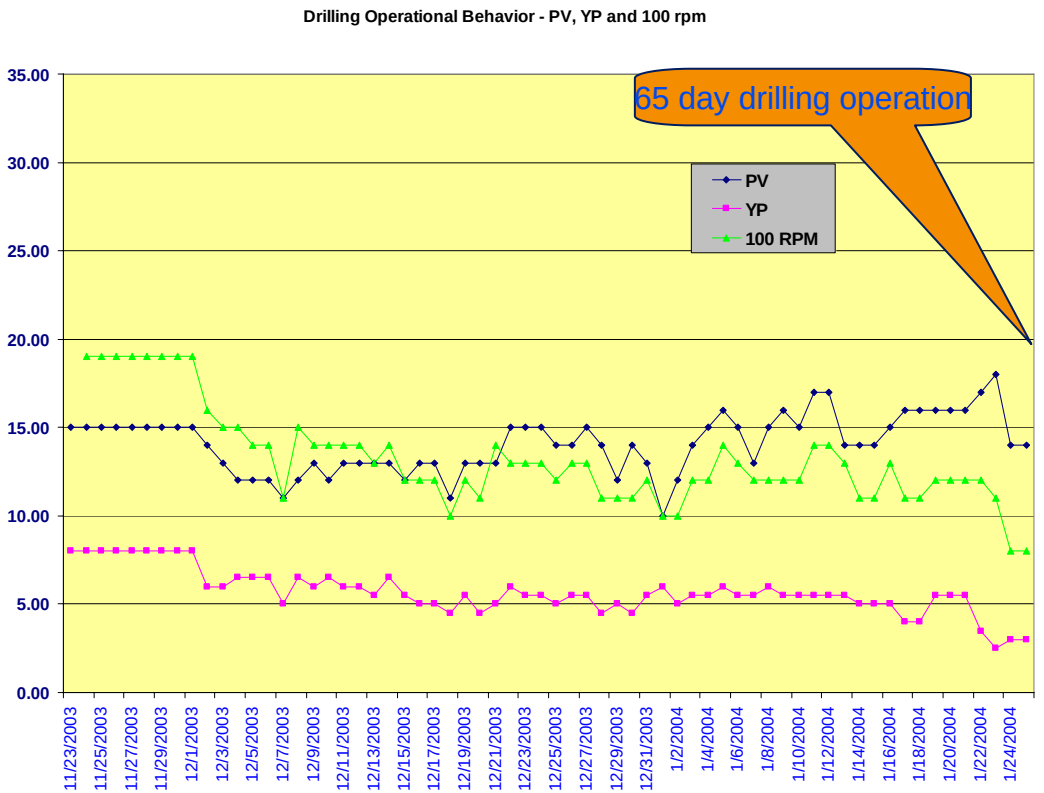
Specialty Fluids

Drilling and Coring with Formate Fluids

Formate fluids are easily maintained and show consistency with only small additions necessary over a drill-in campaign



Typical Fluid Properties (Kristin)

Density s.g./ppg	2.09/17.4
MD, m.	5249
Temp. °C/°F	162/324
600 rpm	36
300 rpm	21
200 rpm	16
100 rpm	10
6 rpm	4
3 rpm	3
Gels 10s/10m	2/4
Plastic Viscosity	15
Yield Pt.	6
pH (9:1)	10.4
HPHT, ml	15.8

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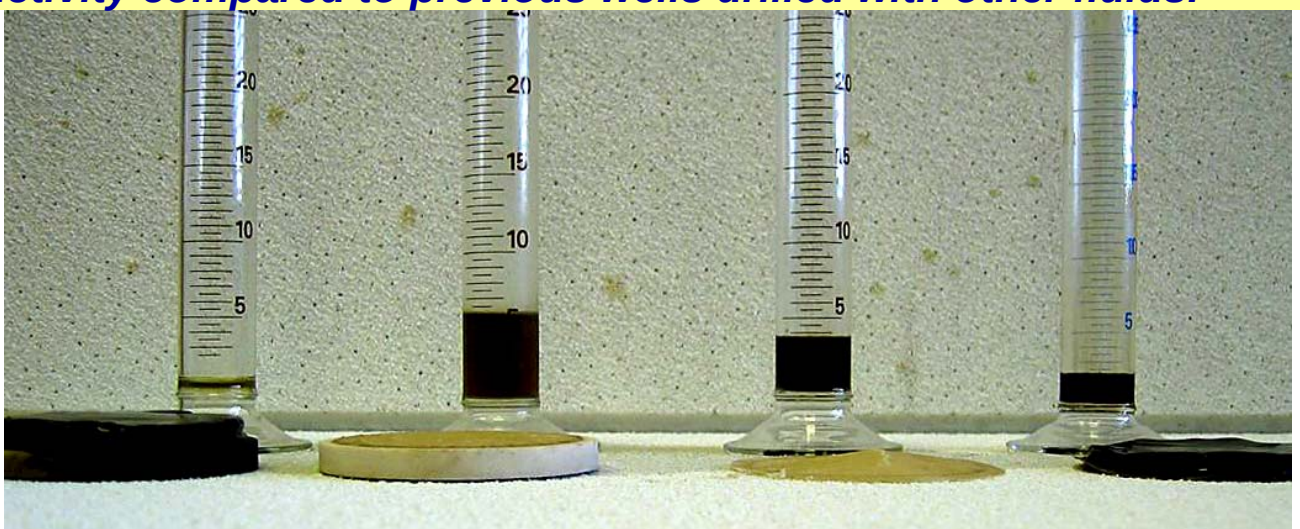
Specialty Fluids

Minimize Differential Sticking and Lower Formation Damage

- *Low Solids significantly reduces the risk of pore plugging*
- *Monovalent base fluid enables drilling of calcium sensitive reservoirs without the risk of precipitation induced impairment.*
- *Extremely low permeability filter cakes minimize filtrate invasion once formed*
- *Extremely thin filter cakes are easily removed during back-flow*
- *LCM pills formulated of more robust drill-in formulation on-the-fly, i.e. increase PSD of CaCO3 and polymer fluid loss additives. Also weighted solids free 'wall building' LCM pill*
- *All Case Histories have reported substantial gains (up to 300 %) in well productivity compared to previous wells drilled with other fluids.*



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Specialty Fluids

Improved Hydraulics with Formate Fluids

- *Lower Surge and Swab Pressures*
  - *Faster tripping times*
- *Lower Transient Pressure Changes*
  - *Reduced risk of hole instability or well control incidents*
- *Lower System Pressure Losses*
  - *More available power for motor - higher ROP*
- *Lower ECDs'*
  - *Drill in narrower window between pore and fracture pressure gradients*
  - *Less chance of fracturing well and causing lost circulation*
- *Low Coefficient of Friction of Base Formate Fluid*
- *Higher Flow Rates*
  - *Higher annular velocities give better hole cleaning*

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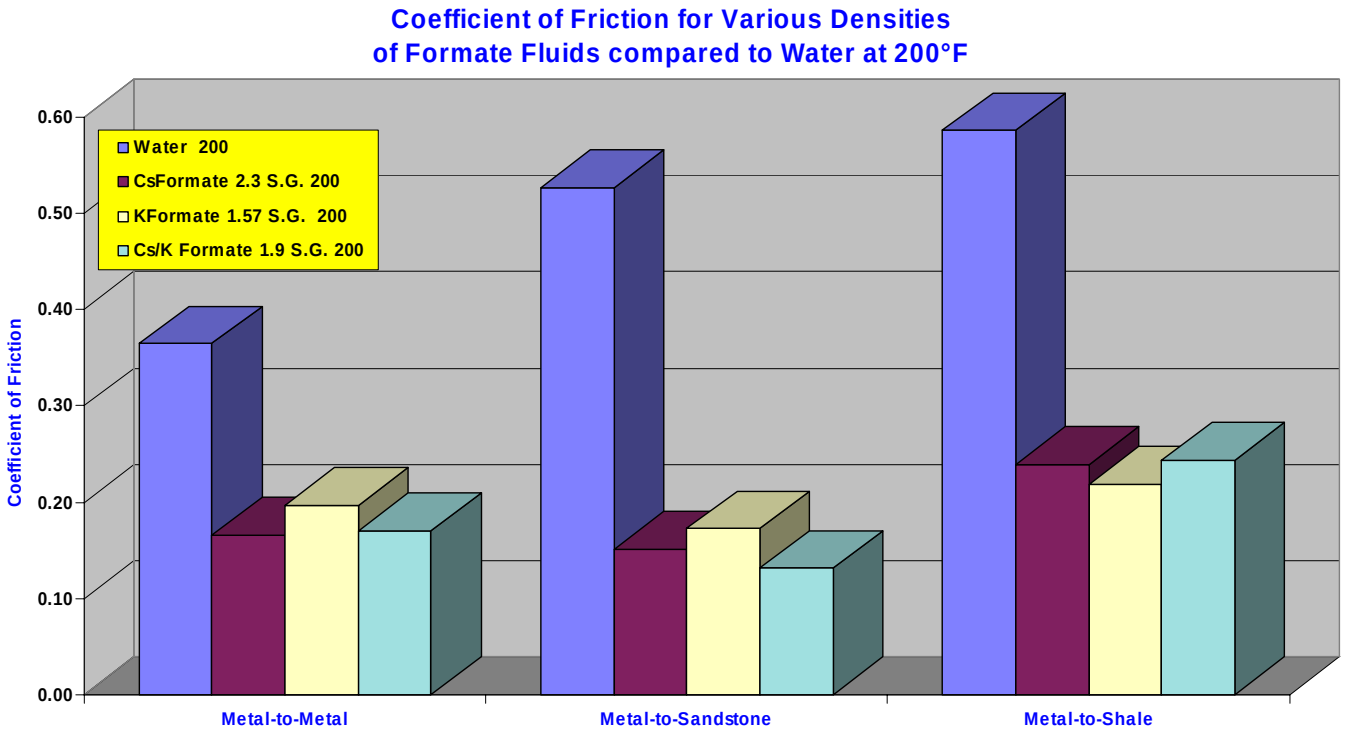
Specialty Fluids

Coefficient of Friction and Inherent Lubricity of Saturated Formate Fluids



- *The more saturated a formate fluid the lower the coefficient of friction and the better the lubricity*
- *If a more lubricious fluid is needed, such as for ER and horizontal wells, formate compatible, non-formation damaging lubricants with COF as low as 0.04 are available*

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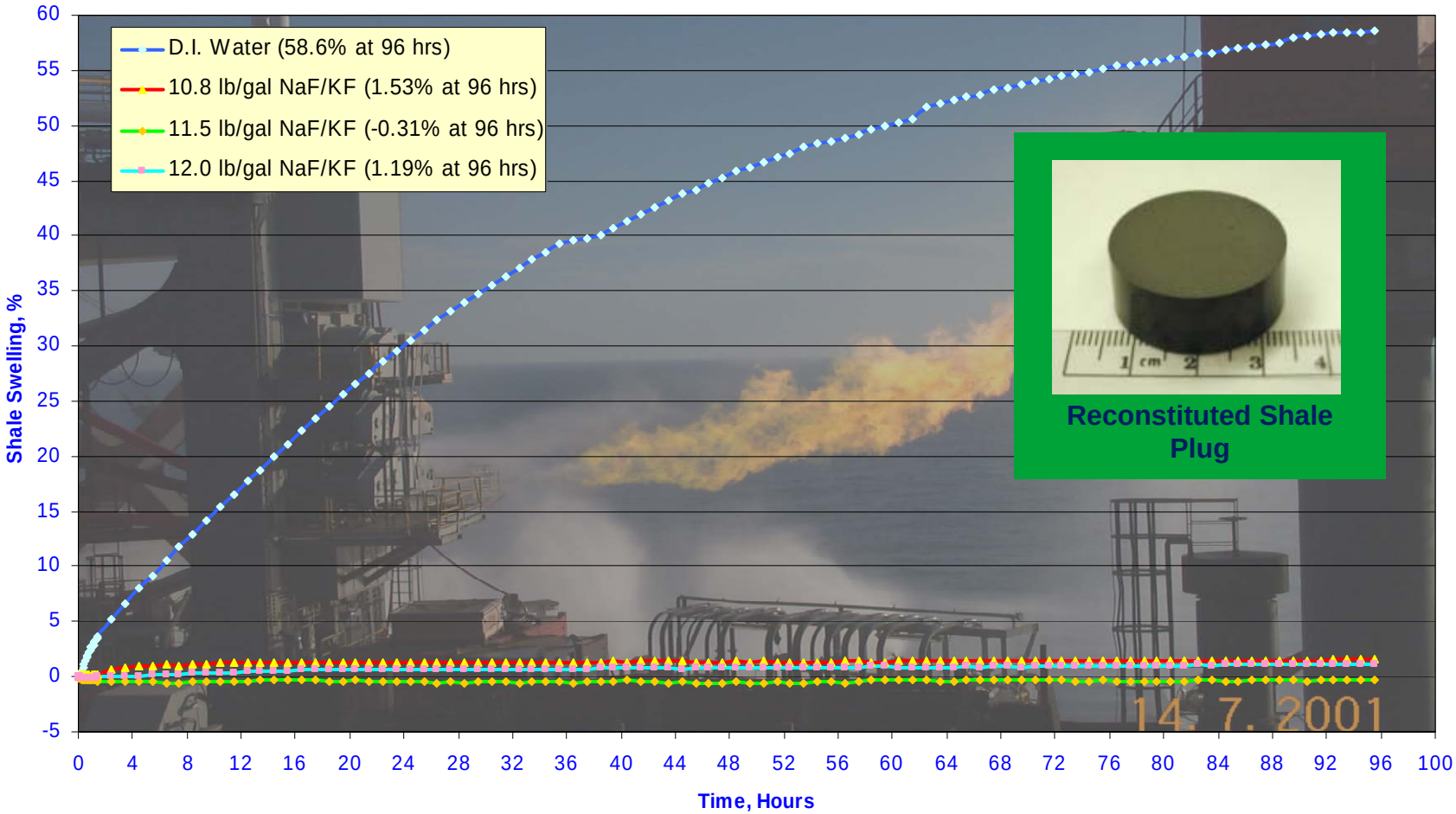
Specialty Fluids

Green Canyon Shale Swelling with Formate Fluids

Shale Swellmeter Testing
GC 782 No 1 ST3 Shale Exposed to
Deionized Water, 10.8, 11.5, and 12.0 lb/gal
Sodium Formate/Potassium Formate Fluids



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Well Control during Drill-In Phase - Diffusion

- Diffusion of methane into wellbore => trip gas, kick, degradation of mud properties, increased sag
- Diffusion of methane into wellbore much reduced with formates compared to OBM
  - Reduced diffusion rate
  - Reduced concentration of methane
  - Particularly important for horizontal and high angle HPHT wells

Solubility of methane in drilling fluids: T = 300°F (149°C), P = 10,000 psi (690 bar)

Fluid	Solubility (kg/m^3)	Diffusion Coefficient ($m^2/sec \times 10^8$)	Diffusion Flux** ($kg/m^2s \times 10^6$)
Oil Based Mud	164	1.1500	53.3000
Water Based Mud	4.8	2.9260	3.9800
Formate Fluid	1.0926	0.8072	0.2494

*** Diffusion fluxes vary more than diffusion coefficients because they are affected by the increase in solubility – formate > water > oil*

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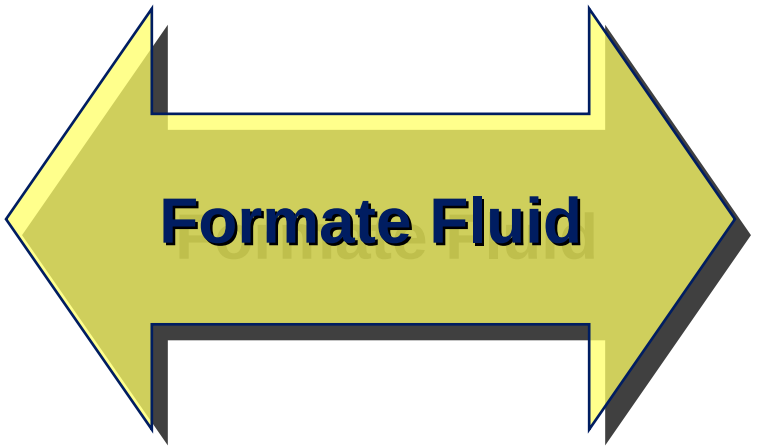
No Swapping-Out of Base Fluid with Formate Fluids

Drilling/Reservoir

Drill-In Fluid



Well Control during Completion

- ✓ Much simpler completion operation
- ✓ Very simple displacement operation
- ✓ Cleanout/Sweep pills are also formate based and hence same density and compatibility between drilling/drill-in fluid and completion fluid
- ✓ Run screens in fluid (fluid run over 300 – 400 mesh)
- ✓ Expandable screens have been run in formate fluid
- ✓ Very limited, if any, UB exposure (*no UB fluids, pills needed)*
- ✓ High heat transfer rate extends life of tools in HT wells
- ✓ Less tripping = rig-time saved = less $$$$$

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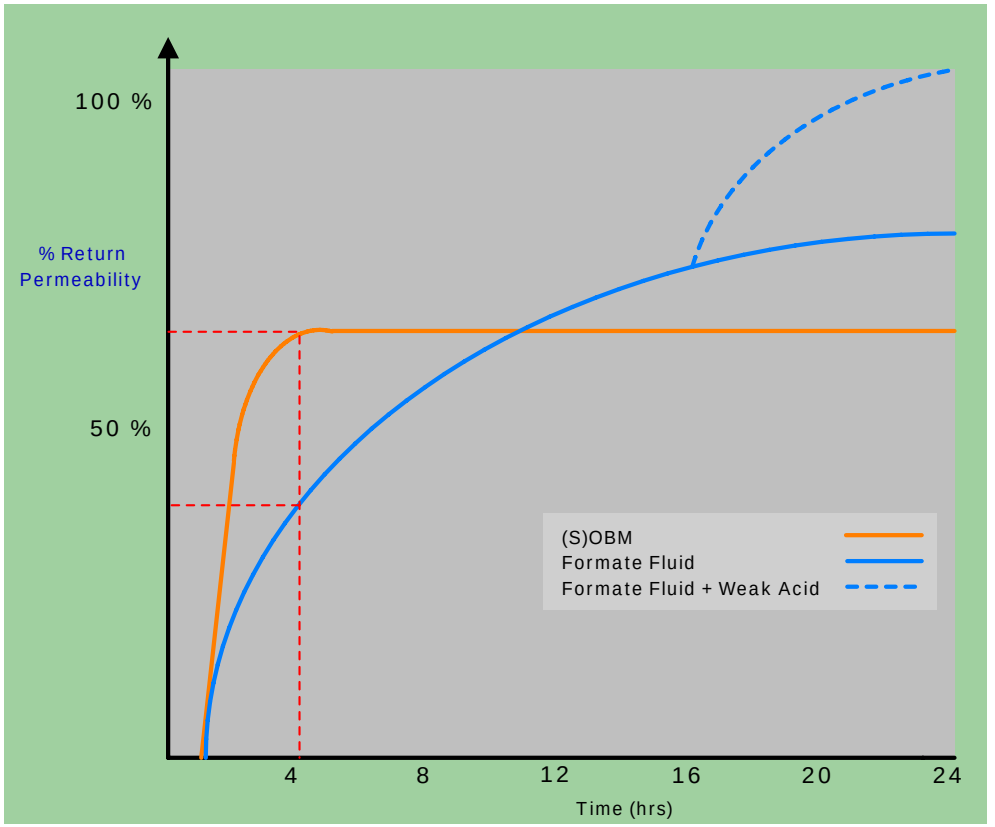
Formation Evaluation - Return Permeability



- *Difference in clean-up behavior between OBM and Formate Mud*
- *Particle Size Distribution (PSD) optimized to permeability and pore throat size*
- *Filtrate invasion can be higher than OBM – needed for thin filtercake deposition*
- *Weak Acid wash can provide improved return perm (even > than 100%)*

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Specialty Fluids

Selected Field Experience with Formate Based Fluids

HPHT Field Experience with formate fluids over the past twelve years. No corrosion problems have been reported in buffered formate fluids without added corrosion inhibitor.

		Statoil Kvitebjørn	Statoil Kristin	BP High Island A-5	Devon West Cameron 165 A-7, A-8	Devon West Cameron 165 A-7, A-8	Walter O&G Mobile Bay 862
No. of wells		7 to date	6 to date	1	1	1	1
Hydrocarbon		Gas condensate	Gas condensate	Gas	Gas condensate	Gas	Gas
Max. temp	°C	150	171	163	149	163	216
	°F	302	340	325	300	325	420
Completion material	CRA	S13Cr	S13Cr	S13Cr	13Cr	13Cr	G-3
Liner material	CRA	13Cr	S13Cr	S13Cr	13Cr	13Cr	G-3
Brine density	g/cm^2	2.00 - 2.06	2.09 - 2.13	2.11	1.03	1.14	2.06
CO_2	%	2-3	3.5	5	3	3	10
H_2S	ppm	Max 10	12 - 17	12	5	5	100
Exposure time	days	57	57	4 3 yrs packer	240 and 270	120	16 325 packer
Application		Drilling Completion / Screens / Liners	Drilling Completion	Well kill Completion Packer	Packer	Packer	Well kill Completion Packer

References:

- **SPE 98391 "Taking Nondamaging Fluids to New extremes: Formate Based Drilling Fluids for High-Temperature Reservoirs in Pakistan" R.J. Oswald, Petrom SA and D.A. Knox and M.R. Monem, M-I Swaco**
- **IADC/SPE 99068 "Drilling and Completing HP/HT Wells with the Aid of Cesium Formate Brines – A Performance Review" J.D. Downs, M. Blaszczynski, J. Turner, M. Harris, Cabot Specialty Fluids**

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Specialty Fluids

Selected Field Experience with Formate Based Fluids

HPHT Field Experience with formate fluids over the past twelve years. No corrosion problems have been reported in buffered formate fluids without added corrosion inhibitor.

		BP Rhum 3/29a	Shell Shearwater	Marathon Braemar	BP Devenick	Total Elgin/Franklin	Statoil Huldra
No. of wells		**3**	**6**	**1**	**1**	**10**	**6**
Hydrocarbon		**Gas condensate**	**Gas condensate**	**Gas condensate**	**Gas condensate**	**Gas Condensate**	**Gas Condensate**
Max. temp	**°C**	**149**	**182**	**135**	**146**	**204**	**149**
	°F	**300**	**360**	**275**	**295**	**400**	**300**
Completion material	**CRA**	**S13Cr**	**25Cr**	**13Cr**	**13Cr**	**25Cr**	**S13Cr**
Liner material	**CRA**	**S13Cr**	**25Cr**	**22Cr**	**VM110**	**P110**	**S13Cr**
Brine density	**g/cm^2**	**2.00-2.20**	**2.05-2.20**	**1.80-1.85**	**1.60-1.65**	**2.10-2.20**	**1.85-1.95**
CO_2	**%**	**5**	**3**	**6.5**	**3.5**	**4**	**4**
H_2S	**ppm**	**5 - 10**	**20**	**2.5**	**5**	**20 – 50**	**10 - 14**
Exposure time	**Days**	**250**	**65**	**7**	**90**	**450**	**45**
Application		**Perforation Completion Workover**	**Well kill CT Workover Perforation**	**Workover Perforation**	**Drill Completion**	**Workover Completion CT / Well kill Perforation**	**Drilling / Completion Screens**

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Specialty Fluids

Selected 2006 Field Experience with Formate Based Fluids

- *Workover – Total Elgin/Franklin F7 well has been suspended with 2.15 s.g. (17.92 ppg) Cesium Formate open hole at full temperature (400 °F) for 18 months – awaiting rig availability, possibly Jan 2007*
  - *Well is being continuously monitored for gases, changes in fluid properties, none detected to-date*
  - *Plan thorough inspection and analysis of metals for corrosion and fluid for changes after project is complete (and this will be published)*
- *March 2006 Total E&P UK plc – Development well Glenelg 22/30c-G10Y Satellite from Elgin/Franklin, drilled 24,229' Highly Deviated Inclination 16.34° -> 64°*
  - *Brought on production after completion and UB perforation through 7" liner with 1.78 s.g.(14.84 ppg) Cesium/Potassium formate*
  - *Reservoir*
    - *Temperature – 195 °F (383 °F) @ 5,859 m TVD*
    - *Pressure – 1,126 bar (16,331 psi) @ 5,539 m TVD*
  - *Total Depth – 7,383 m MD, TVD – 5,815 m TVD, Gas Condensate*
  - *Perforation Losses – 2.0 m^3 (12.58 bbl)*
  - *Production potential – 30,000 boe per day – Well test has been performed - Actual production – n/a*

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Petrobras Energia – El Campamento, Santa Cruz, Argentina

- *Exploratory/Appraisal well - drilling with Cs/K formate*
- *Drilled a 'gage' hole to 3000 m*
- *Found gas in section above target zone – 575 bar (8340 psi), 1.93 s.g. (16 ppg)*
- *No indication of gas from offset P&A'd well*
- *Well being cased and cemented and then perforated through formate fluid*

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Thank You for your attention

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