Wellbore Strengthening

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18–20 April 2005
The Woodlands Resort and Conference Center
2301 N. Millbend Drive
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An SPE Applied Technology Workshop

atw

Borehole Strengthening and Stability

- To address various technological issues related to borehole strengthening and stability
- Limitations of current technologies and direction of potential future development
- Subject experts from various disciplines – presentations, discussions

79 participants from 8 countries – Europe, North & South Americas

Mechanical, Chemical, Thermal Aspects ← Rock Mechanics, Hydraulic Fracturing, Drilling Fluids
Fluids Design & Issues ← Drilling Fluids
Field Applications, Theoretical Aspects

Outline

- What is wellbore strengthening
- Means
  - Mechanical
  - Thermal
- Some theoretical aspects
- Possible mechanisms
- Laboratory and Field Observations
- Gaps
- Summary

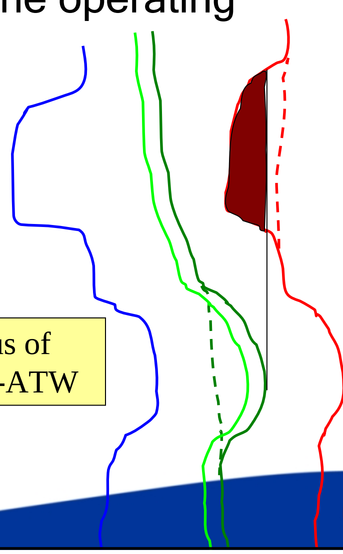
What is wellbore strengthening

A procedure to widen the operating mud window by

Increasing the shear strength
↓
Reduce minimum mudweight required to keep hole open

Increasing the near-wellbore compressive tangential stress
↓
Increase the maximum mudweight prior to fracture initiation

Focus of SPE-ATW



Means to strengthen wellbores

Mechanical

- Plug pores to prevent seepage losses, impermeable zone near wellbore
- Increase compressive tangential stresses in near-wellbore region

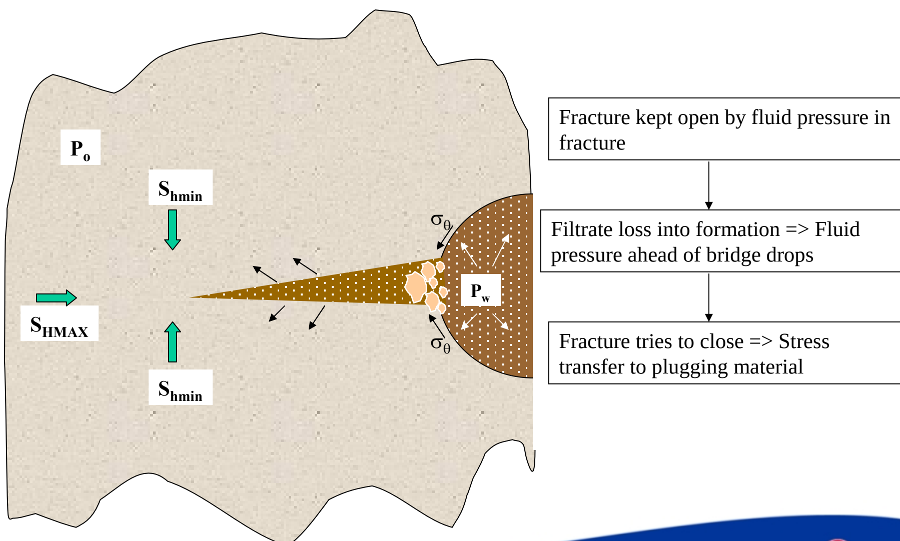
Thermal

- Thermal gradient between drilling fluid and formation

Chemical

- Chemical potential gradient towards the wellbore
- OBMs – capillary pressure threshold

Mechanical Means

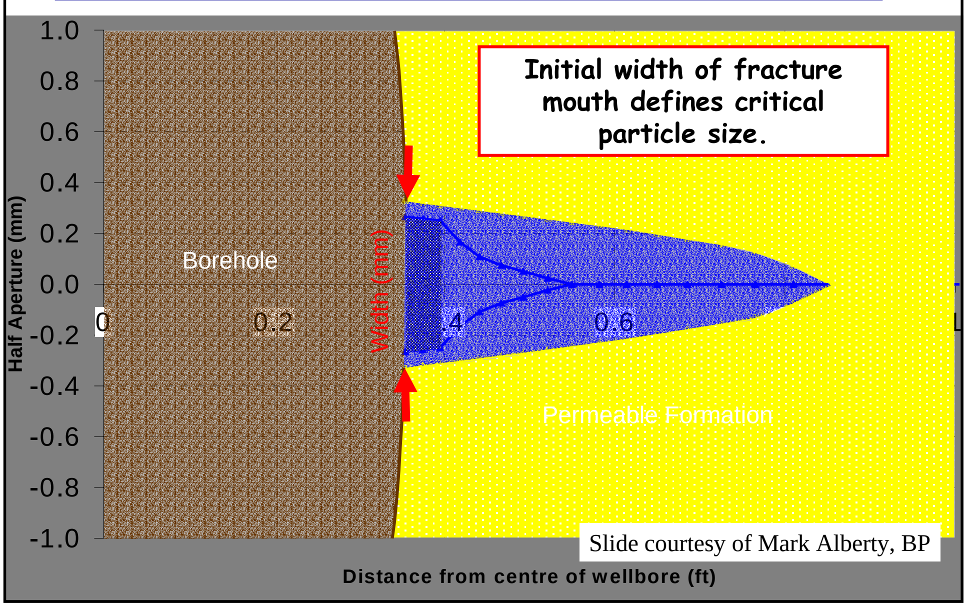


Mechanical Means (Cont.)

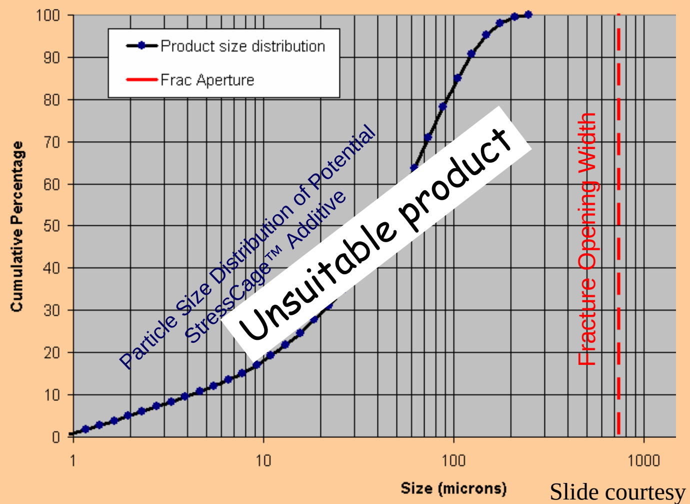
Key Criteria

- Create a ‘bridge’, i.e., plug the fracture close to the wellbore
- Bleed the pressure of the fluid in the fracture after plugging it, i.e.
  - No fluid flux into the fracture
  - Permeable formation
- Correct range of particles in mud => ability to predict fracture width

Numerical Models - Fracture Width

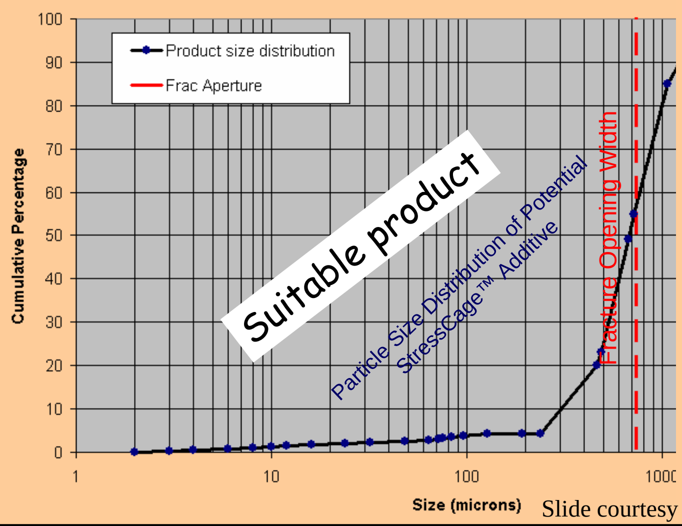


Product Selection



Slide courtesy of Mark Alberty, BP

Product Selection



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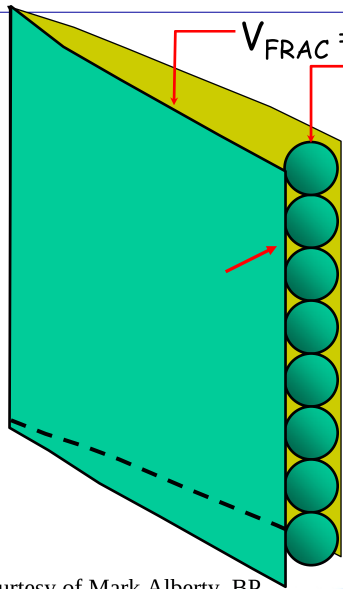
Product Concentration



V_{FRAC} = vol. of fracture

V_{SOL} = vol. of continuous run of solids with diam. equal to frac width.

Frac width

$$\text{Prod Conc} = \frac{V_{SOL} \times \rho_{SOL}}{V_{FRAC} \times P_{GTFW}}$$

P_{GTFW} = proportion of product with solids equal & greater than frac width.

Slide courtesy of Mark Alberty, BP

Theoretical Aspects

Near wellbore effective tangential stress :

$$\sigma'_{\theta\theta}{}^{min} = 3S_{hmin} - S_{Hmax} - P_w - P_{nw}$$

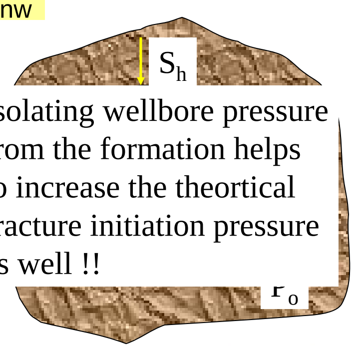
Impermeable Case ($P_{nw} = P_o$)

$$\sigma'_{\theta\theta}{}^{min} = 3S_{hmin} - S_{Hmax} - P_w - P_o$$

>

Permeable Case ($P_{nw} = P_w$)

$$\sigma'_{\theta\theta}{}^{min} = 3S_{hmin} - S_{Hmax} - 2P_w$$



Isolating wellbore pressure from the formation helps to increase the theortical fracture initiation pressure as well !!

Laboratory Observations - Recap

DEA 13 JIP conducted at Drilling Research Labs in mid-80's

- Large sample size (1.5-in bore hole in a 30-in cube)
- Fractures initiation, reopening / extension
- FIP were not different for OBM and WBM
- FPP **lower** for high density OBM than for high density WBM
- Prevention is better than remediation
  - $CaCO_3$ effective in plugging fractures
  - Fibers not tested, "graphitic" LCM materials not available
- Mechanism - Fracture tip "screen-out"
- Morita et al, SPE 20409

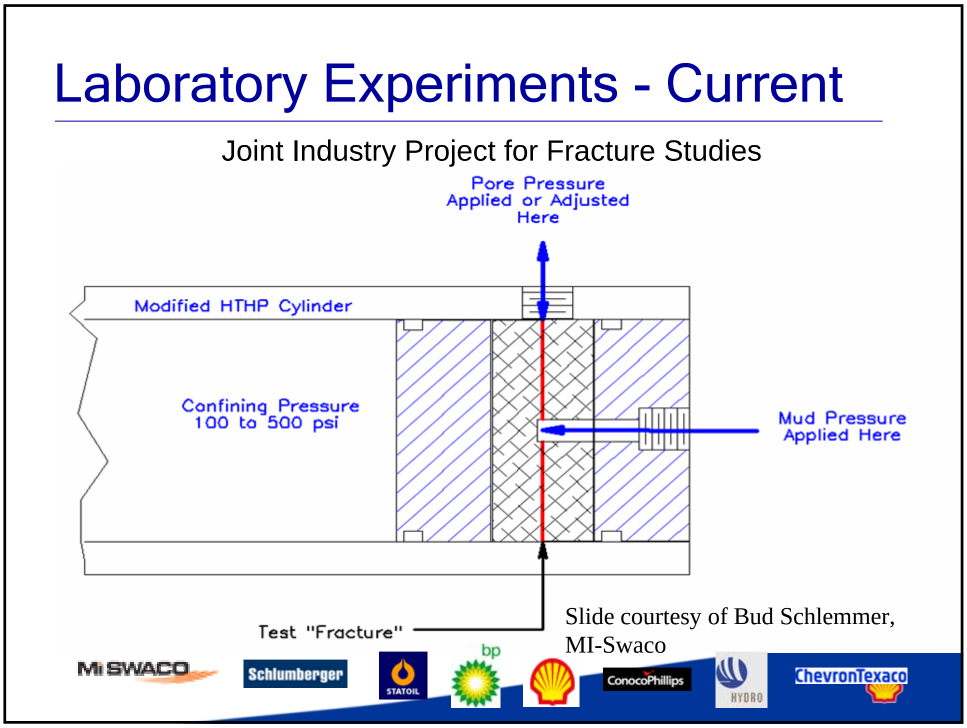
Laboratory Experiments - Recap

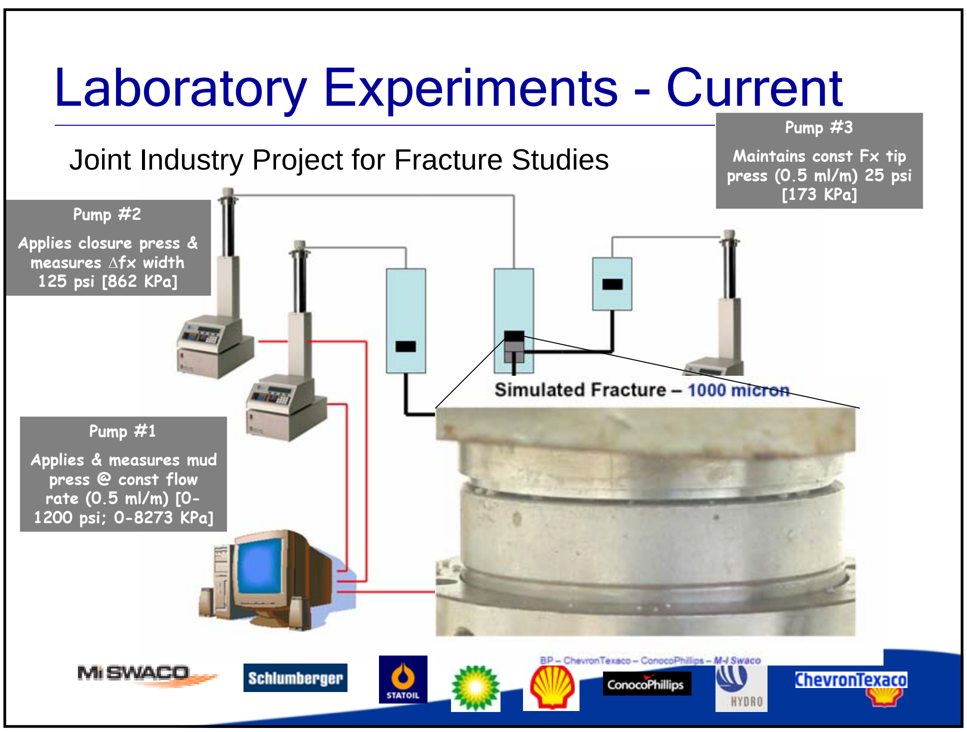
GPRI 2000 : Minimizing Lost Circulation in Synthetic Muds

Members: Shell, BP, Texaco, Marathon, Chevron, Statoil, Norsk Hydro, Halliburton/Baroid, MI, INTEQ

Shell Test System

- Small sample size (4-in diameter)
  - **fractures all the way through upon initiation**
  - **reopening pressures (only) used for evaluation**
  - no fracture tip screen-out possible.

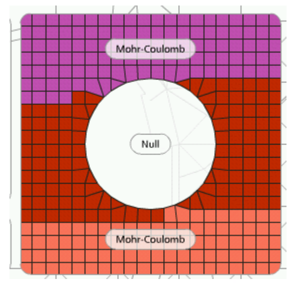

Laboratory Experiments - Current
Joint Industry Project for Fracture Studies
Pore Pressure Applied or Adjusted Here
Modified HTHP Cylinder
Confining Pressure 100 to 500 psi
Mud Pressure Applied Here
Test "Fracture"
Slide courtesy of Bud Schlemmer, MI-Swaco


Laboratory Experiments - Current
Joint Industry Project for Fracture Studies
Pump #3
Maintains const Fx tip press (0.5 ml/m) 25 psi [173 KPa]
Pump #2
Applies closure press & measures Δfx width 125 psi [862 KPa]
Pump #1
Applies & measures mud press @ const flow rate (0.5 ml/m) [0-1200 psi; 0-8273 KPa]
Simulated Fracture – 1000 micron

JIP for Fracture Studies- Development of Mathematical Model

Build an analytical solution for the stresses near the wellbore with a "two winged" fracture, based on the work by Carbonell (1995). This model is based on a "pressure boundary condition" (i.e., pressure inside the wellbore and inside the fracture).

Based on the previous work, try to obtain an analytical or semi-analytical solution for a "wellbore + two-winged fracture" with a rigid wedge at the mouths of the fracture.



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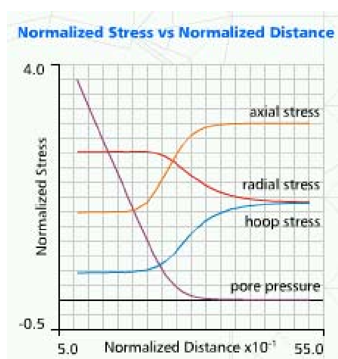
MI SWACO Schlumberger STATOIL bp ConocoPhillips HYDRO ChevronTexaco

JIP for Fracture Studies- Development of Mathematical Model

Two-dimensional continuum code for modeling soil, rock and structural behavior.

The formulation can accommodate large displacements and strains and non-linear material behavior, even if yield or failure occurs over a large area.

Dynamic Analysis - allows modeling of the full dynamic response of a system to be simulated in the time domain.



MI SWACO Schlumberger STATOIL bp ConocoPhillips HYDRO ChevronTexaco

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Suggested Mechanisms

Tip Screenout

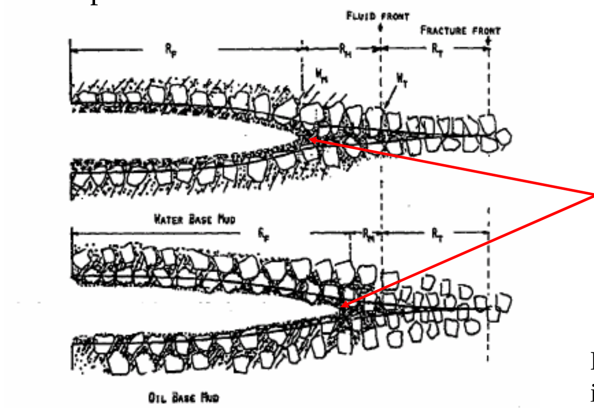


Fig.5- Cross sectional view of mud cake formed around fracture tip.

Morita et al, SPE 20409

In case of WBM, fluid cannot penetrate as close to the fracture tip as in case of OBM

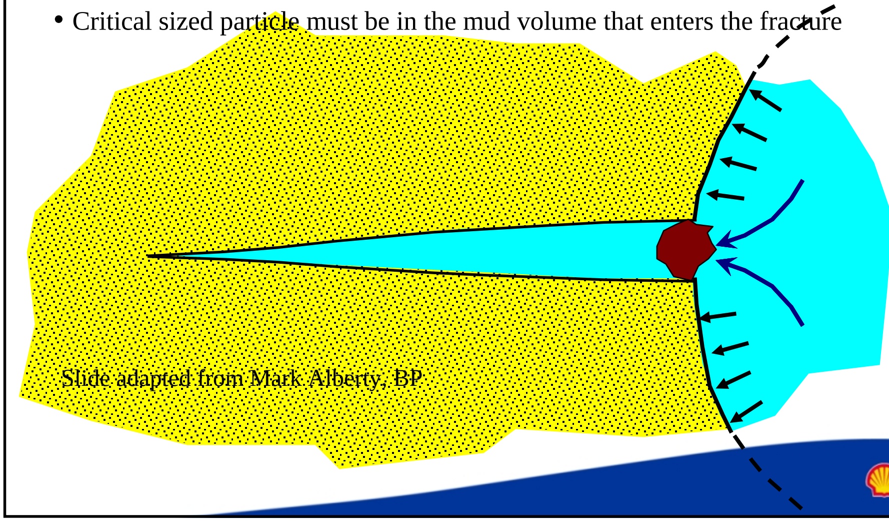
↓

Better 'tip-screenout' in case of WBM

Suggested Mechanisms (Cont.)

Plugging / Bridging

- Particle must wedge in the mouth of the fracture
- Critical sized particle must be in the mud volume that enters the fracture

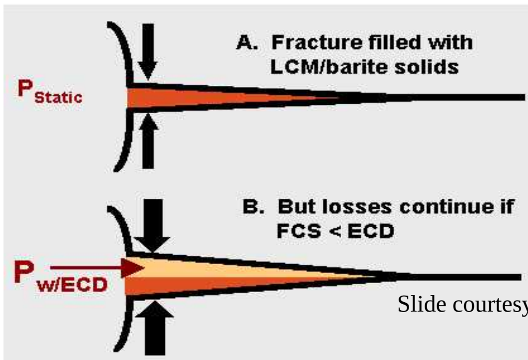


Slide adapted from Mark Alberty, BP

Suggested Mechanisms (Cont.)

SPE 92192 - Fred Dupriest

- Losses are not stopped by simple plugging
- Effective treatments must simultaneously isolate the tip and achieve adequate width so that FCS > ECD



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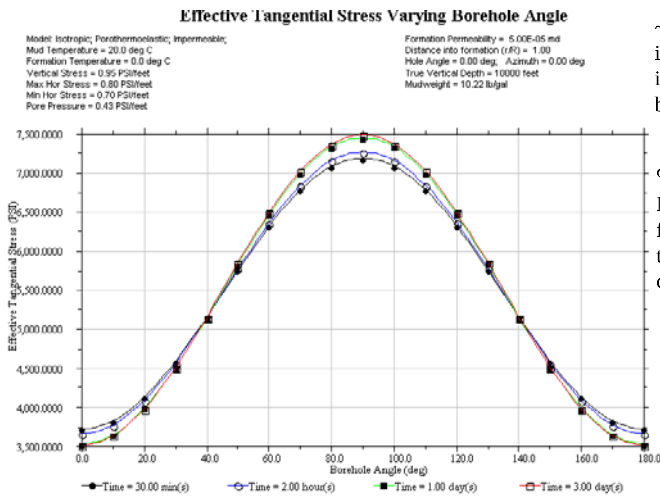
Field Observations

Location	Before	After	Δ HPC
GoM Shelf	13.5	>18.6	>5.1
GoM Miss. Canyon	12.4	13.4	1.0
GoM Miss. Canyon	15.5	15.8	0.3
S. Texas	17.6	22.8	5.2
S. Texas	16.1	18.4	2.3
S. Texas	18.0	18.6	0.6
S. Texas	16.2	17.2	1.0
S. Texas	15.0	18.0	3.0
S. Texas	14.0	14.7	0.7
S. Texas	16.0	16.8	0.8
California	16.5	>17.6	>1.1
Venezuela	13.8	>15.2	>1.4
Venezuela	<10.4	11.5	>1.1
Trinidad	14.7	16.7	2.0
Nigeria	16.2	16.8	0.6

Slide courtesy of Ron Sweatman, Halliburton

Thermal Effect



~ 120 psi (0.2 ppg) increase in tangential stress by increasing mud temperature by 20 deg. C

$\sigma_{\theta\theta}^{\Delta T}$ = (α E ΔT)/(1-ν)

Method is suitable for stiff formations with high thermal expansion coefficient

The pore pressure induced by the differential expansion of the fluid and rock skeleton must dissipate first

Gaps in the industry

- No consensus on interpretation of LOT plots to ascertain 'fracture gradient'
- Mechanism of 'wellbore strengthening' not clearly understood - tip screenout / plugging or both
- Models (semi-analytical, numerical) not calibrated extensively with laboratory and field data
- Fracture geometry and it's impact on near wellbore stresses need to be investigated further

Summary

- Mechanical means of increasing the maximum allowable mudweight
- Mechanisms suggested were tip screenout, plugging at the wellbore and a combination of both
- Numerical and experimental efforts to understand the mechanism and provide cost efficient solutions are underway
- A need to address current knowledge gaps