World Oil® HPHT

DRILLING, COMPLETIONS & PRODUCTION CONFERENCE

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Designing the Next Generation of Top Hole Resilient Cement for HPHT Platform Wells

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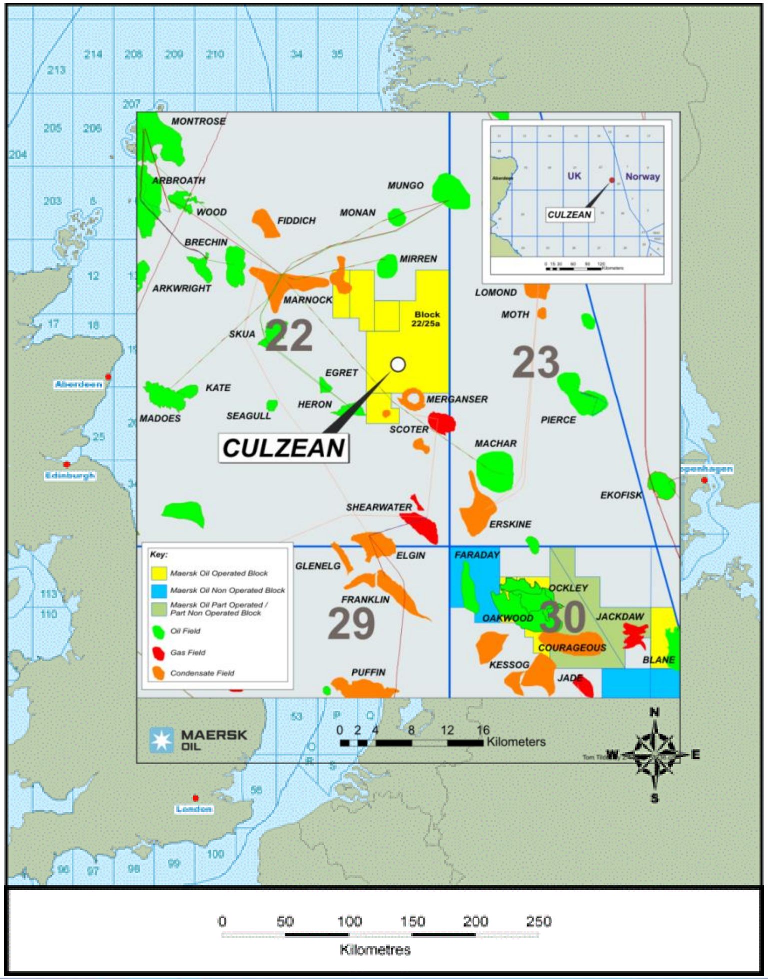
Introduction

This presentation is the reflect of combined efforts and collaboration amongst the following companies and their representatives:

- Maersk Oil:
  - David Vavasseur
  - Kevin Hyland
  - Christian Pasturel
- Altus Well Experts
  - John A. Howard
- Halliburton Cementing
  - Lesley Cartwright
- Curistec
  - Axel-Pierre Bois
  - Gregory Galdiolo

Culzean Field Location

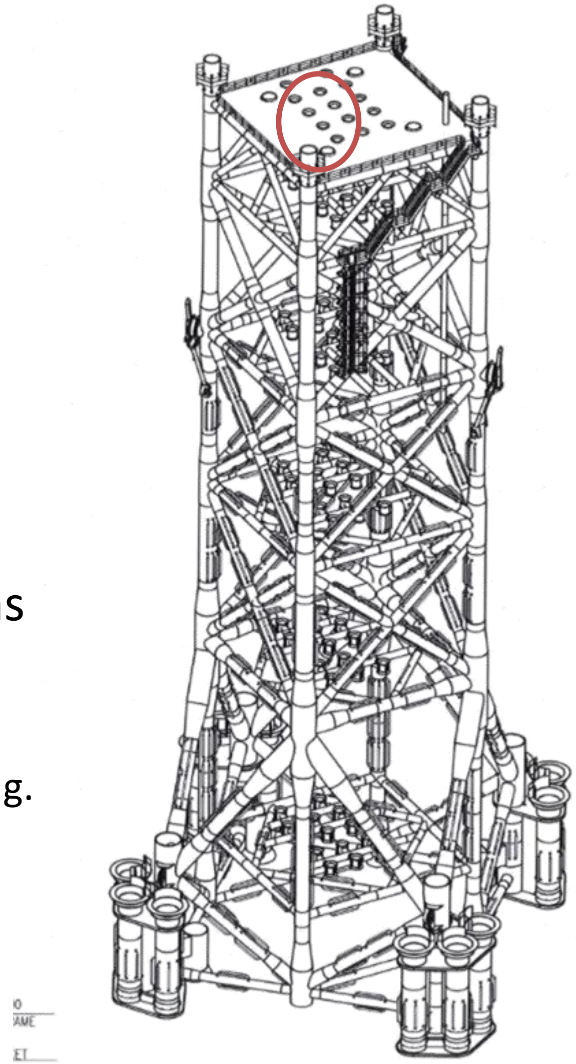


Culzean Field Development Overview

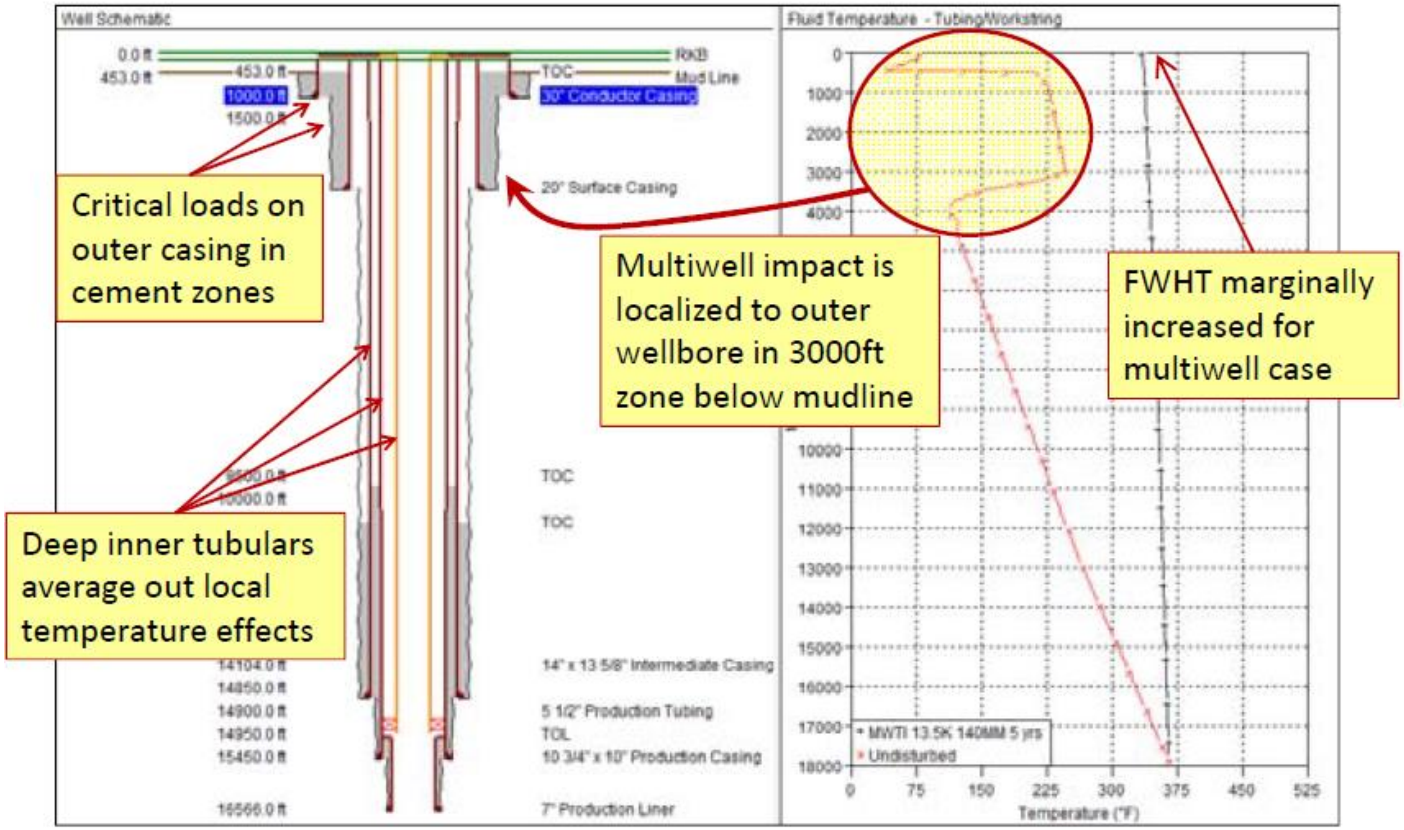
Discovered	2008
Appraisal	2010 - 2012
Field Development	6 HPHT wells + 1 Produced Water Injector Started Drilling: Q3 2016 1st Completion: Q3 2018 1st Gas: Q2/Q3 2019 Production: 500MMSCF/day (±5% of UK gas demand by 2020/2021)
Partners	• Maersk Oil, 49.99% (Operator) • BP, 32% • JX Nippon UK, 18.01%
Well conditions	• Formation pressure: **13,600 psi** @ 15,700 ft TVDSS • Formation temperature: **173° C** @ 15,700 ft TVDSS (343° F) • SITHP: **11,600 psi** • WHFT (steady state): **154°C** (310°F)

Context

- Jacket HPHT Development
- Slot Spacing 10ft centre-centre
- 290ft Water Depth – 90ft airgap to Wellheads
- Vertical Wells to KOP @ 3400ft – 20”Casing Shoe
- 6 Wells as initial development
- 36” & 26” Drilling sections batch drilled
- 30” Conductor Pipe Locked at surface with 20” Casing as mitigation to Wellhead Growth.
  - Production induced thermal cycles leading to Conductor Pipe working either in tension or compression through thermal cycling.

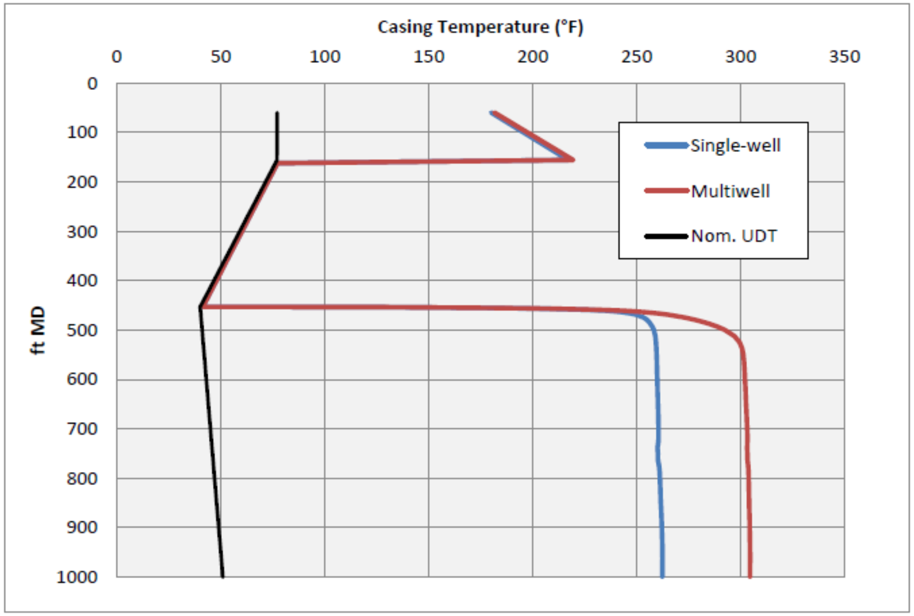


Multi well – Production temperature profile



Impact on Temperature Gradient

Figure 6.2.5 Maersk Culzean BJ24_5 Well, 30" Conductor: Single-well vs Multiwell Casing Temperature



+37° F average temperature increase along 30" CP
+21°F average temperature increase along 20" Casing (against single well thermal simulations)

- Impact on:
  - Material selection
  - Wellhead Growth
  - Temperature profiles for
    - Surface string selection
    - Casing Stress Analysis
    - **Cement Design**

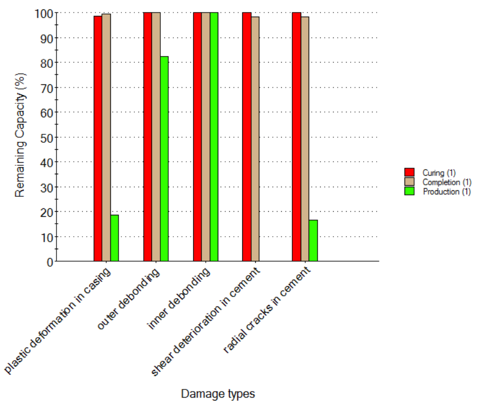
Original Cement proposal and early simulations results

- Initially 4 Slurries were considered
  - 12.0 ppg Water Extended Tuned® Light XLE® (unlikely to prevent wellhead growth during production – dismissed after first pass analysis)
  - 12.0 ppg Tuned® Light cement solution (reduced weight Tuned® light)
  - 12.0 ppg Foam Cement – 16.0 ppg Class G Base Slurry
  - 12.0 ppg Welllife® cement – Enhanced Mechanical Properties Cement System

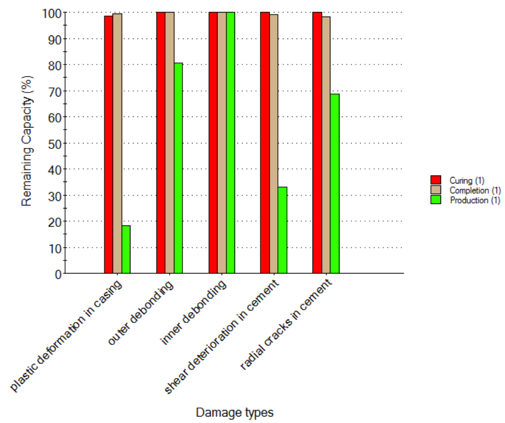
Slurry	TOC @ Mudline	WOC	WellLife Analysis	Cost	Operational Risk	OTJ Flexibility
TLXLE (@12ppg)						
TLS						
Foam						
WellLife						

Halliburton Remaining Capacity for each failure mode @ 990ft MD

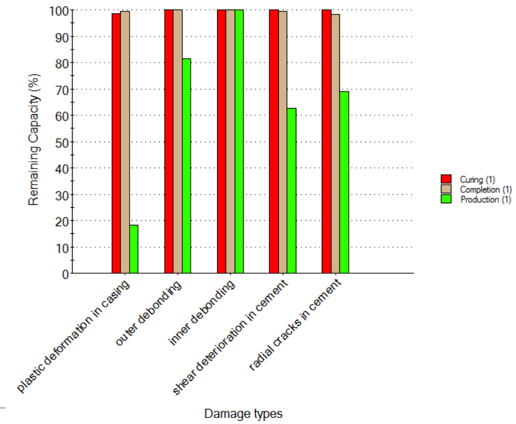
Tuned ® Light cement solution



Foam cement



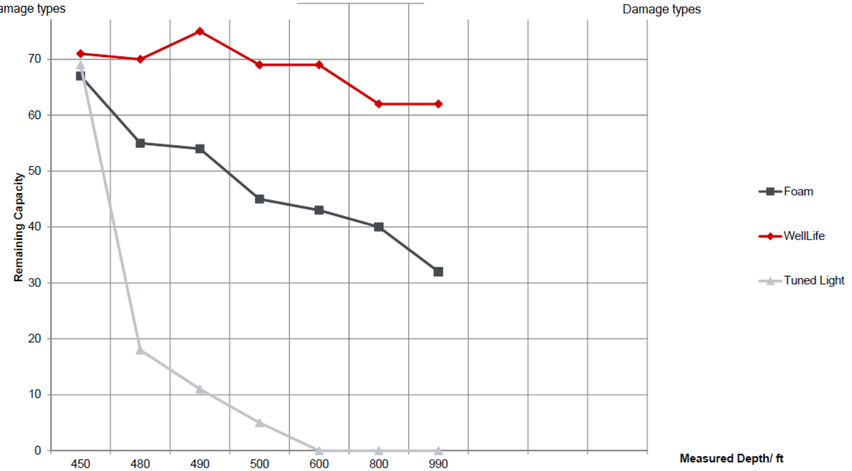
WellLife ® cement



- Predicted potential failure modes for Tuned ® Light designs:
  - Shear deterioration
  - Radial cracks (Tensile mode)

- WellLife ® and Foam have increased RC due to:
  - Improved Young's modulus
  - Increased tensile strength
  - Increased Cohesion

Red= Curing Brown=Completion Green=Production



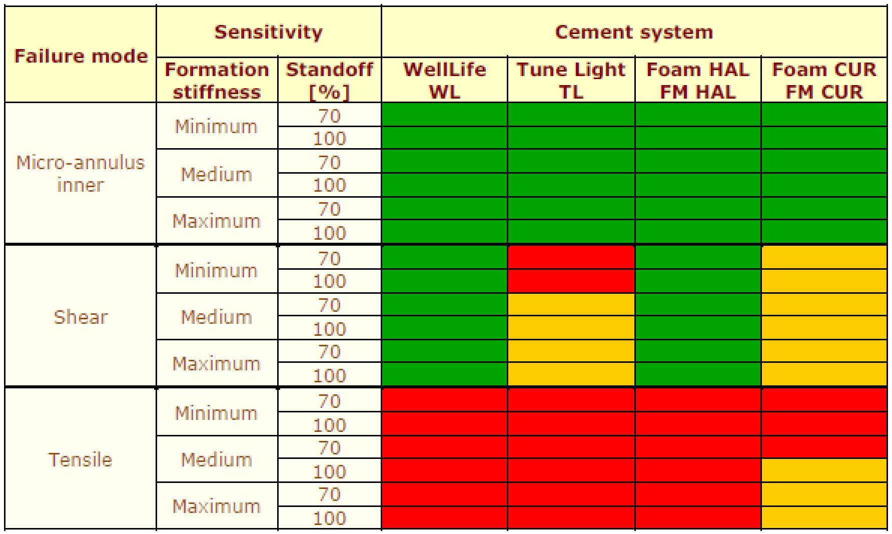
30" Conductor

Conclusions of WellLife® Analysis

- Halliburton WellLife® analysis
  - Tuned® Light XLE® cement 12 ppg: Did not pass Halliburton internal criteria
  - Tuned® Light cement solution 12 ppg: Did not pass Halliburton's internal technical criteria
  - Foam cement: Improved results, not guaranteed for life of well
  - WellLife® cement: Passed Halliburton's internal technical criteria

- Maersk Oil involved Curistec as 3rd party for assessment of cement properties results due to:
  - WellLife® cement being the only cement fully passing Halliburton analysis, resulting in:
    - Extended Waiting On Cement time (>72hrs)
    - Cost impact
    - First time it would be used for a Conductor Pipe primary cementation
    - Plan to batch set our conductors, potential for systematic failure

CurisIntegrity cement integrity results

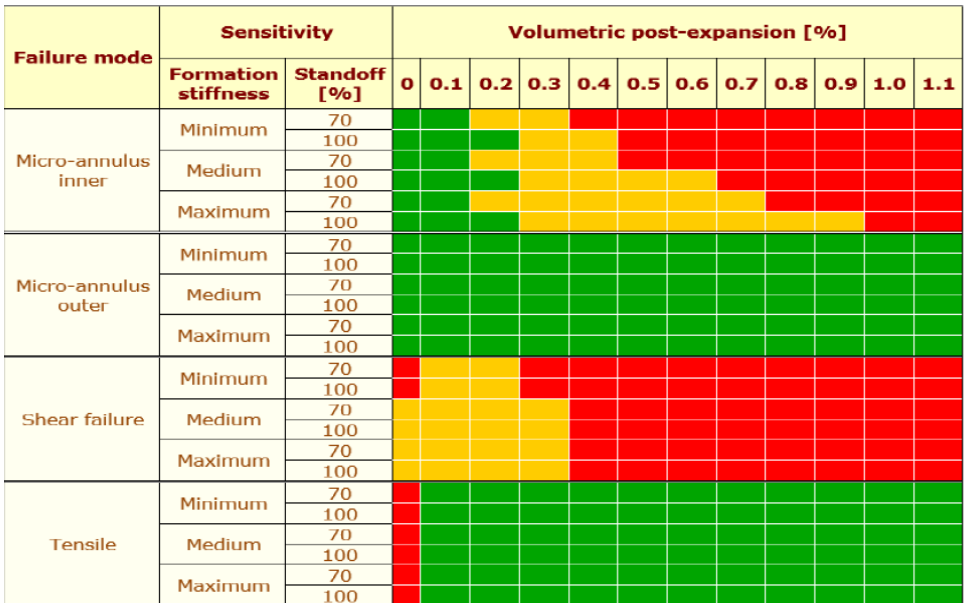


- Halliburton results confirmed for Tuned® Light solution
  - (Need to increase UCS and Friction angle, implies a complete blend re-design)
- Slight discrepancies on Foam cement related to model used.
  - Post expansion on foam to be evaluated
- Welllife® cement showing issues with tensile failure (0% post expansion coefficient).
  - If some risk of debonding close to seabed is accepted, will pass with some post expansion (i.e., 0,5 %)
  - If risk not accepted need to decrease YM

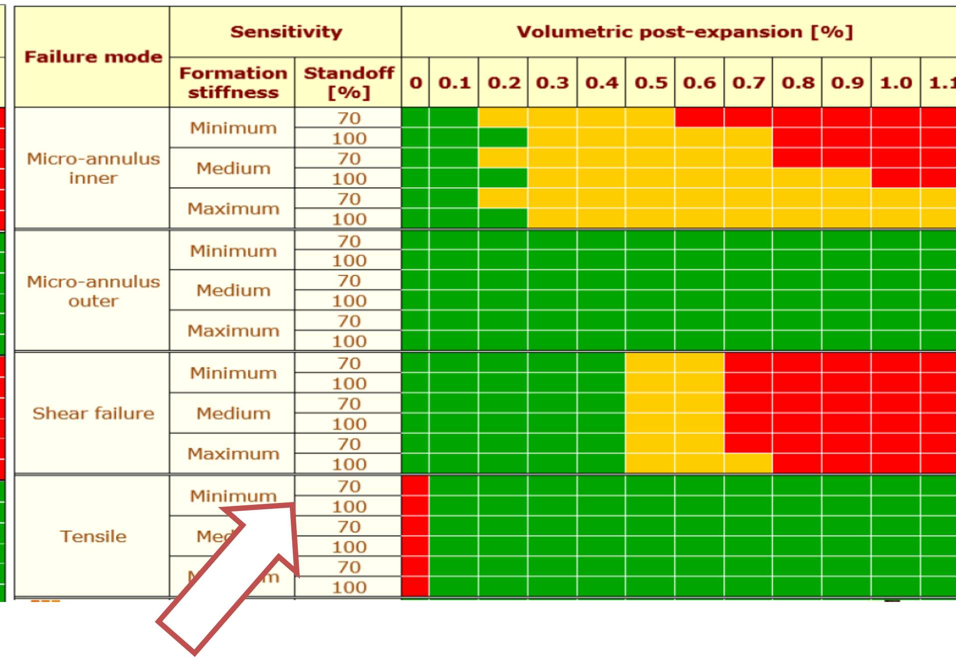
Proposed Action

Tuned® light Blend re-design

Original Tuned® light design



Failure mode and standoff vs. PE with optimized UCS (2500 psi) – YM= 0,975 Mpsi

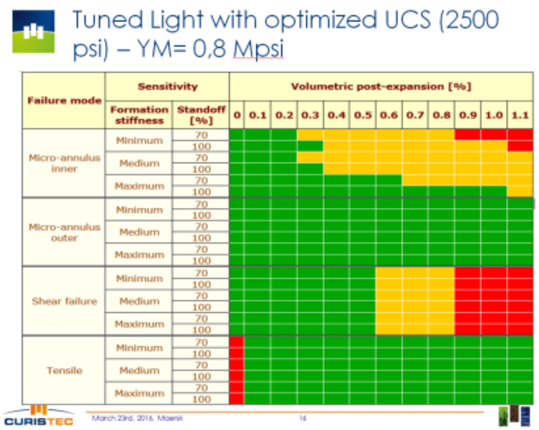


This looks fantastic but is this achievable ???

Halliburton and Curistec

Joint work for 30” conductor solution

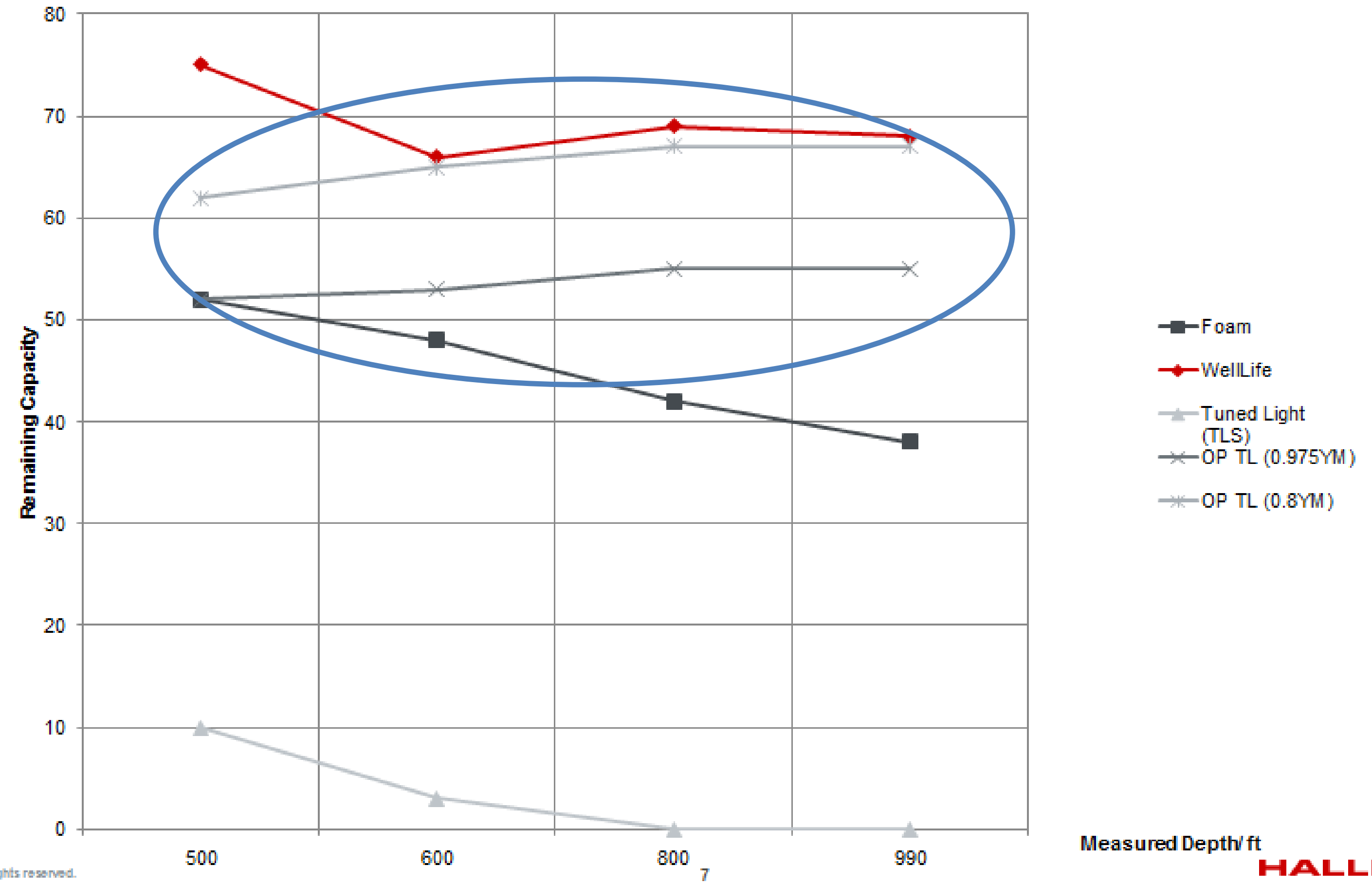
Property	Scenario 1 (Tuned® Light)	Scenario 4	Scenario 5
UCS (psi)	1335	2500	2500
YM (Mpsi)	0.975	0.975	0.8
PR	0.29	0.29	0.29
Friction Angle	4.7°	10°	10°
Cohesion (psi)	615	1049	1049
Tensile Strength (psi)	241	241	241
Expansion	0%	0.1-0.5%	0.1-0.5%



- Scenario 4 and 5 both pass Halliburton WellLife® modelling (good correlation with Curistec CurisIntegrity model)
  - Scenario 4: 55% remaining capacity
  - Scenario 5: >60% remaining capacity
- Halliburton specialists confident optimised scenario 4 properties can be achieved, aiming for properties displayed on scenario 5

Halliburton & Curistec

Running Scenario 4 & 5 through WellLife® Analysis



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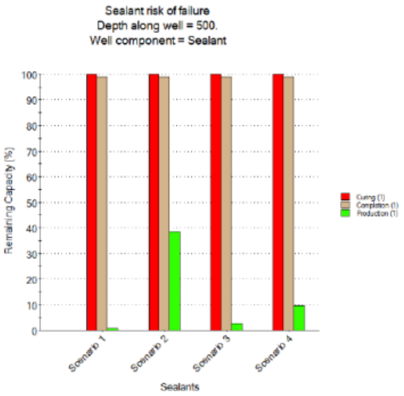
Conductor, Engineered Tuned® Light cement

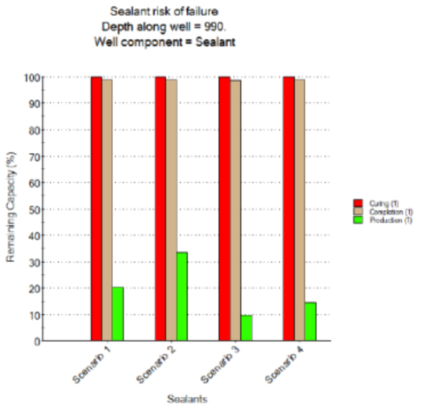
First Trials on blend optimization

Testing Summary

Property	Tuned Light 1	Tuned Light 2	Tuned Light 3	Tuned Light 4	Target
YM	0.641 Mpsi	0.663 Mpsi	0.6 Mpsi	0.578 Mpsi	0.8 Mpsi (or lower)
PR	0.253	0.257	0.23	0.22	0.29
Cohesion	628 psi	889 psi	473 psi	564 psi	1049 psi
Friction Angle	9.64°	0°	14.6°	7.72°	10°
Tensile Strength	250 psi	250 psi	250 psi	250 psi	241 psi
Expansion	0%	0%	0%	0%	0.1 – 0.5%
UCS	1587 psi	1706 psi	1392 psi	1370 psi	2500 psi

Overview of results (tested designs)



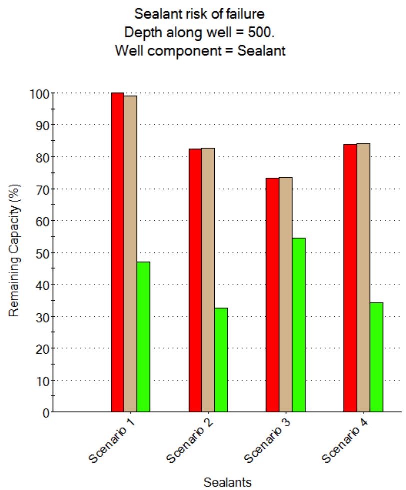


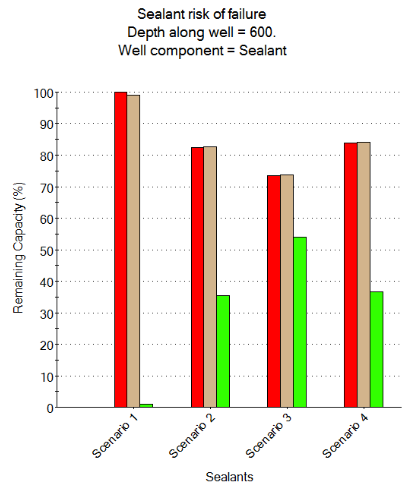
Early results highlighting challenges in obtaining proper blend and mechanical properties.

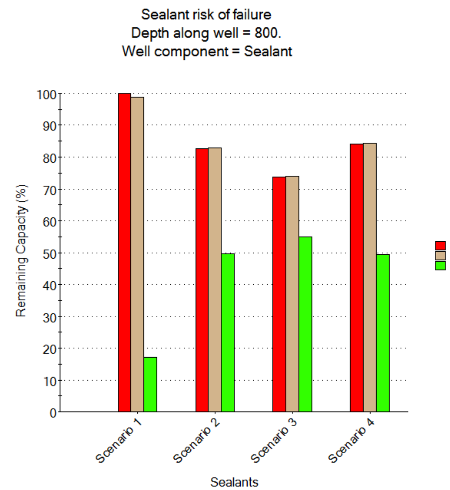
Blend design re-work and Final Lab testing

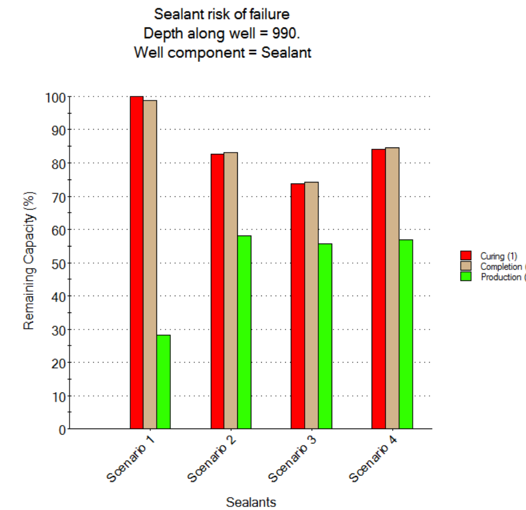
Property	TL 5	Modified TL5 #1	Modified TL5 #2	Modified TL5 #3
Scenario No.	1	2	3	4
YM	0.826 Mpsi	0.826 Mpsi	0.826 Mpsi	0.826 Mpsi
PR	0.24	0.24	0.24	0.24
Cohesion	1204 psi	1204 psi	1204 psi	1204 psi
Friction Angle	4.1°	4.1°	4.1°	4.1°
Tensile Strength	422 psi	241 psi	257 psi	300 psi
Expansion	0%	0.115%	0.175%	0.105%
UCS	2656 psi	2656 psi	2656 psi	2656 psi

Overview of final results









Final system engineered with a specified Youngs Modulus, UCS and volumetric expansion.
Achieved mechanical properties verified as suitable using WellLife analysis ®

Top Hole Batching operations conducted successfully using modified Tuned® Light cement (scenario 3) between September 2016 and January 2017 cementing 7 x 30" conductor pipes to mudline and 6 x 20" casing string to surface. A total of 2300 metric tonnes of Modified Tuned® light cement @ 12ppg were pumped.
Typical properties: 5hrs thickening time at 58°F / 500psi CS after 21:00hrs

Further Lab results have shown post expansion and cement properties in line with expectations.

Conclusions

- Early Well Life Cycle cement bond analysis was not performed by cementing contractor nor required to third party during tendering process for surface cement strings.
  - This would have highlighted issues with proposed blend and allowed precious time to engineer blend.
  - Well life type analysis is critical on HPHT platform wells where WH growth is a key element of design.
  - Key element in "failing" blend has been identified as elevated temperature induced by Heat island
- Complete engineering / design / blending / lab testing and tuning process to reach optimum solution took approximately 10 months.

- Engineering a blend is a long and iterative process requiring lab testing.
  - Expect multiple failures before reaching a balanced solution
  - Expect lengthy optimization of cement properties through testing.

- Constant care will be required in order to obtain good co-operation between different companies cementing experts !

Questions ?

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