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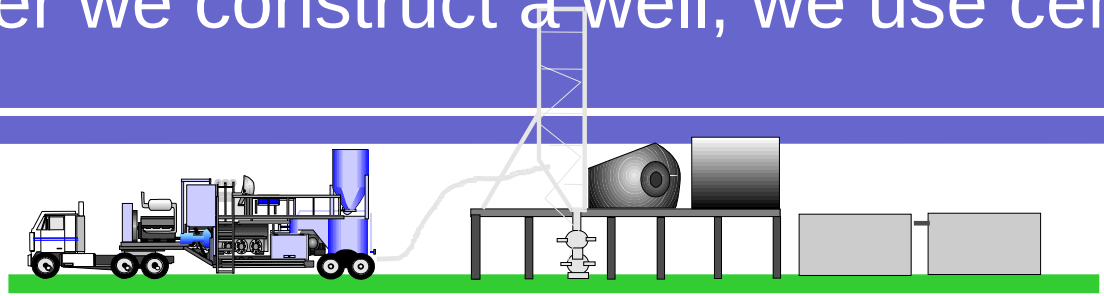
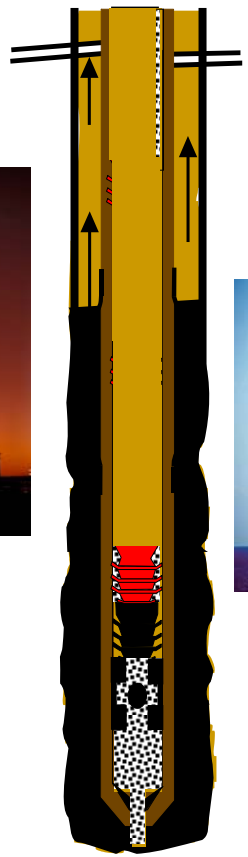
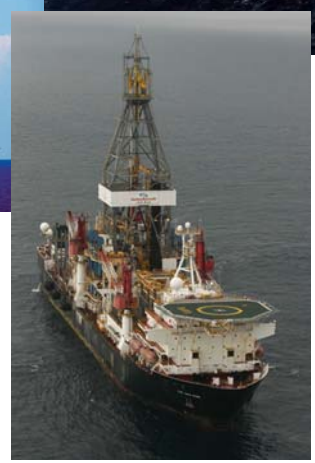
CEMENTING
Planning for success to ensure isolation for the life of the well

Daryl Kellingray, BP Exploration

Wherever we construct a well, we use cement







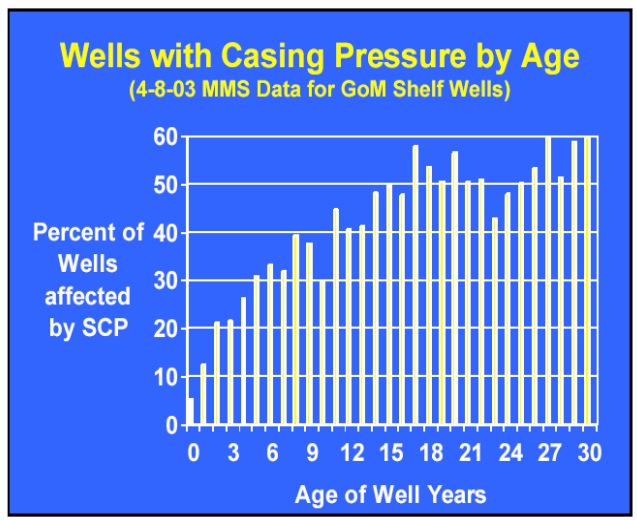
Why is cementing important ?

Prevention of flow to surface

- MMS identified 19 cement related well control incidents 1992 -2002.

Sustained Casing Pressure

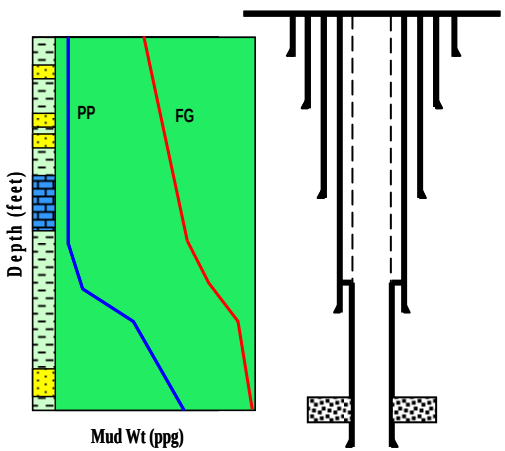
- 25-30% of wells are estimated to have annular pressure problems, cementing is one of the primary route causes.



Why is cement important ?

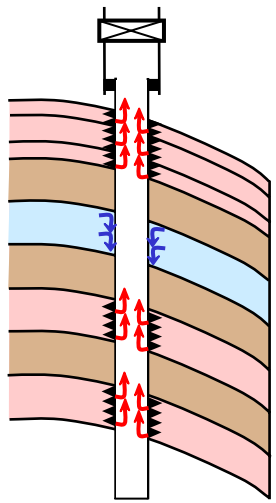
Mechanical well integrity during drilling

- Isolation of weak formation & structural support



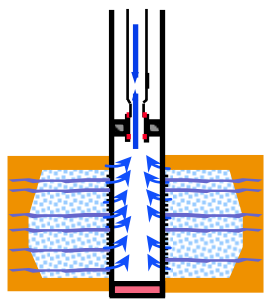
Reservoir Isolation and Protection

- Isolating production from other fluids



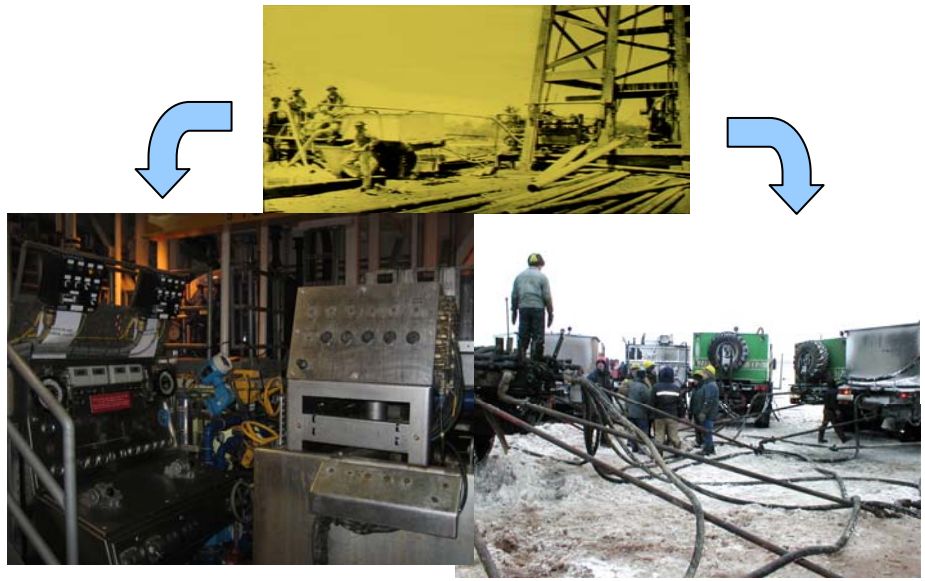
Production Optimisation

- Optimising stimulation treatments



Cementing Planning For Success

- Drilling Related Problems and Learning
  - Gas migration
  - Deep water
- Long Term Isolation
  - Isolation breakdown
  - Cement bonding
  - Mechanical Issues
- Integrated Mud and Cement Design
  - Balancing drilling fluids and cementing requirements
  - Spacers
  - Cement placement



Classification of annular flows

Annular flow after cementing falls under three general classifications:

- Percolation through unset cement
- Influx via mud channels (poor mud displacement)
- Flow and/or pressure transmission through set cement (microannuli, stress cracks, etc.)

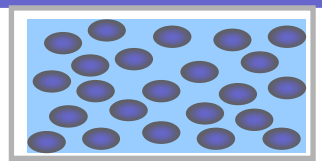
In the MMS reporting system nearly all post cementing flows occurred 3 - 8 hours after the job

Gel strength terminology

- Static Gel Strength - rigidity in the matrix which resists forces placed on it
- Critical Gel Strength - the gel strength which the hydrostatic column (when accompanied by volume reduction)
- Zero Gel Time or Delayed Gel Time - time to start of critical gel strength (approx. 100 lb/100 ft^2)
- Transition Time (nothing to do with thickening time) - time from zero gel time (usually 100 lb/100sqft) to 500 lb/100 ft^2

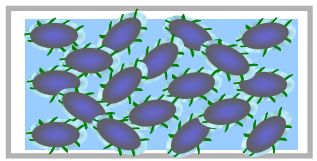
Pressure decay

SETTING



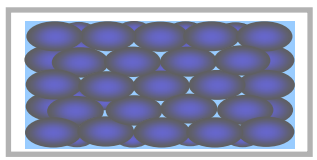
Fully Liquid

Full hydrostatic transmission < 100 lb/100sqft.
Migration risk from insufficient slurry density.



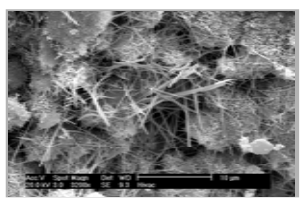
Early Gelation

Cement static with gels between 100–500 lb/100sqft.
Volume reduction by fluid loss reduces hydrostatic.
High risk of migration, mitigated by <30 min transition times and compressible cements.



Hydration

Cement is no longer deformable with rapid development of strength, pore pressure in cement dropping. Migration risk if high permeability.



Set Cement

Cement now has high compressive strength and low permeability.

Effect of gel strength on pressure transmission

$$\text{Gel Strength to support overbalance} = \frac{(OBP)*(300)}{(L/D_{eff})},$$

where
OBP = overbalance pressure (psi)
300 = conversion factor (lb/in.)
L = length of the cement column (ft)
D_{eff} = effective diameter (in.) = D_c - D_{OH}
D_c = diameter of the casing (in.)
D_{OH} = diameter of the open hole (in.)

E.g.
For 26”OH and 20” casing with a 50 psi overbalance 1000 ft beneath seabed

$$\text{Gel Strength} = \frac{300 * 50}{1000/6} = \underline{9 \text{ lb/100sqft !!!!}}$$

Prevention of annular flow

- Quantify the risk (overbalance and cement column height dependent)
- Design mud displacement and cement placement
- Determine rate of static gel strength development
- Determine fluid loss requirements

Issues impacting deepwater slurry selection

Common cementing questions ?	Deepwater Considerations
Should cement be tested at seabed temperatures?	Ignores impact of cement heat of hydration.
Will WOC always be extended in deepwater surface strengths?	Actual strength requirements are low (<100psi for pipe support)
Is foam cement the only option?	API RP 65 favours foam but not the only solution.
Low fracture gradients require low density cements?	In deep water the seawater column reduces cementing ECD's and can permit use of 1.92 SG slurries

Cementing temperatures in deepwater wells

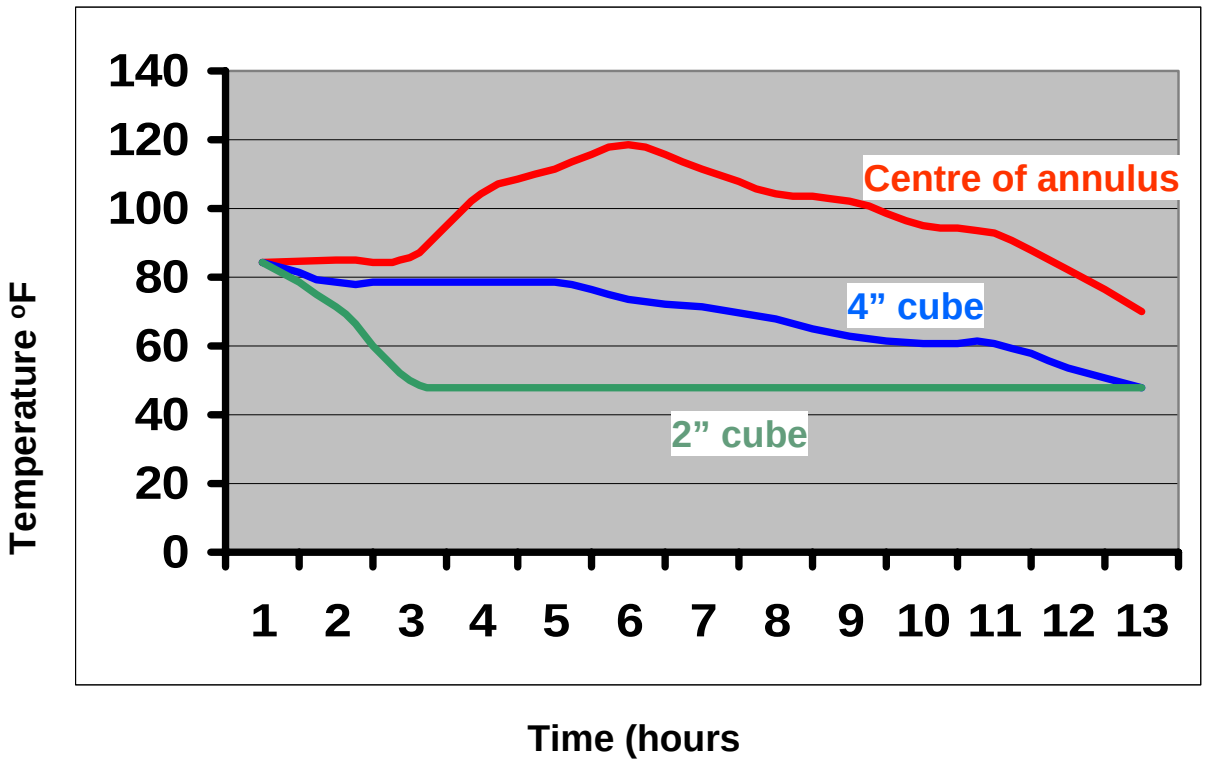
Computer simulated cement circulating temperatures v API circulating temperatures for a deepwater 13 3/8” casing string 9000 ft below seabed.

Water depth	3000 ft	3000 ft	6000 ft	6000 ft
BHST (°F)	Simulated cementing temperature (°F)	API Spec 10 cementing temperature (°F)	Simulated cementing temperature (°F)	API Spec 10 cementing temperature (°F)
106	84	87	80	87
146	100	128	100	128

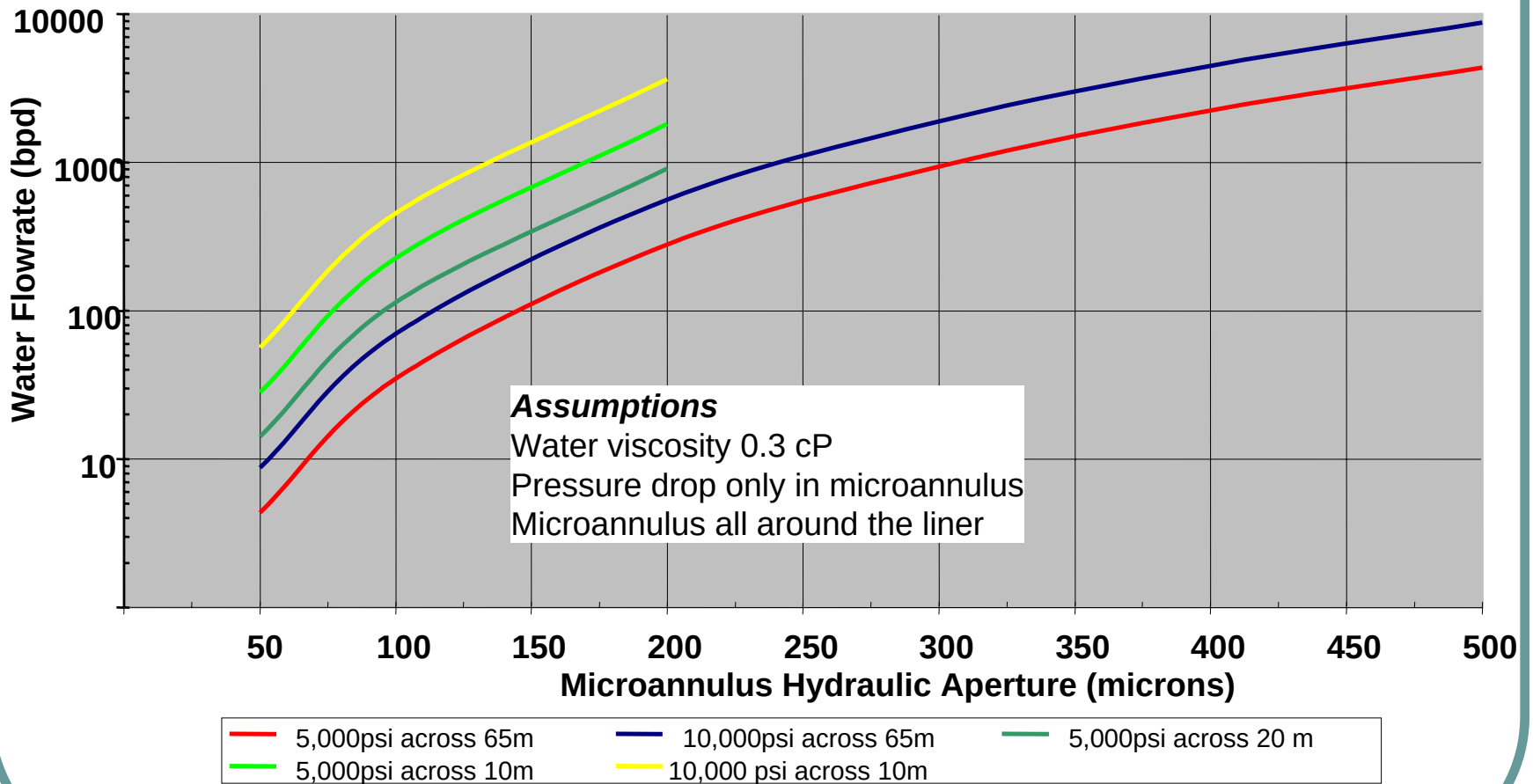
Cement setting at low temperature

Are industry compressive strength tests representative when cementing surface strings in deep water ?

Large scale experiment in temperature controlled room at 43ºF using simple 16 ppg class G cement.

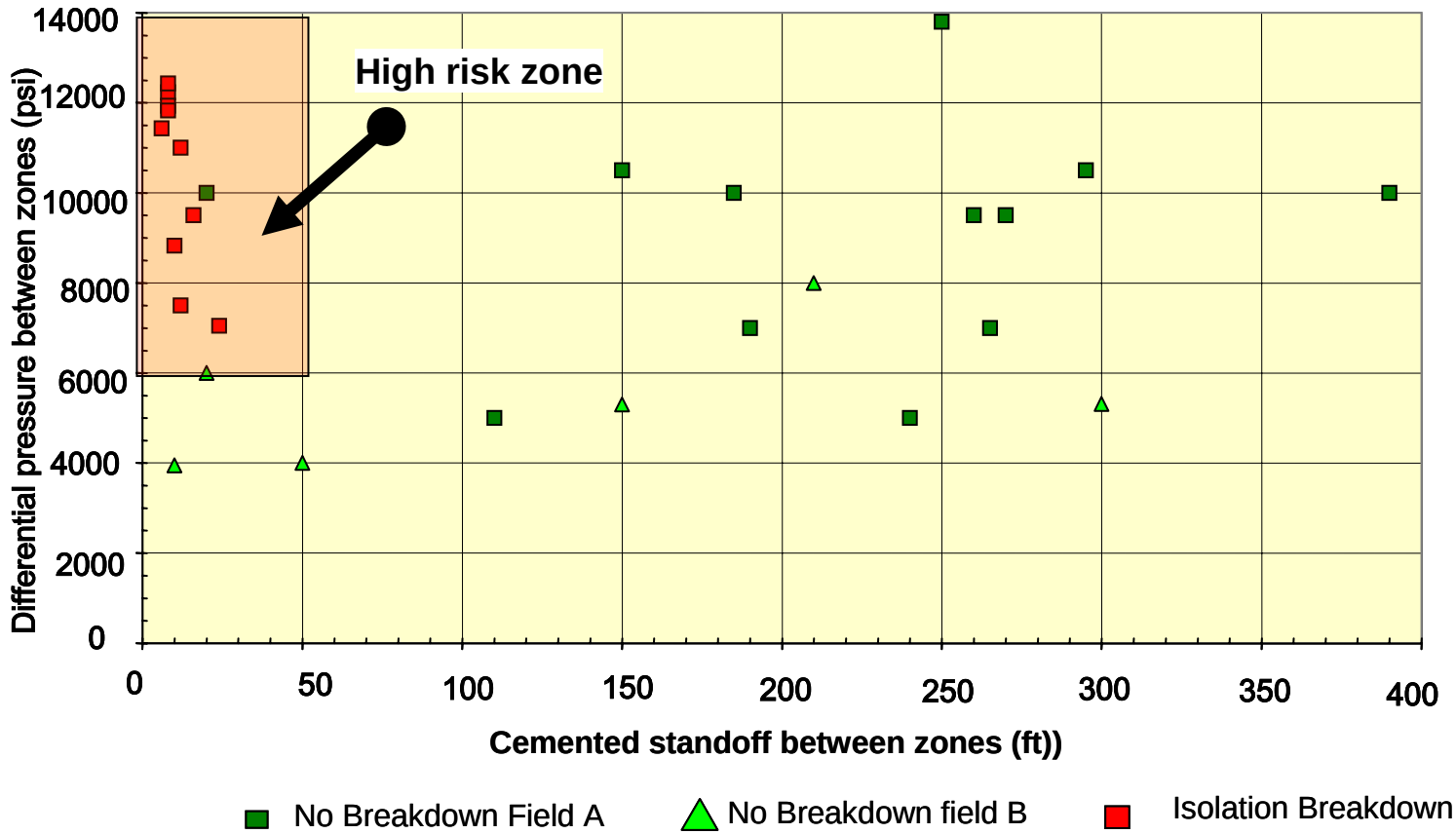


Crossflow in a micro annulus



When does cement provide a seal?

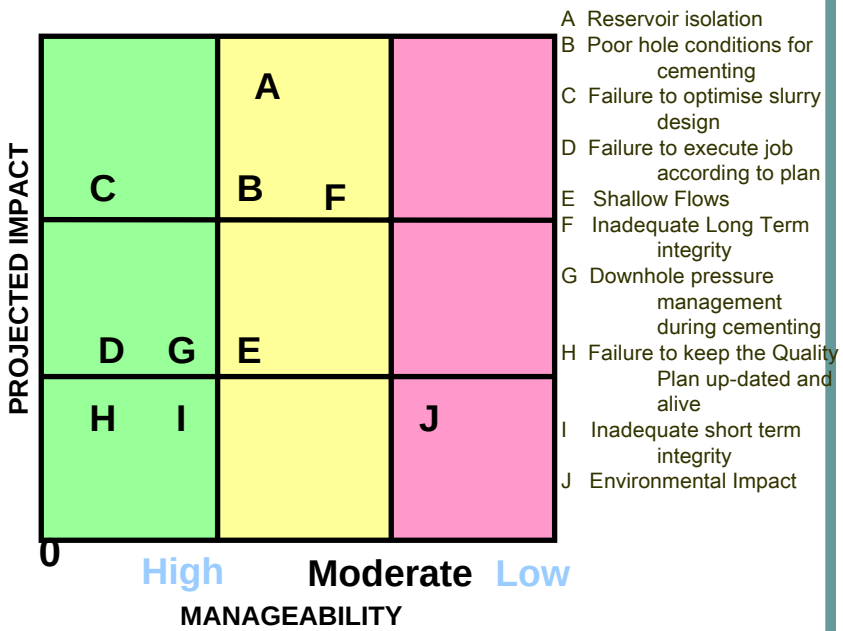
Only good primary cement jobs were included in the analysis



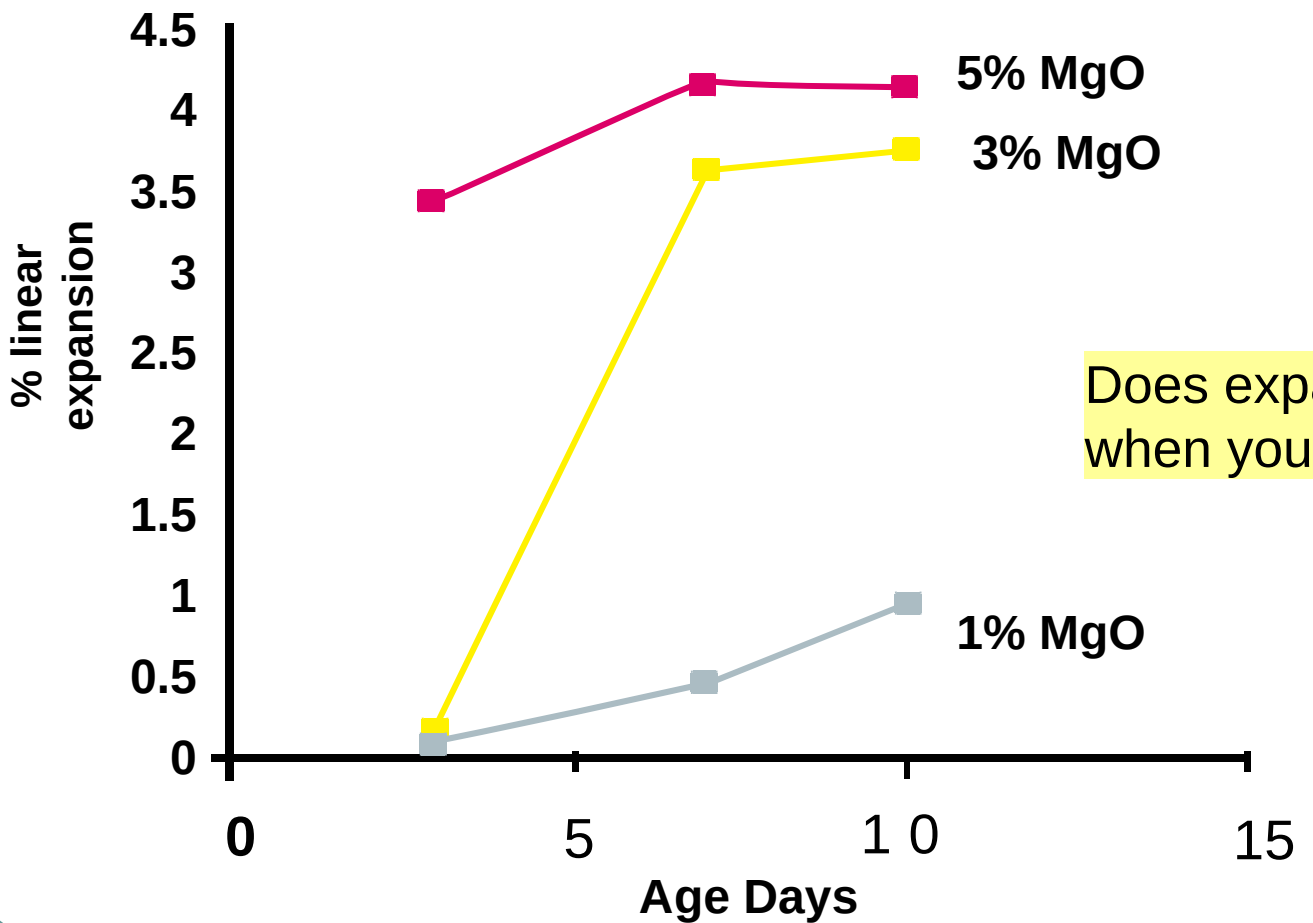
Design steps for selecting a slurry

Develop an assurance process

- Review analogous developments
- Identify options and risk assess including assessment of flow potential
- Determine mechanical loadings and complete modelling
- Can robust pumpable slurries be designed which can be effectively placed?
- Are the benefits real ? Warranting cost and complexity?

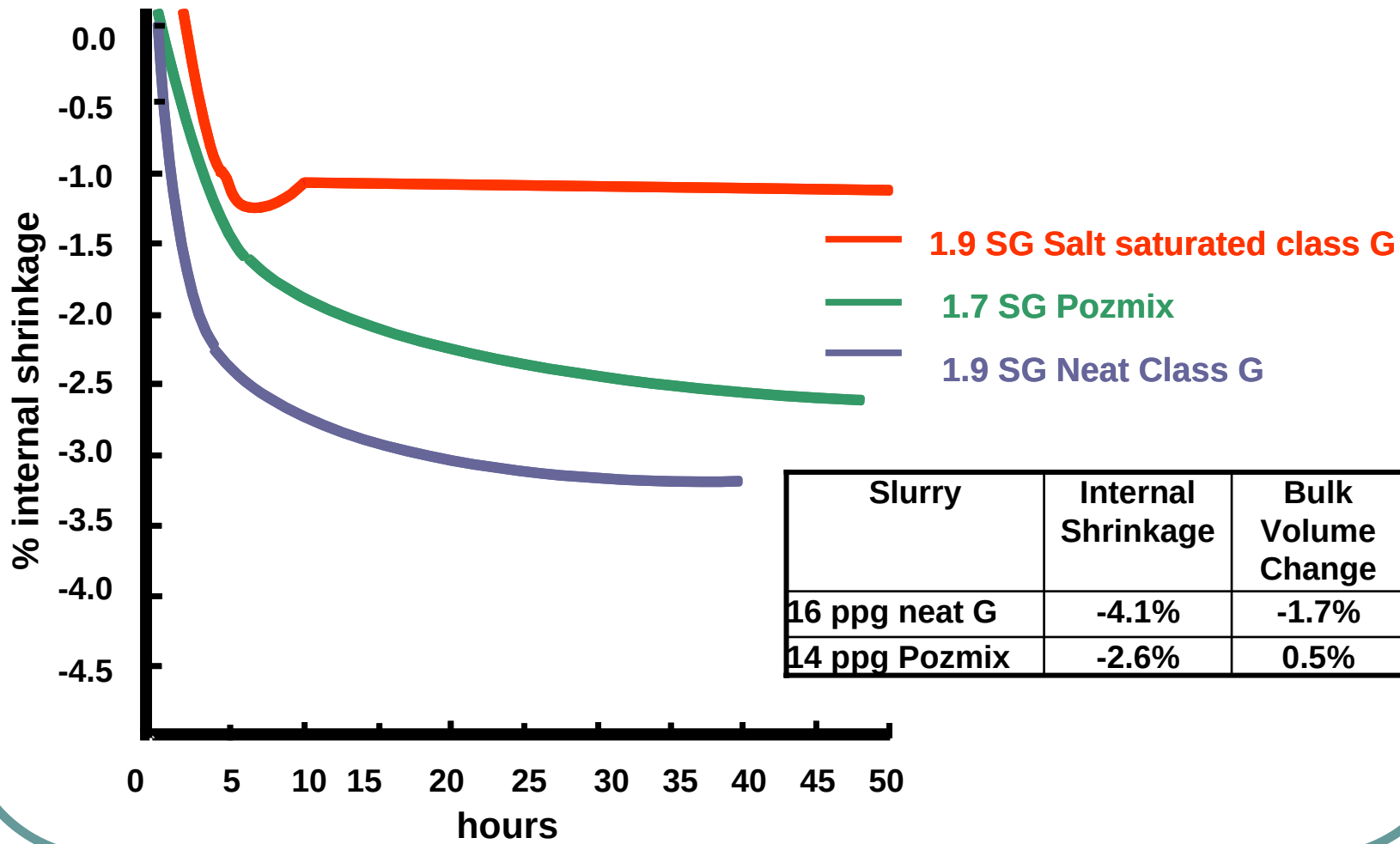


Cement expansion



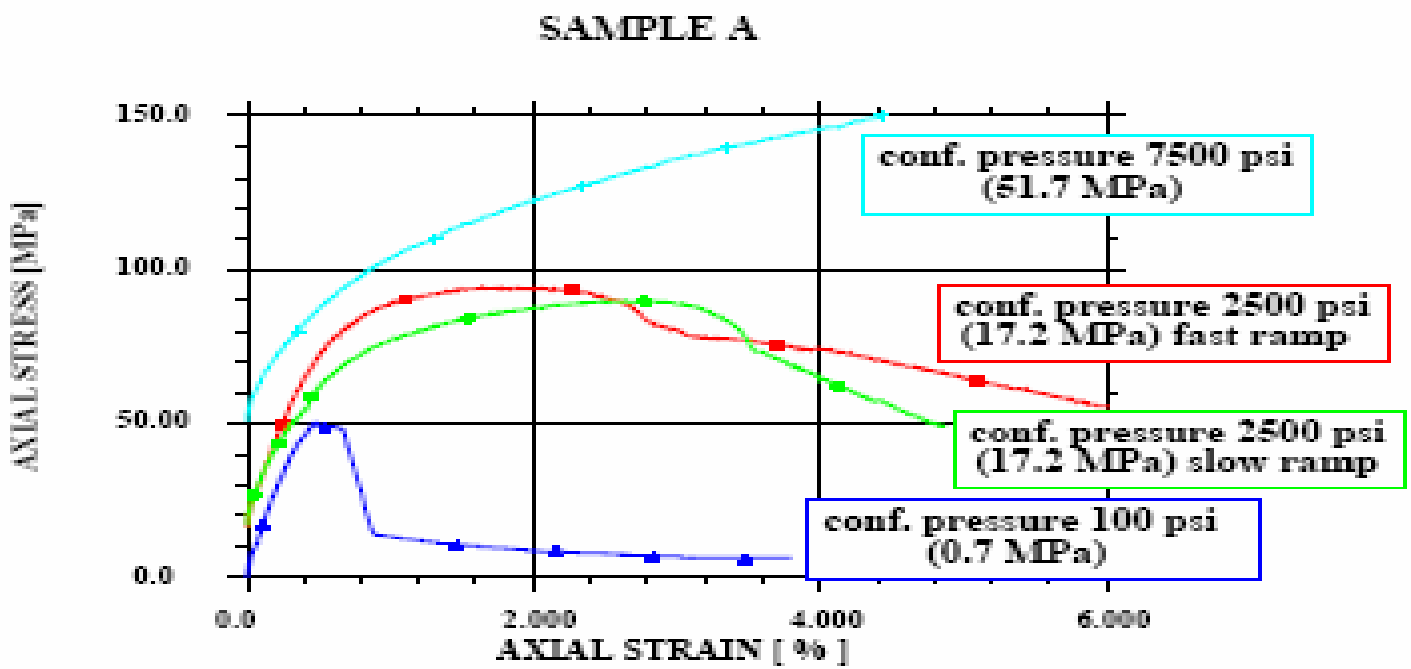
Does expansion occur when you need it ?

Internal and external volume changes



Slurry	Internal Shrinkage	Bulk Volume Change
16 ppg neat G	-4.1%	-1.7%
14 ppg Pozmix	-2.6%	0.5%

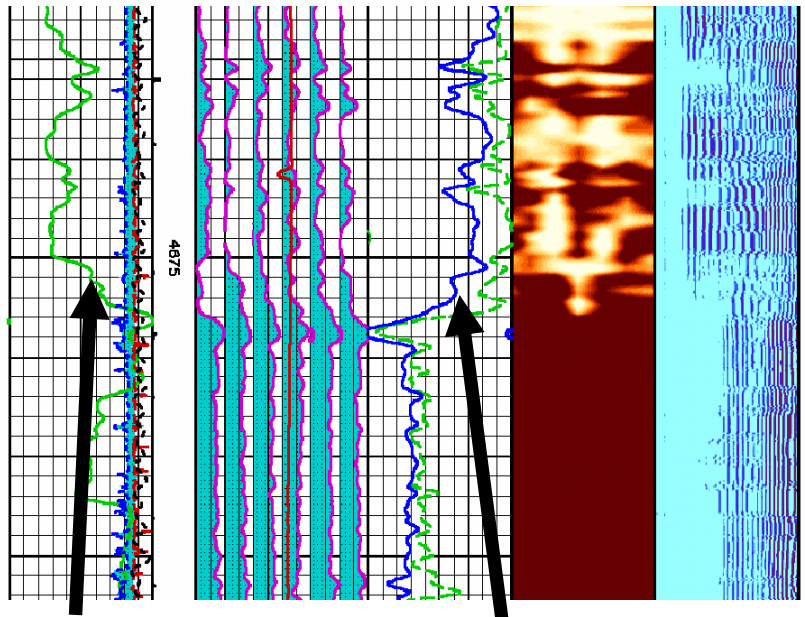
Cement mechanical properties



- To impact the mechanical resistance novel cements must decouple stiffness (Young's modulus) from tensile strength.
- Determination of mechanical properties under triaxial conditions is critical for modelling.

Bond variability across sands and shale

Commonly, cement evaluation indicates superior bonds are obtained against shale's compared to sandstones.



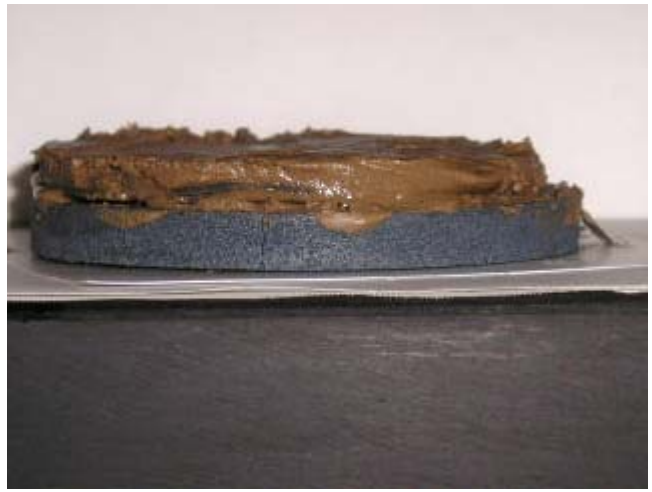
gamma ray

attenuation

Possible explanations for lithology effect

- The log is wrong!
- Cement shrinkage due to fluid loss or bulk shrinkage
- Formation fluids entering cement impacting acoustic properties
- Shale squeezing onto the pipe
- Mud filter cake

OBM and WBM filter Cakes



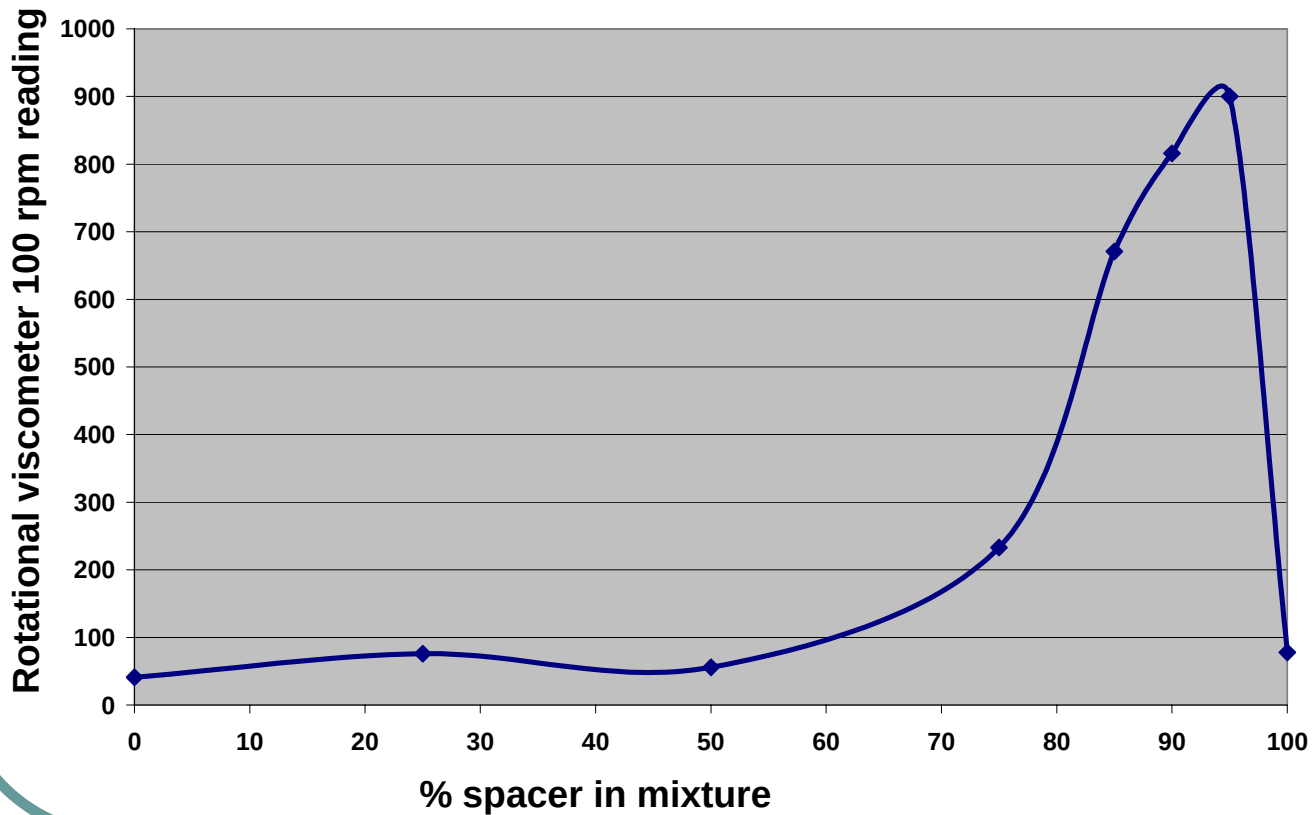
WBM @ 280 deg F		OBM @ 280 deg F	
24 hour fluid loss	= 40.2 ml	24 hour fluid loss	= 9.9 ml
Cake height	= 5/32”	“Cake” height	= 6/32”

Areas of concern

- Contamination of fluids
- Spacer Design
- Cement Bonding
- Cement Placement
- Execution / Logistics
- Annular Pressure Build Up
- Completion / Productivity

Mud Contamination of the cement spacer

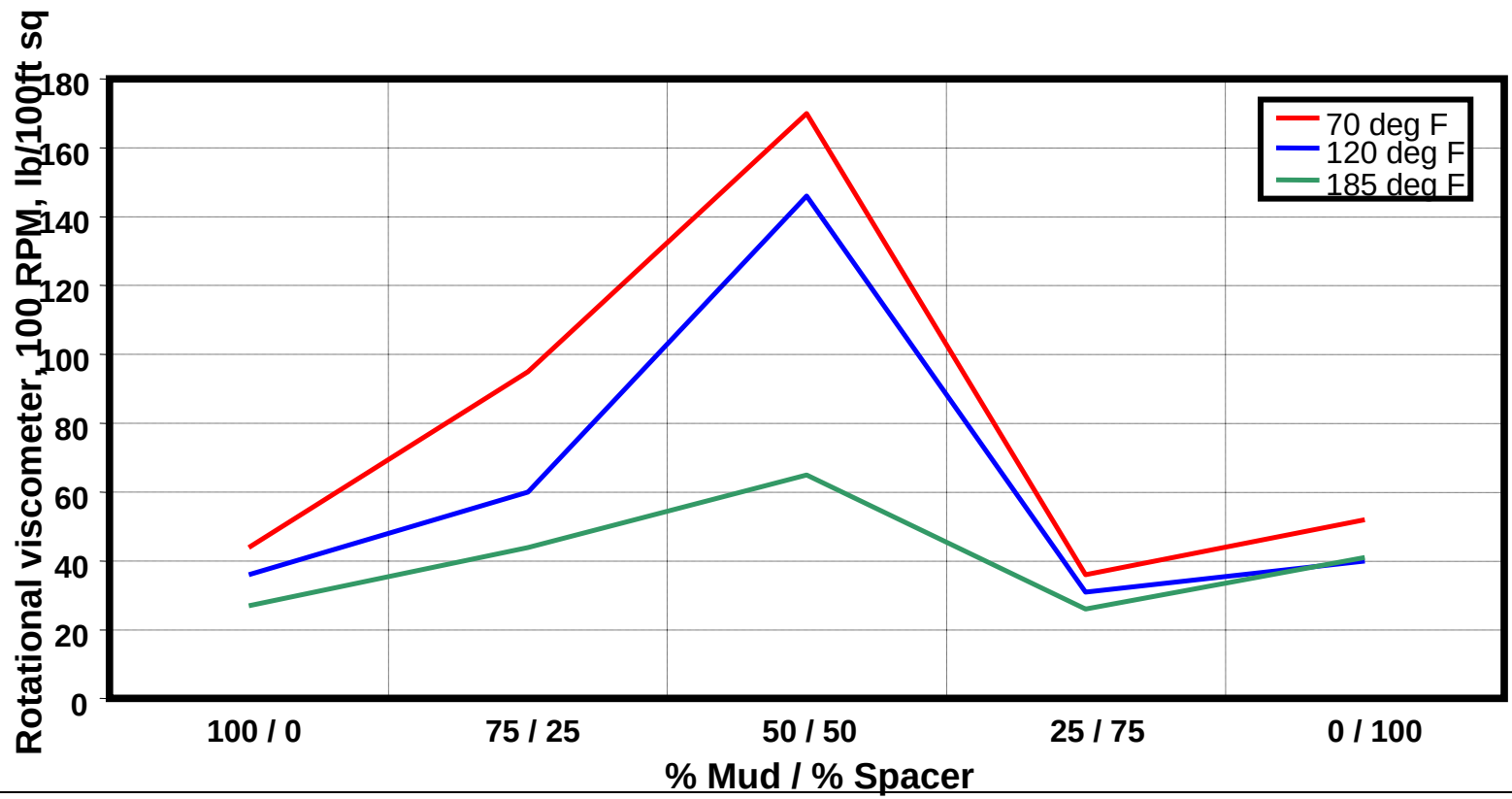
- Barite Sag due to surfactants impacting oil based fluids
- Unpumpable mixtures formed in surface lines or downhole



Spacer compatibility with mineral oil based mud
(some values extrapolated as reading off scale).

Note: Problem not really evident at 25% mud contamination !

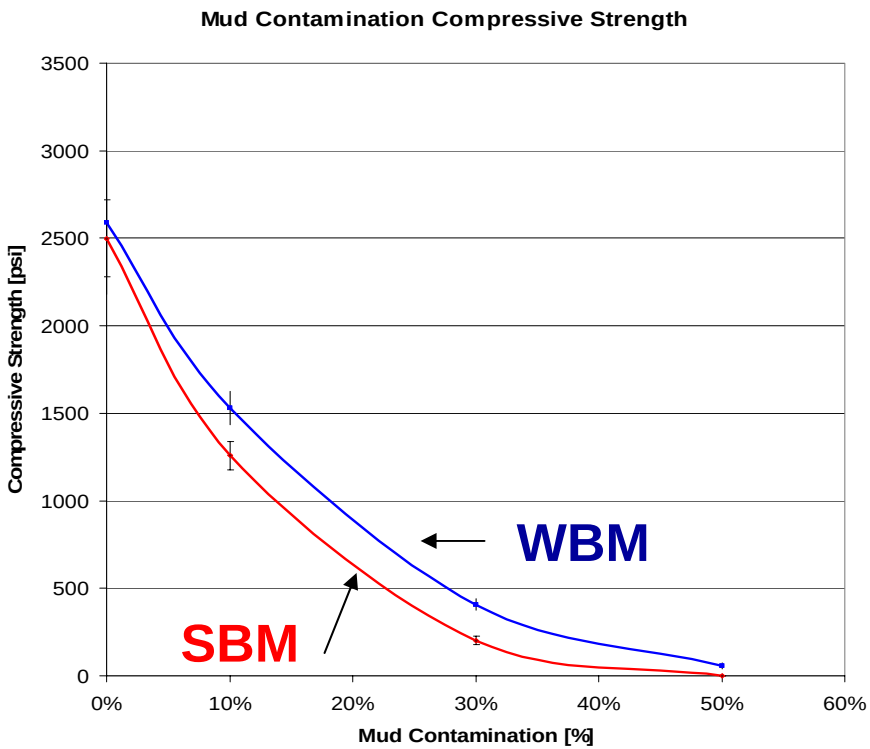
Temperature effect on compatibility



Surfactants are Temperature Dependent,
Very Critical in Deep Water

Mud contamination of cement

- Acceleration of cement due to brine phase in cement (cemented in liner running tools)
- Retardation by WBM (lignins/HEC/citrates/ borates)
- Impact on strength/acoustic impedance and ability to quantify cement bonding



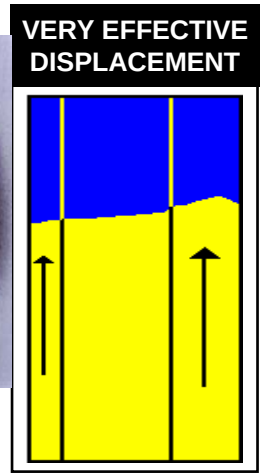
Forces dictating efficient fluid displacement

- Pressure Force
  - Due to rheology hierarchy and increases with increasing flow rate.
- Buoyancy Force
  - From the density contrast between fluids, the buoyancy force reduces with increasing hole angle.
- Resistance Force
  - The resistance to movement of the gelled mud in the annulus, increases as mud rheology increases and casing centralisation decreases.

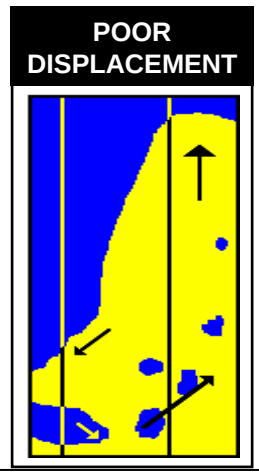
Simplistically for mud removal

$$\frac{\text{Pressure + Buoyancy}}{\text{Resistance}} > 1$$

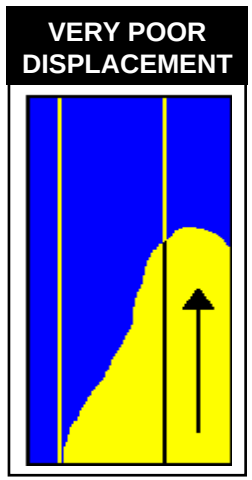
Displacement variables



Thin muds with good pipe centralisation and high flow rates



Thicker gelled muds displaced with lighter fluids with poor centralisation

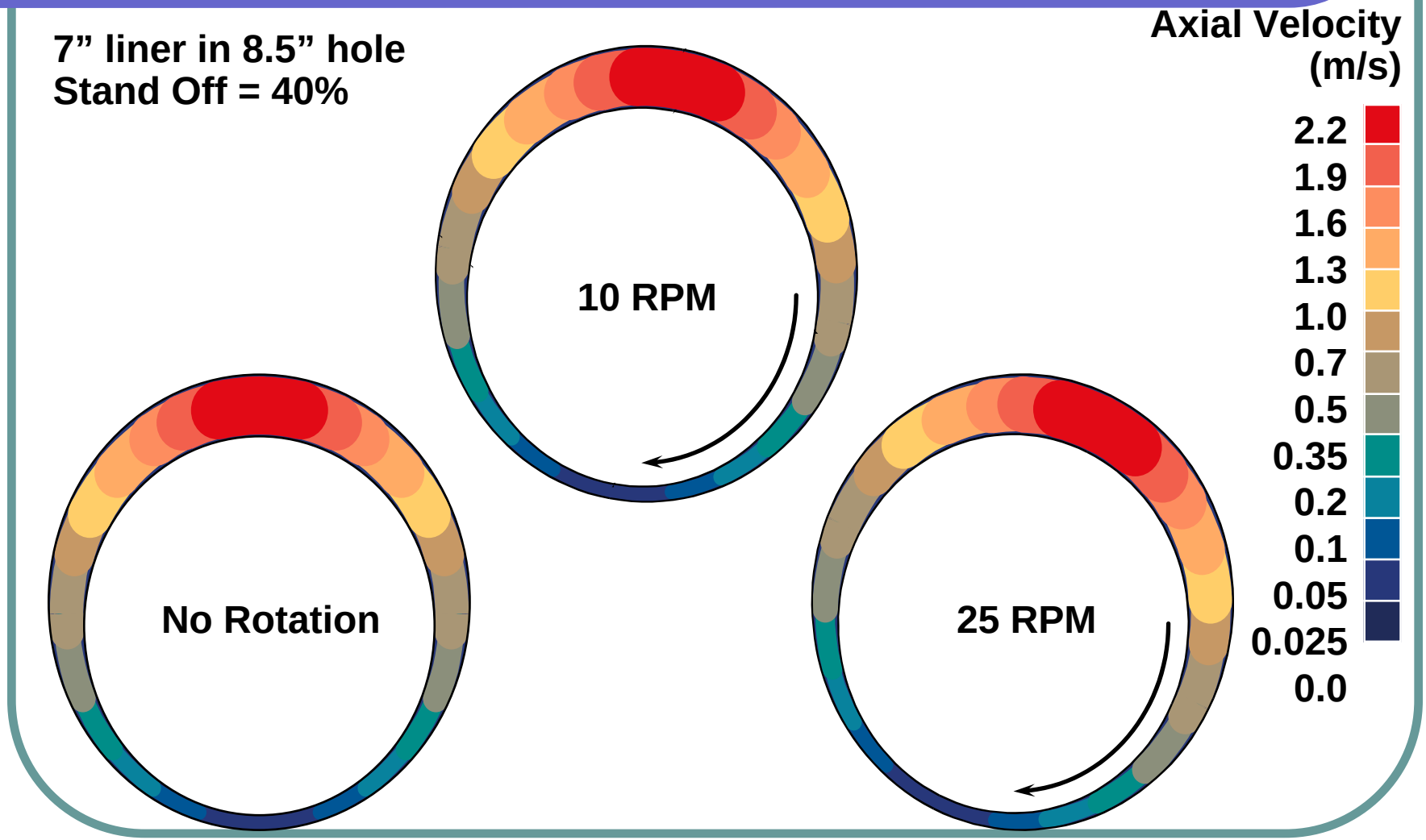


Thicker gelled muds displaced with ineffective spacers and poor centralisation

Variables to Improve Displacement

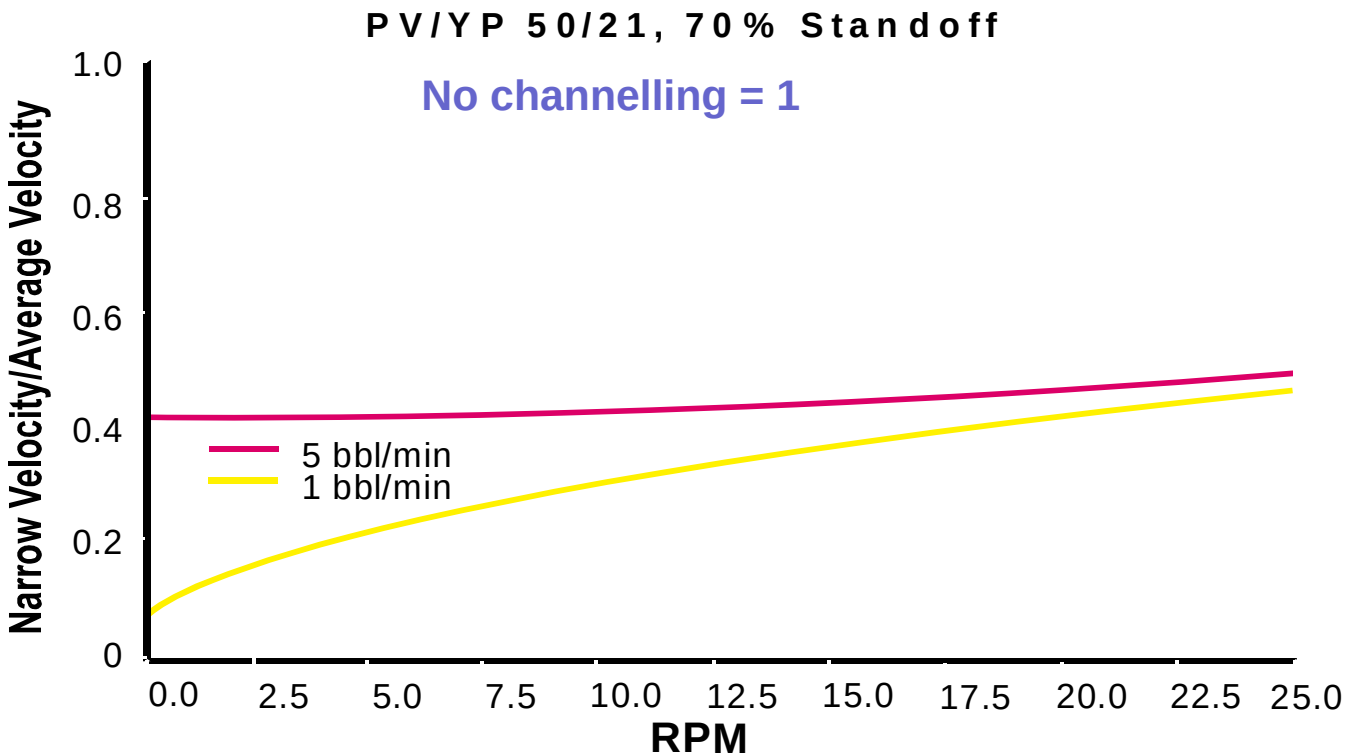
* Density Difference
* Flow Rate
* Rheology of Pill and Mud
* Volume / Contact Time
* Pipe movement

Predicted effect of rotation on annular velocity

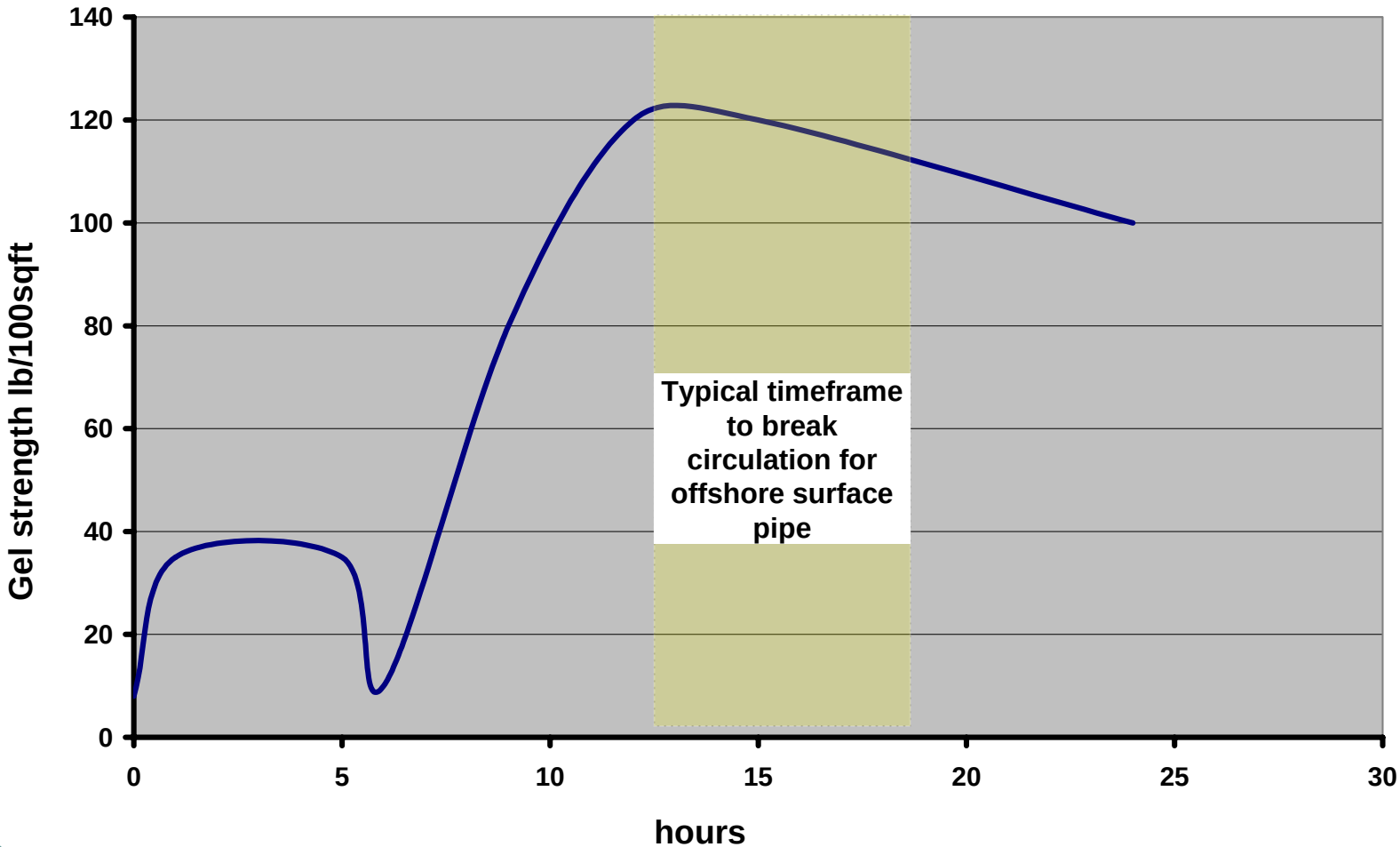


Does pipe rotation help ?

Computer modelling of flow during liner rotation



Extended gel strength development for gel mud



Conclusions

- There is a large industry problem related to the integrity of the cement sheath providing Long Term Isolation.
- Cement mechanical properties are important, but are highly dependent on confining forces.
- Temperatures in deepwater have a big impact on cementing temperatures and surfactant efficiency in cement spacer.
- Mud displacement and subsequent cement placement is the main cause of poor zonal isolation.

END