Use of Cement Bond Logs for de-risking annular cement remediation via Perforate, Wash and Cement (PWC) techniques & a newly designed Tubing Conveyed Perforation System to permit successful placement of PWC plugs between concentric casings

Alex Lucas, SPE Aberdeen 7th European Well Abandonment Seminar, 27th June 2017

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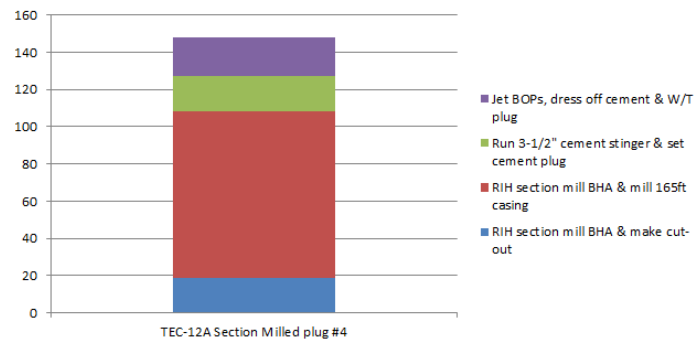
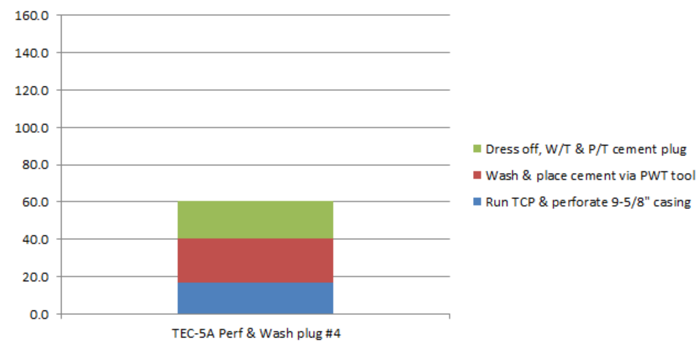
Why use Perforate & Wash?

Section mill 50m (165 ft) of 9-5/8" casing inside 13-3/8" & set plug: 148 hrs / 6.2 days



PWC 50m (168 ft) 9-5/8" x 13-3/8" concentric casing annulus & set plug: 60.5 hrs / 2.5 days



- When used correctly, Perforate & Wash can be a very efficient technique.
- Is performed in the more benign cased-hole environment = less risk.
- Can now be performed in concentric casing = even less risk, even more efficient & enabling a further step-change in performance
- Now ca. 2.5 times faster than 'typical' section milling performance (ca. 2 ft/hr).

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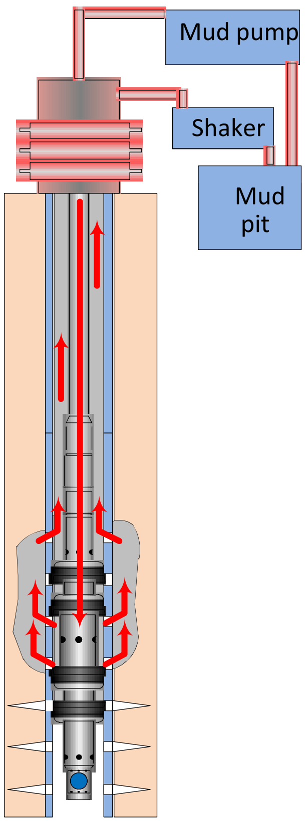
Main Perforate & Wash Methods: Closed-System ‘Cup-Type’ & Open-System ‘Jetting-Type’



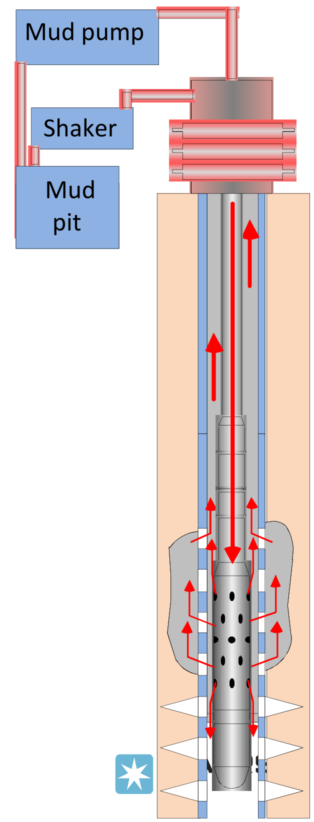
Closed-system Cup Type

1. Has double swab cups above and below nozzles.
2. Washing fluid is forced out of 6 x 0.906in nozzles between swab cups and into annulus via perforations.
3. Fluid has only 1 way to go and has to be forced into the annulus, i.e. is a ‘closed system’.
4. Can rotate string above cups by means of a swivel.
5. Cement is forced between cups and into annulus behind perfs.
6. Fluid bipass minimises surge/swab.
7. 12 to 18 spf with ~0.4 - 0.5in EH preferred

1. Due to closed system, standpipe pressure gives continuous *clear feedback signal of washing effectiveness*.
2. Washing data can be used to correlate vs. CBL data and *de-risk chance of washing success*.
3. If annulus is plugged or perforation unsuccessful/blank section, cannot circulate → *tool provides diagnosis*.

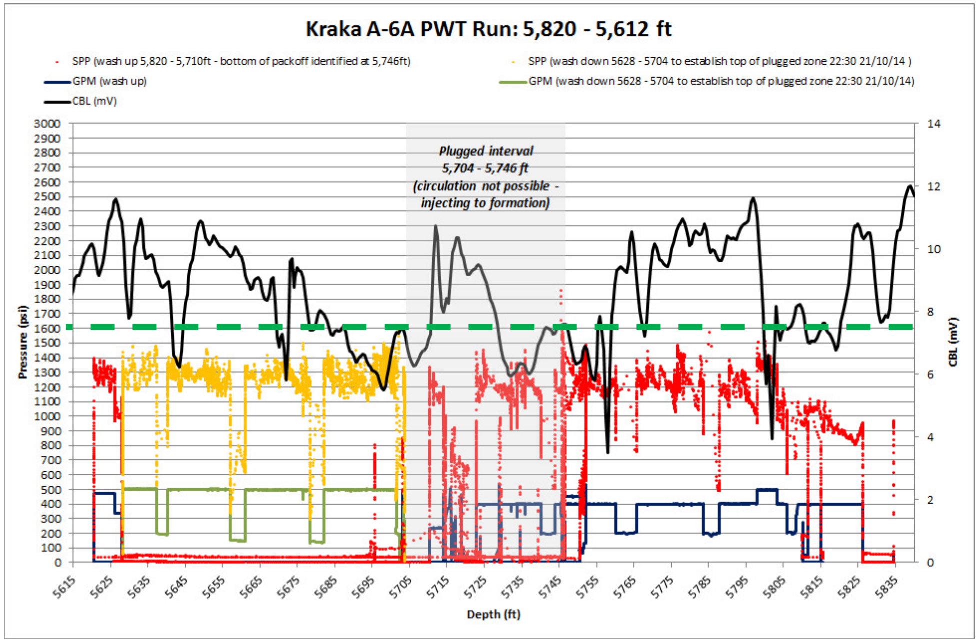
Open-system Jetting Type

1. Does not require swab cups.
2. Washing fluid is jetted out of e.g. 30 x 1/8in nozzles in a ca. 2.5 ft long sub at high velocity & impact force.
3. Fluid can flow both through perforations to annulus behind and also DP/casing annulus, i.e. is an ‘open system’.
4. Can rotate entire BHA at 6 rpm (when over perfs) & 120 rpm (when outside perfs).
5. Cement is sprayed out of nozzles from a ca. 3 ft long cementing valve with 4 x 1/8in nozzles.
6. Cement is pushed in to perforations after spraying using an ‘Archimedes’ tool.
7. 18 spf with 1.1in EH or greater preferred



Observations from 1st use of Cup-Type PWC for workover annular cement remediation in Denmark (2013): lower zone

208 ft zone 1 perforated with 12 spf , 7", 12 SPF, 135/45°, 39G RDX charges with 0.53in av. EH.



- *Tertiary shale section, inclination 49.4 degrees at top of section, 50.1 degrees at bottom of section.*
- *Run duration: 53 hrs (39.5 hrs washing = 5.27 ft/hr or 0.09 ft/min).*

- Able to establish circulation at 400-500 gpm/1100–1400 psi
- But washing was very challenging indeed. Very slow progress: 39.5 hrs to wash 208 ft = 0.09 ft/min!.
- CBL was never above 12mV.
- At ca. 8-12mV, washing 'just' possible but at very slow rates (0.1 – 0.2 ft/hr)
- In shaded region where CBL was ca. 6 – 7.5 mV (with ca. 7.5 -11 mV 'hump' in the middle), **annulus pack-off established: circulation was impossible without injecting to the formation.**
- Signs of hole collapse (cm-sized returns)

Circulation at CBL values of ca. 8-12 mV possible, but marginal. Very difficult to impossible below this level.

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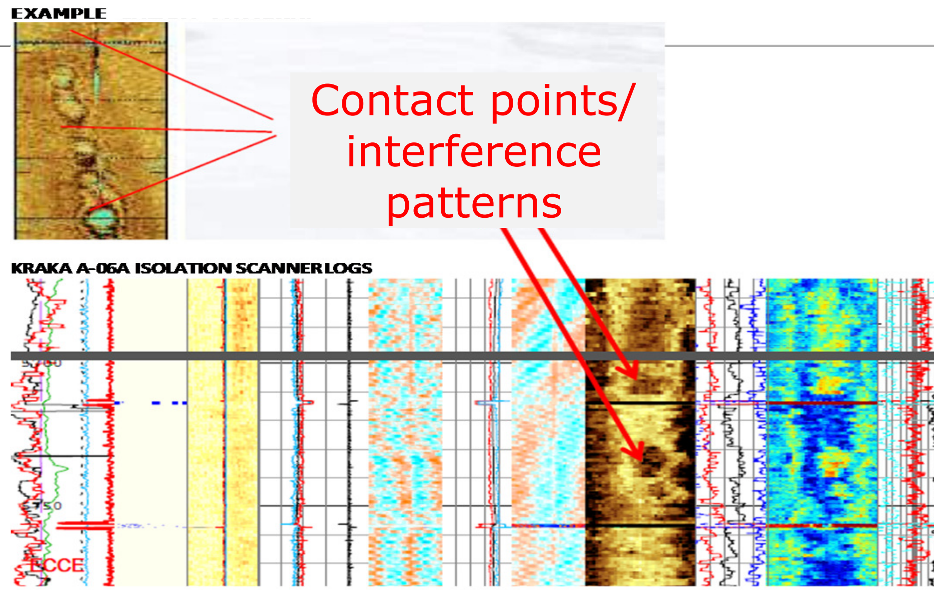
Evidence of plugged interval on acoustic impedance log (not noticed before PWT run for lower zone of Kraka A-6A)



- Subsequent re-analysis of the Acoustic Impedance track (AIBK) suggested there may be some formation contact with the casing on the low side, as well as the channel containing fluid already identified. The "interference patterns" - the darker colours presenting in oval shapes are indicative of this. See above textbook example, and the A-06A log.
- Interference patterns between ca. 5,705 ft – 5,746 ft appeared to correlate very well with the 5,704 – 5746 ft plugged interval, and 6-7.5 mV CBL 'trough'.
- ***Could a simple CBL log be a good general indicator for the ability to gain circulation with Perf & Wash?***

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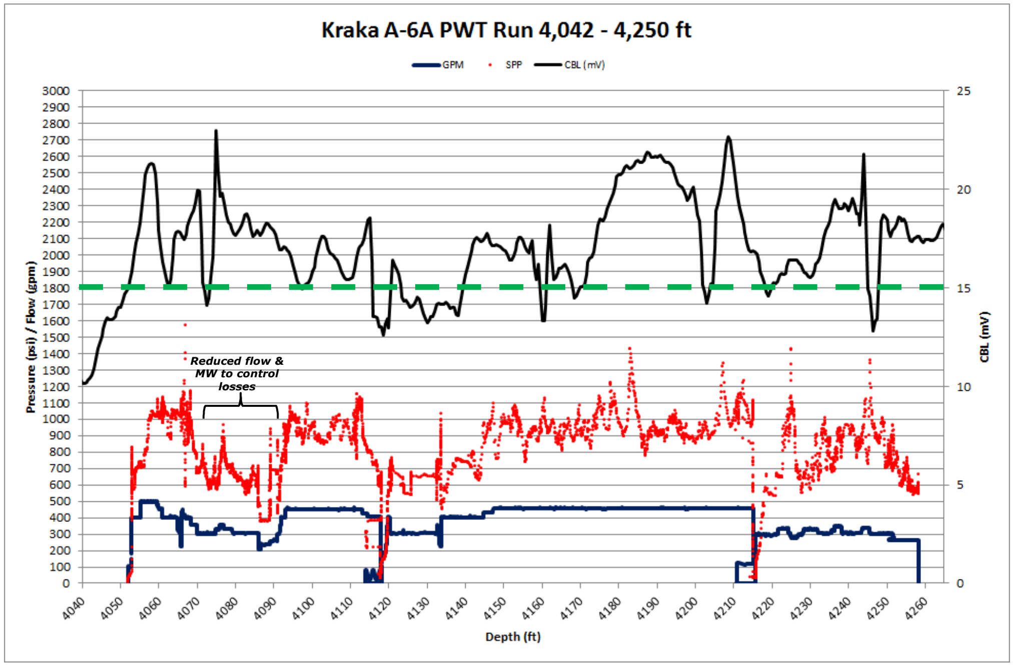
Observations from CBL vs Cup-Type PWC data from Kraka A-6A: upper zone



- *Tertiary shale section, inclination 8.1 degrees (bottom of section), 1.5 degrees at top of section.*
- *Run duration: 38.5 hrs (11.5 hrs washing = 18.1 ft/hr / 0.3 ft/min)*

- Much less problematic operations.
- Able to achieve relatively consistent loss-free circulation at 400 – 500 gpm @ 800 – 1100 psi after mud-weight adjustment in top 50ft.
- Washed at 0.3 ft/min - 3 times faster than lower zone, albeit at slower than target rates of 1ft/min.
- CBL was never lower than ca. 12.5 mV.
- ***Suggests CBL values of above ca. 15 mV in 47 # casing can be washed effectively.***
- ***Equivalent to ca. 11 mV for 40# casing.***

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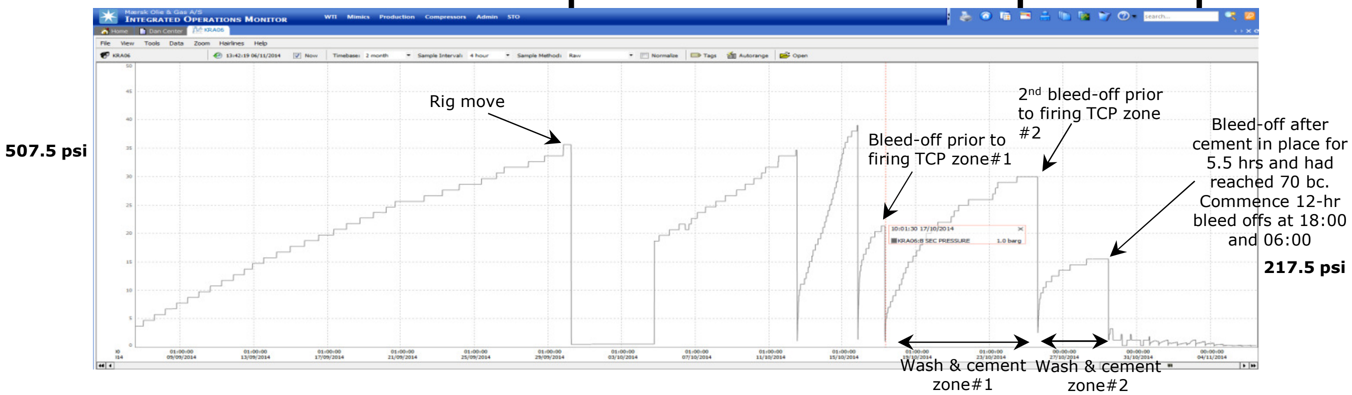
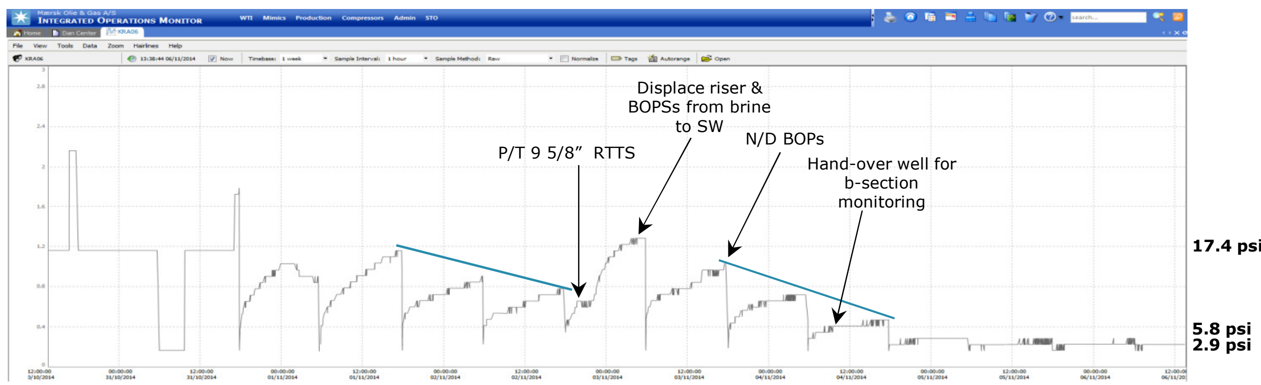
Kraka A-6A: B-annulus pressure trend pre & post-treatment





- B-section pressure build-up rates originally 1.2 bar/day (17.4 psi/day).
- Well suspended after treatment & PBU trends were monitored for several weeks to determine if remediation had been successful.
- ***Annulus stabilised & considered cured. Proceeded to install cemented tieback casing + completion.***
- ***Monitoring period was key to success!***

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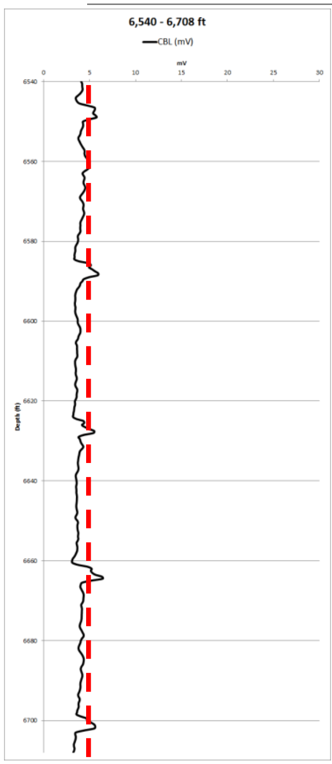
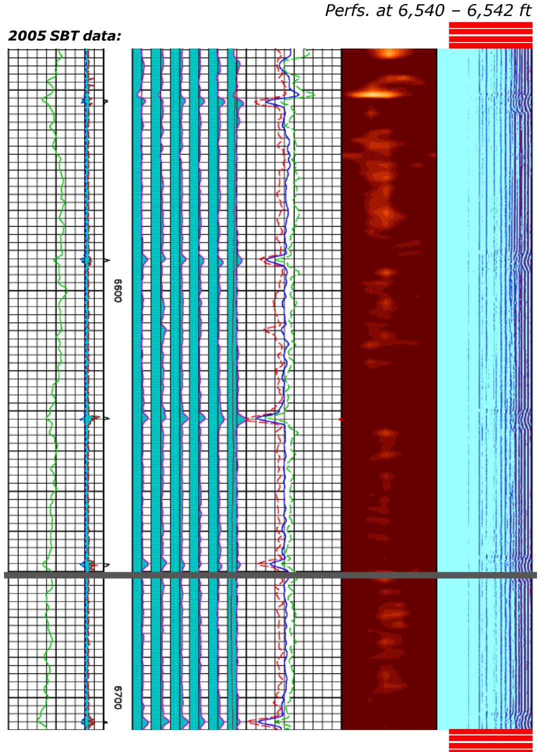
Observations from CBL & SBT vs Formation Tester (Defender) Tool (MFA-19, 2016)



Inclination 48.3 degrees at top of section, 48 degrees at bottom of section.

Perfs. at 6,540 – 6,542 ft

2005 SBT data:

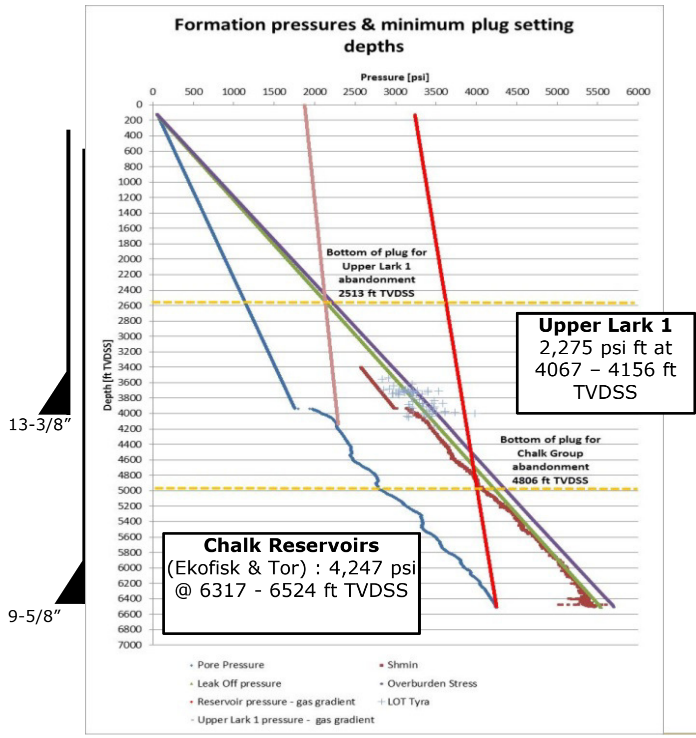


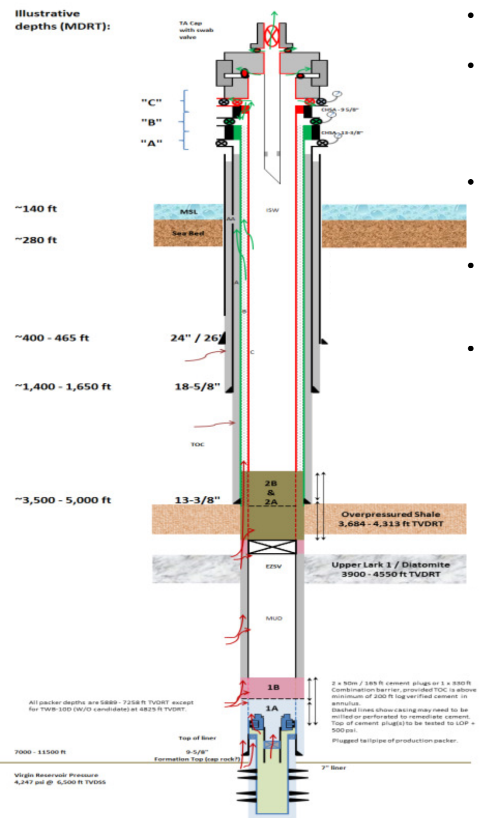
Perfs. at 6,706 – 6,708 ft

- Perforated with 2 x 2ft guns, 12 spf, 135/45 deg. phasing, 164 ft between perforated intervals. Distance between upper cups and lower cups: 13.91 ft.
- RIH to place mid-point between cups across lowermost perforated interval.
- P/U string and in-between cups to 300 psi and monitored trip tank for returns for 30 min. No returns. Lost a total of 14 psi over 30 mins.
- ***Hydraulic 'seal' confirmed.***
- Total job time: 24.5 hrs.

- ***Suggests CBL levels CBL ≤ 5 mV do not permit hydraulic communication/are hydraulically sealing for 40# casing.***
- ***Equivalent to ~7 mV for 47# casing.***
- Consistent with previous observations when attempting to wash.
- Formation tests on TEC-5A & TEC-12A showed very similar results.

‘Tyra Future’ Redevelopment Project: plug setting depths & ***temporary abandonment*** concept for a producing asset





- Tyra to remain on production until 2042.
- Isolation strategy of double isolation (2 x 165ft) above Ekofisk and double isolation (2 x 165ft) above Upper Lark to ‘***restore cap rock***’.
- Virgin pressure assumed for minimum plug setting depths.
- Upper Lark 1 is usually the suspected source of SCP.
- Preferable to be able to remediate inside 13-3/8” shoe if possible (less risk & more efficient)

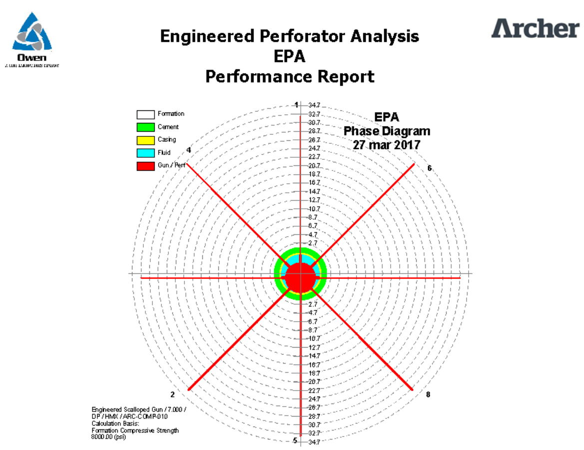
Requirement for new TCP system to perf. thin 40# casing without damaging 13-3/8”

Proposed new charge & 5-1/2" centralised gun system for concentric casing remediation

- New AP360 (ARC-PUNC-007) designed in co-operation with Owen Oil tools to meet client-specific requirement
- New 5-1/2" centralized gun system developed by Archer Oiltools

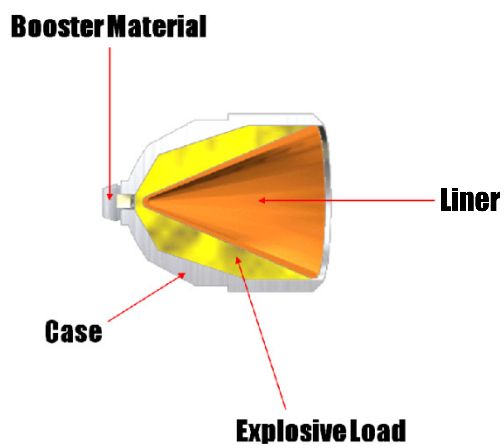
Conventional guns & charges for open hole

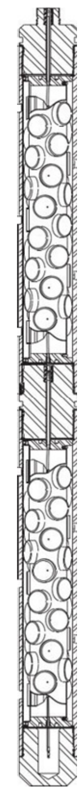
7" 12spf 135°/45° Spiral DP 39g RDX charge
(ARC-COMP-007)
Average Entrance Hole size: 0.4995"
Average Penetration: 32.77"



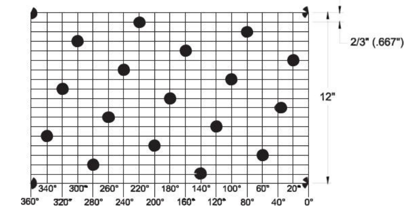
New guns & charges for concentric casing

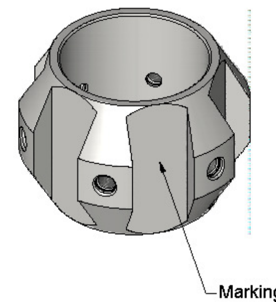
5-1/2" 18 spf, 140°/20° Spiral 26g HMX AP360 charge
(ARC-PUNC-007)
Average Entrance Hole size: 0.44"
Average Penetration: 0.005" into 13-3/8





SPECIFICATIONS		
PRESSURE RATING	68.9 Mpa	10,000 psi
TEMPERATURE	UP TO 260°C	UP TO 500°F
TENSILE STRENGTH	62,600 kg	138,000lbs
CARRIER THREAD	5" - 6 ACME	
GUN WEIGHT LOADED	57 kg/m	36 lb/ft





220.2 mm/8.669" OD Centraliser for 40# csg with 8.835" nominal ID / 8.679" drift casing

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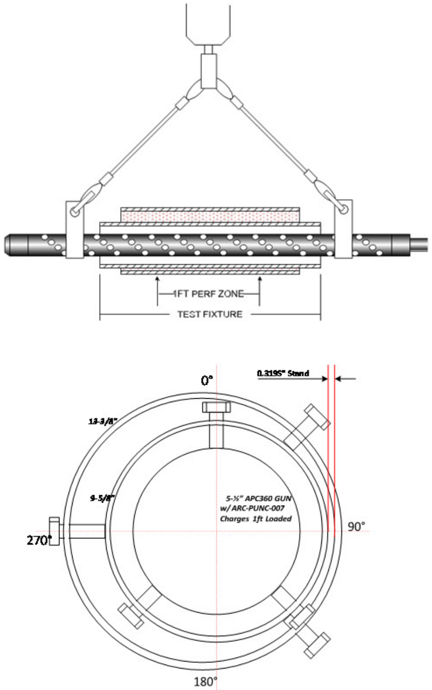
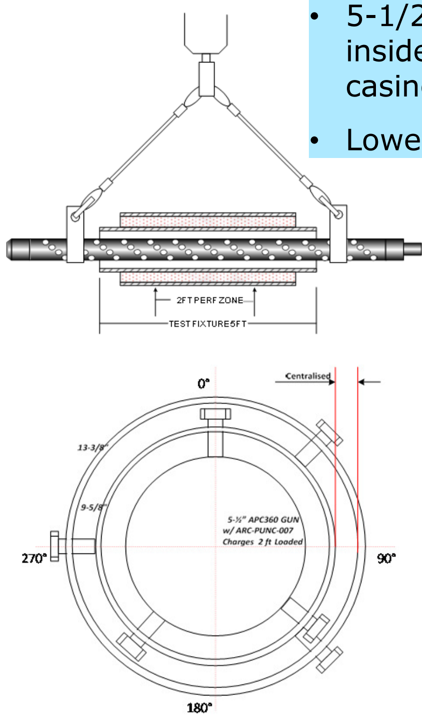
Full system test at Limehillock Quarry, UK (Owen): test setup

- 5-1/2” 18 spf, 140°/20° gun loaded with AP360 charges centralised inside 40# L-80 9-5/8” VM80HC casing placed inside 68# K-55 13-3/8” casing
- Lowered into survival pit water depth of 10-15 ft & detonated



Scenario 1
Fully decentralised 9-5/8” with 0.3195” stand-off



Scenario 2
Fully centralised 9-5/8”

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Full system test at Limehillock Quarry, UK (Owen): test results

Scenario 1
Fully decentralised 9-5/8″ with 0.3195″ stand-off

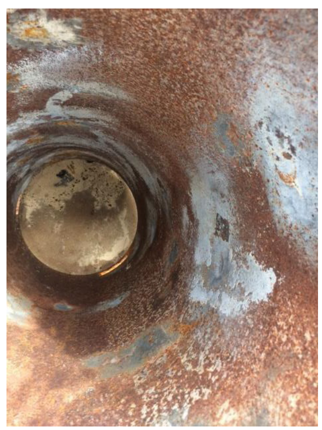
Scenario 2
Fully centralised 9-5/8″

- Charges did not damage 13-3/8″. Only slag deposits seen.
- Average EH size **0.44** in for both tests.
- However for **fully decentralised** 9-5/8″, only **6/18 (33%)** shots made hole. Others showed stretched/dimpled casing.
- For **fully centralised** 9-5/8″, only **19/36 (53%)** shots made hole. Penetrations observed sporadically over the 2ft section. Casing looked stretched/dimpled at the perforating point.
- Suspicion at the time was that this may be due to chrome content of the casing, allowing casing to stretch and absorb charge energy.

Full system test Ft. Worth, Texas (Owen): test results

Both tests conducted with 9-5/8" fully decentralised:

- **20/25 shots (80%)** made hole in **L-80 casing**. Av. EH size: **0.44"**
- **11/22 shots (50%)** made hole in **22Cr casing**. Av. EH size: **0.40"**
- Negligible damage **(0.005in)** to 13-3/8" casing
- Some stretch/deformation of 9-5/8" seen
- More shots expected to make hole in downhole conditions
- Coupon test directly on 13-3/8" showed only **~0.183"** penetration (38% of 0.48" WT)



Conclusion:

- AP360 can perforate 40# L-80 9-5/8" *<u>without damaging 13-3/8"</u>*
- Chrome content has a *strong influence* on ability of these charges to penetrate casing
- Lack of holes in VM80HC due to higher tensile & yield strength

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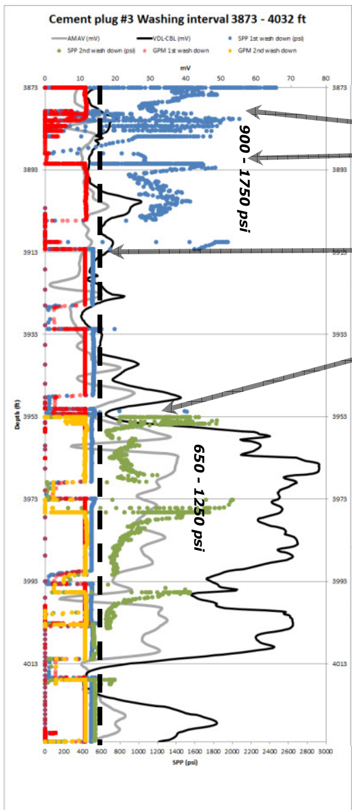
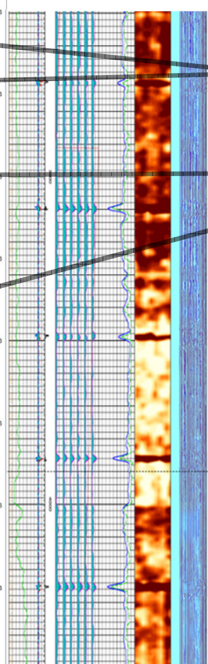
Concentric casing remediation application & CBL vs PWT parameters (TEC-05A, 2016 Tyra Campaign)



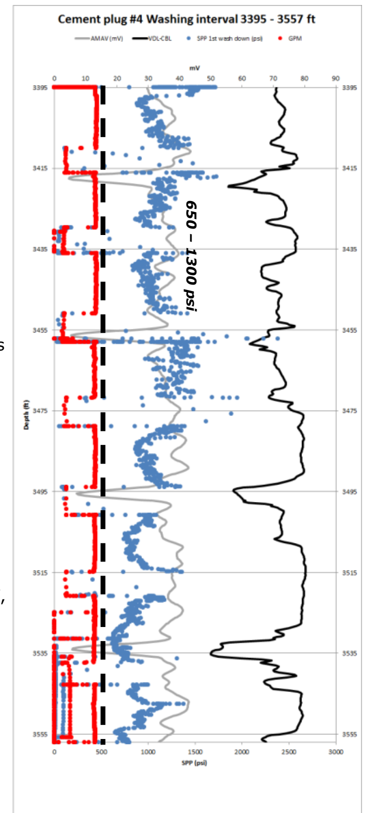


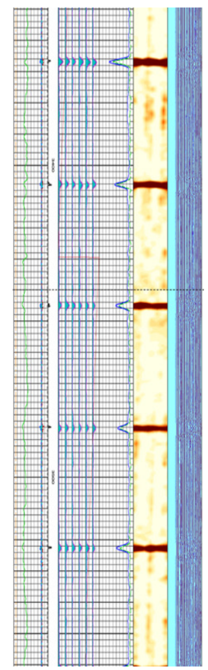
Inclination 7.3 degrees at top of section, 6.8 degrees at bottom of section.

- 3,873 – 3,912: high and erratic SPP experienced @ 420 gpm
- 3,875 – 3,891 ft : no circulation possible. After this point 1ft/min achievable.
- 3,912ft: SPP dropped markedly, suspected damaged casing from this point causing damage to swab cups
- 3,952 onwards: re-washed with new PWT tool – higher pressures seen than first wash, confirming cups were already damaged at this point during first wash.
- Actual washing time: 7.5 hrs.

Observations vs. CBL log:

- At ≥ **ca. 10 mV**, washing appears **possible.**
- **AMAV** curve is even more pessimistic & shows near casing response. Where circulation not possible at top, CBL picks up to 20 mV but **AMAV drops to ca. 6 mV**, indicating ***good near casing bond***.
- Where CBL is ca. **≥ 15 mV**, washing is **more consistent**: circulation always possible, more stable parameters.





Inclination 7.0 degrees at top of section, 6.9 degrees at bottom of section.

- More consistent washing parameters seen at similar flow rates.
- Achieved 425 – 450 gpm @ 600 – 1300 psi over the whole section
- 1 ft/min planned washing rate achievable
- Actual washing time: 4 hours.
- Total job time including dress off & W/T & P/T cement plug: 60.5 hours / 2.52 days

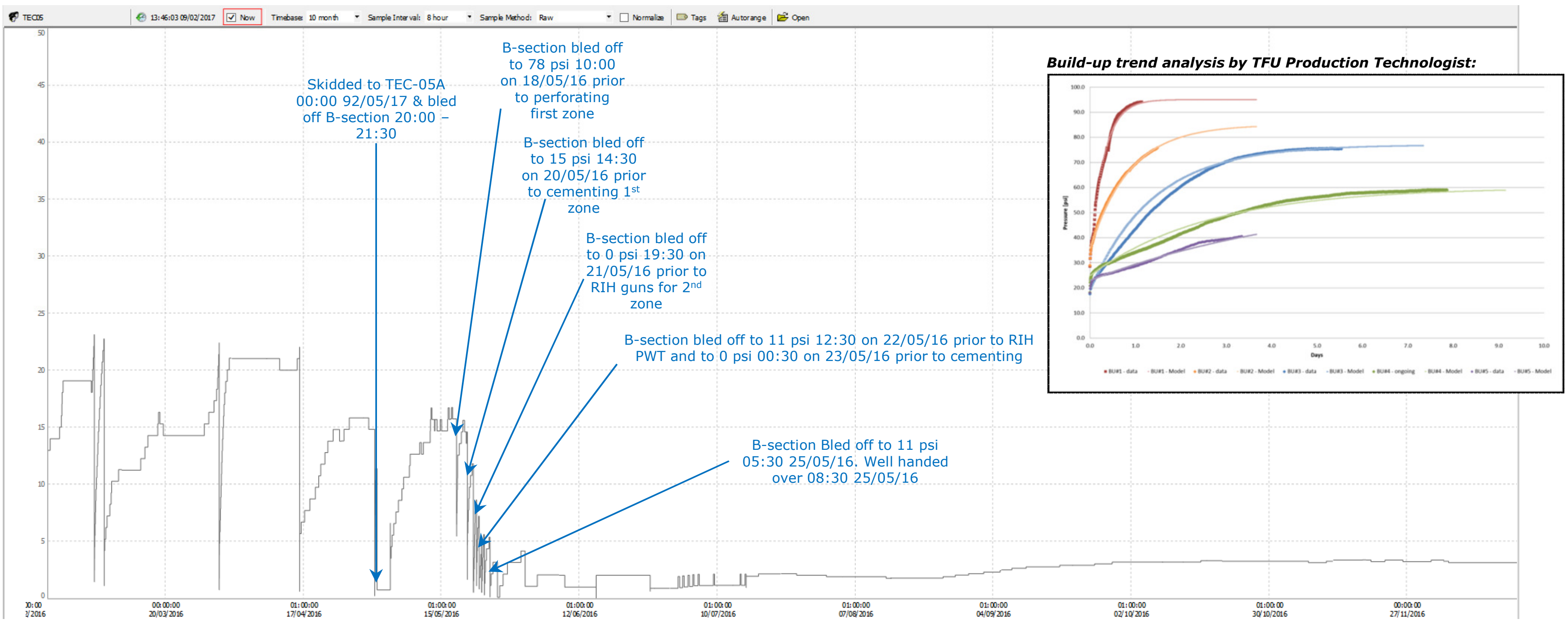
Observations vs. CBL log:

- CBL is generally ca. ≥ 70 mV, and washing parameters are more stable in the 650-1250 psi range and circulation is always possible.
- AMAV is generally ca. ≥ 30 mV

Conclusion:

- The TCP system worked.
- Able to successfully wash behind perforations in concentric casing annulus with CBL >10-15mV.
- AMAV also needs to be ca. 10 mV or above?

TEC-05A: B-annulus pressure trend pre & post-treatment



- Well previously displaying B-section pressure build-up of 32 psi/day (2.2 bar/day)
- **Well now static at 45 psi/3.1 bar. Annulus considered cured. No change to 13-3/8” x 18-5/8” annulus.**
- Annulus may take several weeks to fully stabilise – zero pressure at well handover is an unrealistic target?

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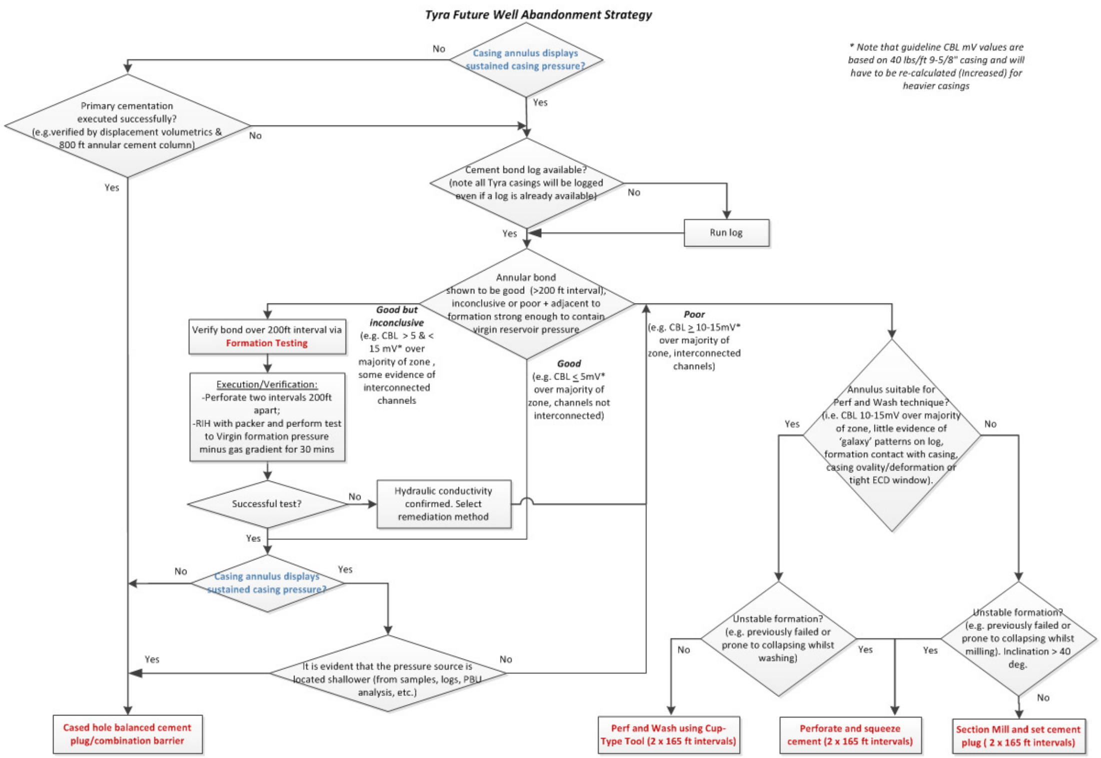
Use of CBL response for de-risking annular cement remediation & decision making



- Suggest guideline CBL values to 'quantify' bond quality and assess likelihood of successful remediation.
- AMAV may be of value. Where < 10mV, near casing bond may prevent circulation.
- Ca. $\leq$5 – 7.5 mV indicates the annulus probably provides a hydraulic seal.
- Where PWT was used to perform Perf & Wash operations on intervals with <5 mV, this may have been a waste of time.
- Can propose decision trees based on such limits to aid in remedial decision-making and method selection.

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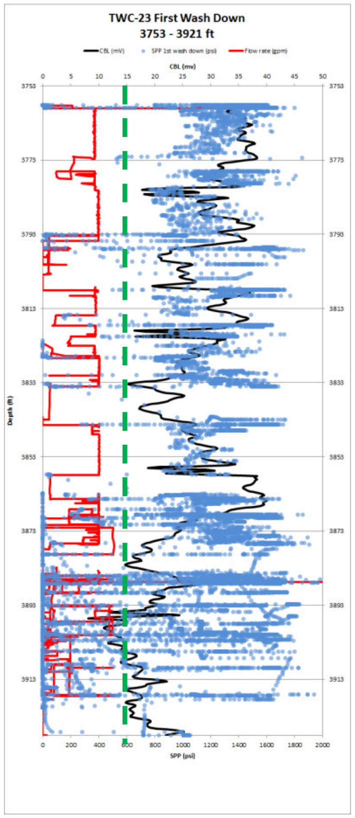
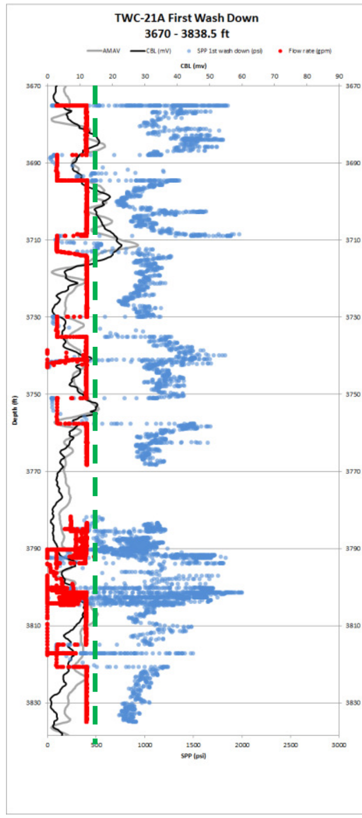
Application of the new approach to concentric casing B-annulus remediation: 2017 Tyra campaign

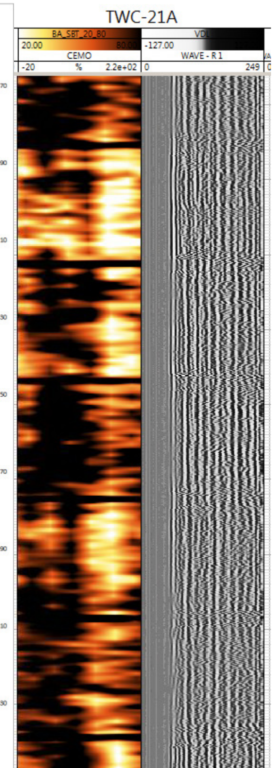


TWC-23 worked as expected:

- CBL at 20 – 38 mV over most of top ¾ of the section.
- Able to circulate effectively over the top ¾ of the section.
- Lower ¼ more difficult – had to wash at reduced rate 50 – 340 gpm due to persistent pressure spikes.
- Last 33ft, unable to achieve any circulation except for at 3,900, 3,903 and 3,907 ft.
- CBL dropped to below 15 mV over this interval.

Inclination 22 – 21 degrees.



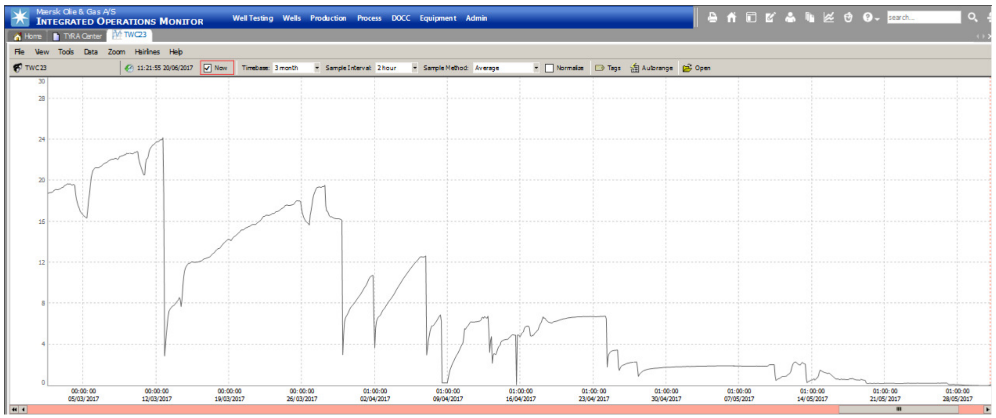


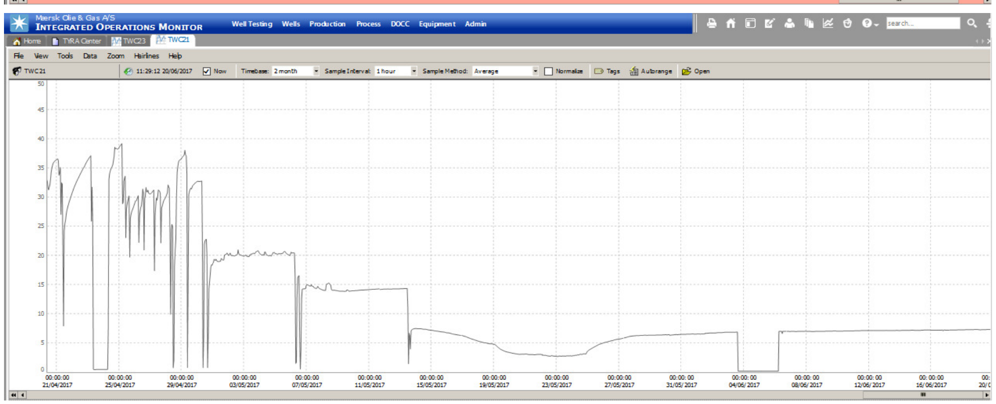
Inclination 25 – 27 degrees.

TWC-21A assessed as marginal:

- CBL shows avarage amplitude of 10mV, but varying between 15mV in shallowest interval and 5-10mV in the rest.
- Normally more pessimistic AMAV follows CBL closely.
- On VDL casing arrivals are visible in the shallow zone but is more attunuated in the lower parts
- **However, upper 2/3 of section washed surprisingly well at 400 gpm. Even despite CBL & AMAV values of 5-10 mV in top 5 ft.**
- AMAV averaged ca. 10mV however over the top - may mean near casing bond is sufficiently poor?
- Lower 1/3 (from 3,786 ft) observed frequent pressure spikes, where both low CBL/AMAV and VDL more attentuated. Lower flow rates resulted in overpulls.

Post-remediation B-annulus response





TWC-23

- Formerly 35 psi/day.
- Graph shows peak at 24 bar / 336 psi.
- Annulus treated with PWT in 5.4 days (total time incl. dress-off and test plug).
- 64.5 hours of washing.
- Cement left undisturbed for ~2 weeks, then bled off.
- **Now showing zero annulus pressure.**
- **No change to 13-3/8” x 18-5/8” annulus.**

TWC-21

- Formerly up to 900 psi/day.
- Annulus treated with PWT in 4 days (total time incl. dress-off and test plug).
- 37.5 hours of washing.
- Installed a second 173.6 ft PWT zone. Left cement undisturbed for almost 5 days, then bled off.
- **Casing pressure now static at 7 bar / 102 psi.**
- **No change to 13-3/8” x 18-5/8” annulus.**

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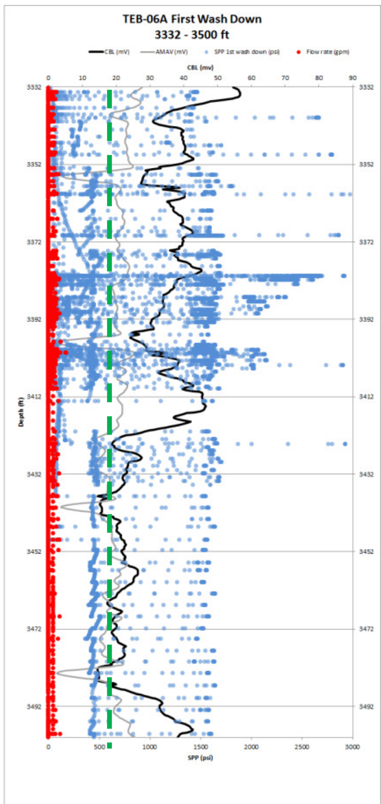
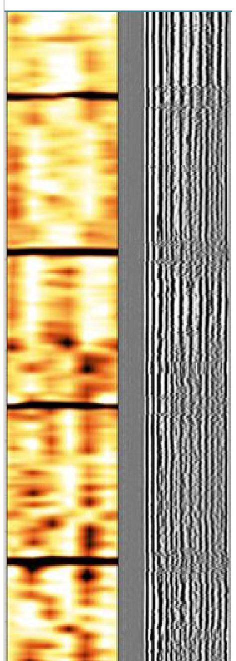
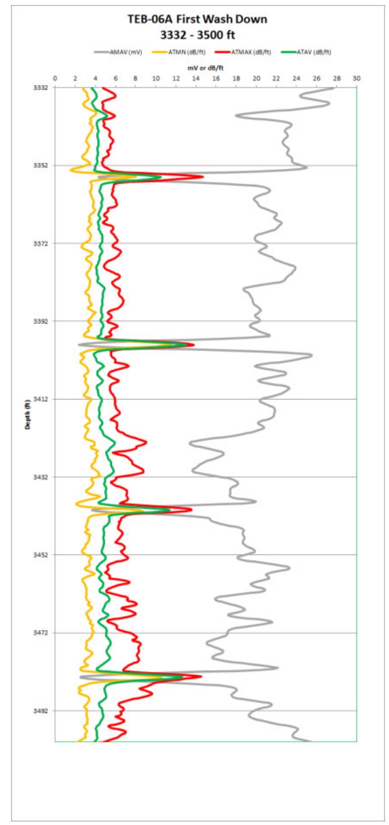
Application of the new approach to 2017 campaign: where even re-perforating didn't work!





Inclination 39 – 41 degrees.

- CBL & AMAV amplitudes above 15 mV for entire interval
- VDL shows very little attenuation and there are clearly visible casing arrivals and casing collar signals
- Cement map shows very light to no cement bonding. Very few areas appear to have bonded cement all around the casing
- **TEB-06A was hence expected to be one of the easiest to wash, but circulation could not be fully established even after re-perforating and spending 4.7 days trying!**
- **Had to resort to cement squeeze and then section milling for upper zone.**



- Attenuation curves (ATMN, ATAV, ATMX) are always above free pipe attenuation value of 2 dB/ft.
- Cement map calibrated to 2000 psi compressive strength – possibly too high and masks presence of solids.

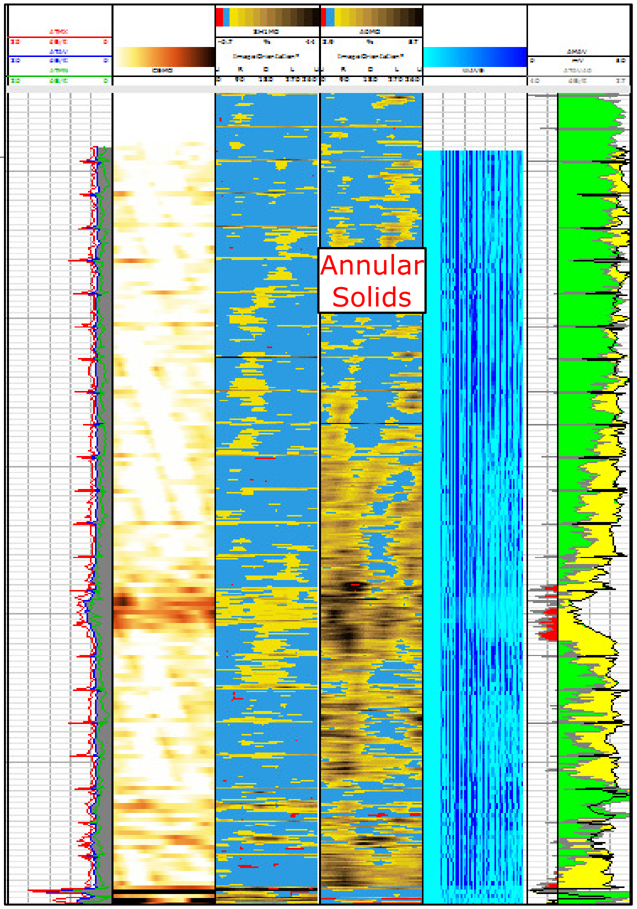
Conclusion:

- CBL & AMAV provide a good 'rule of thumb' but the devil is in the detail!

- A multivariate approach may be the way to go.

Conclusions and way ahead

1. Perforate & Wash can be an effective method for zonal isolation if applied in the right circumstances
2. New 5-1/2" centralised TCP gun system with AP360 charges enables efficient concentric casing cement remediation
3. Washing response from cup-type tool can be used to calibrate logging response and help ensure that the right zones are selected for treatment
4. CBL and AMAV responses are a good semi-quantitative 'rule of thumb' guideline to assess ability to wash successfully
    - Further work on a multi-variate approach is needed using the attenuation and VDL data to ensure a more comprehensive assessment



New technology to consider:

- Baker *Integrity eXplorer* solution recently launched on the market shows far greater resolution and sensitivity to annular solids
    - Tests being carried out across the North Sea at present
- New TCP charge technology under development

Thank you. Any Questions?

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