Cairo. Egypt. November 7-8, 2022

MENAPS 2022

MIDDLE EAST AND NORTH AFRICA PERFORATING SYMPOSIUM

EXPRO

Presentation Title:

Offshore Malaysia Production Well Requires Unique Solution to Maximize Production using Minimal Dynamic Underbalance (DUB) for Clean-up in Low Compressive Strength Sand-Producing Formation via Shoot & Pull Tubing Conveyed Perforating (TCP).

Authors:

- Ahmed Abbas- Project Manager- DST TCP
- Kerry Daly- Global Product Line Manager- TCP (Presenter)

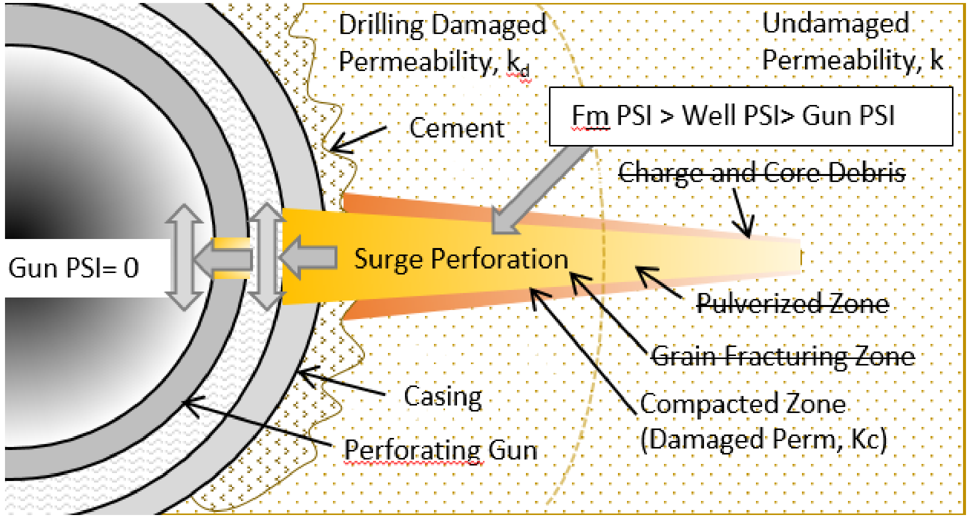
Contents:

- **What is Dynamic Underbalance (DUB)?**
- **What is unique about this job?**
- **Modelling required**
- **Modelling verification**
- **Analysis of Data**
- **Production results**
- **Technical Contributions**
- **Conclusion**
- **Questions?**

What is Dynamic Underbalance (DUB)?

- Dynamic Underbalance (DUB), a technique used in the completion of oil and gas wells, is driven by the differential pressures of natural occurring formation pressure against operator-controlled lower wellbore pressures.
- Typically associated with Tubing Conveyed Perforating (TCP) due to its ability to create and clean long sections of perforating interval at one time, the technique employs vacuum chambers (0 psi) to create the wellbore pressure differential.
- The perforating event, which uses explosive jet charges to create holes in the perforating gun body, holes in the wellbore casing, and perforation tunnels into the formation, allows higher pressure formation fluid to surge-clean the perforations into lower pressure evacuated guns (0 psi).
- In most situations, some amount of DUB is created, which if not controlled can damage the formation due to excessive surging, potentially collapsing the perforation tunnel and thereby reducing hydrocarbon production.
- For this reason, most DUB jobs are limited to high compressive strength formations which do not produce sand, and use Deep Penetrating (DP) type charges.

Dynamic Underbalance (max surge into wellbore/ max cleaning)



Ref: Fadzil et al, 2021

DUB is a timed event:
- **First guns fire**
  - **Completed in µsec**
- **Next DUB occurs**
  - **Completed in msec through secs**

Offshore Malaysia Production Well Requires Unique Solution to Maximize Production using Minimal Dynamic Underbalance (DUB) for Clean-up in Low Compressive Strength Sand-Producing Formation via Shoot & Pull Tubing Conveyed Perforating (TCP).

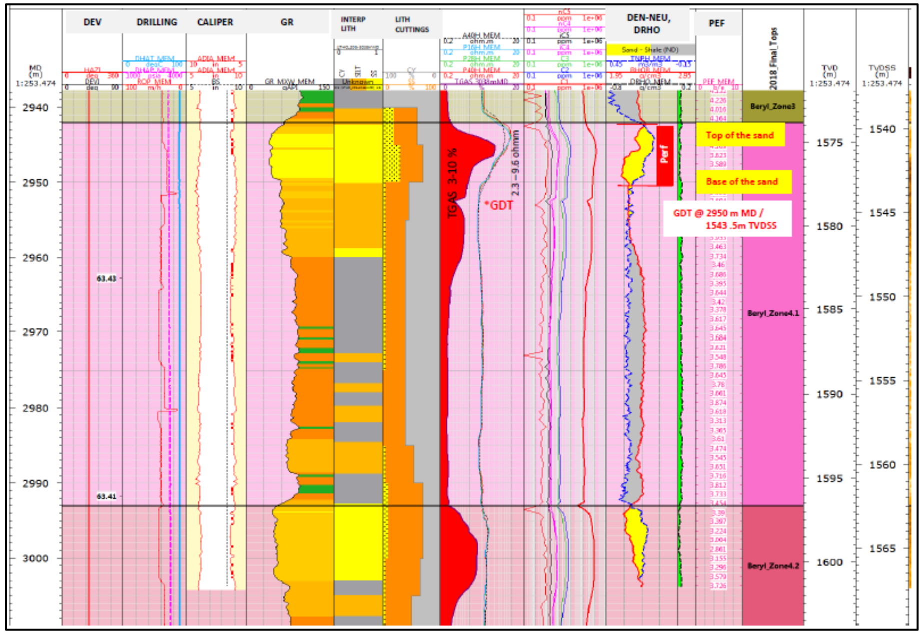
What is unique about this job?

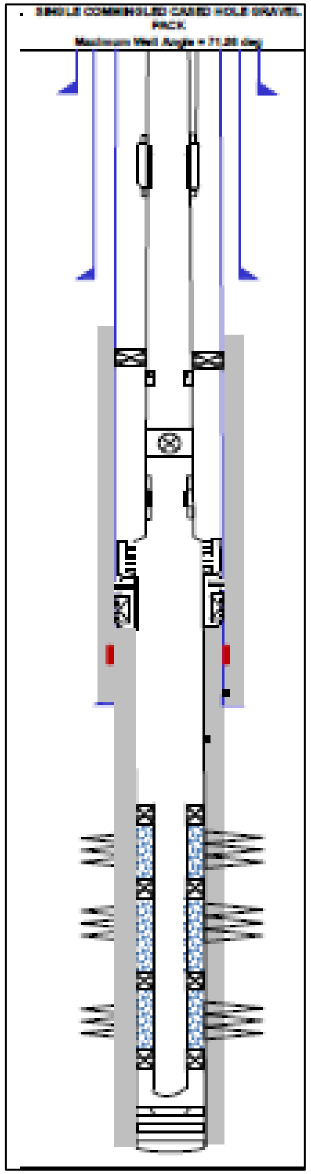
In this case, client requested DUB in a low compressive strength formation with planned sand production.

- Compressive Strength (UCS) was not known, confirmed however known as “low”
- Expected sand production so Gravel Pack completion was to follow perforating
- First zone originally requested 500 psi DUB based on 19m perforation
  - Final configuration was 300 psi DUB based on 7m perforations
- Three zones planned, commingled production, with gravel pack completion following.

Perforated Zone interval (TVD top-

Top (TVD)	1578
Bottom (TVD)	1587
Top (MD)	2840
Bottom (MD)	2859
Deviation	63
Rock type	RT1,2,3
Porosity Ave	20.60%
Permeability Ave	5.18mD
Bulk density ,g/cc	2.11-2.36
Rock strength	
Vertical stress	
Pore pressure (psi)	2239
Temperature	69 degC



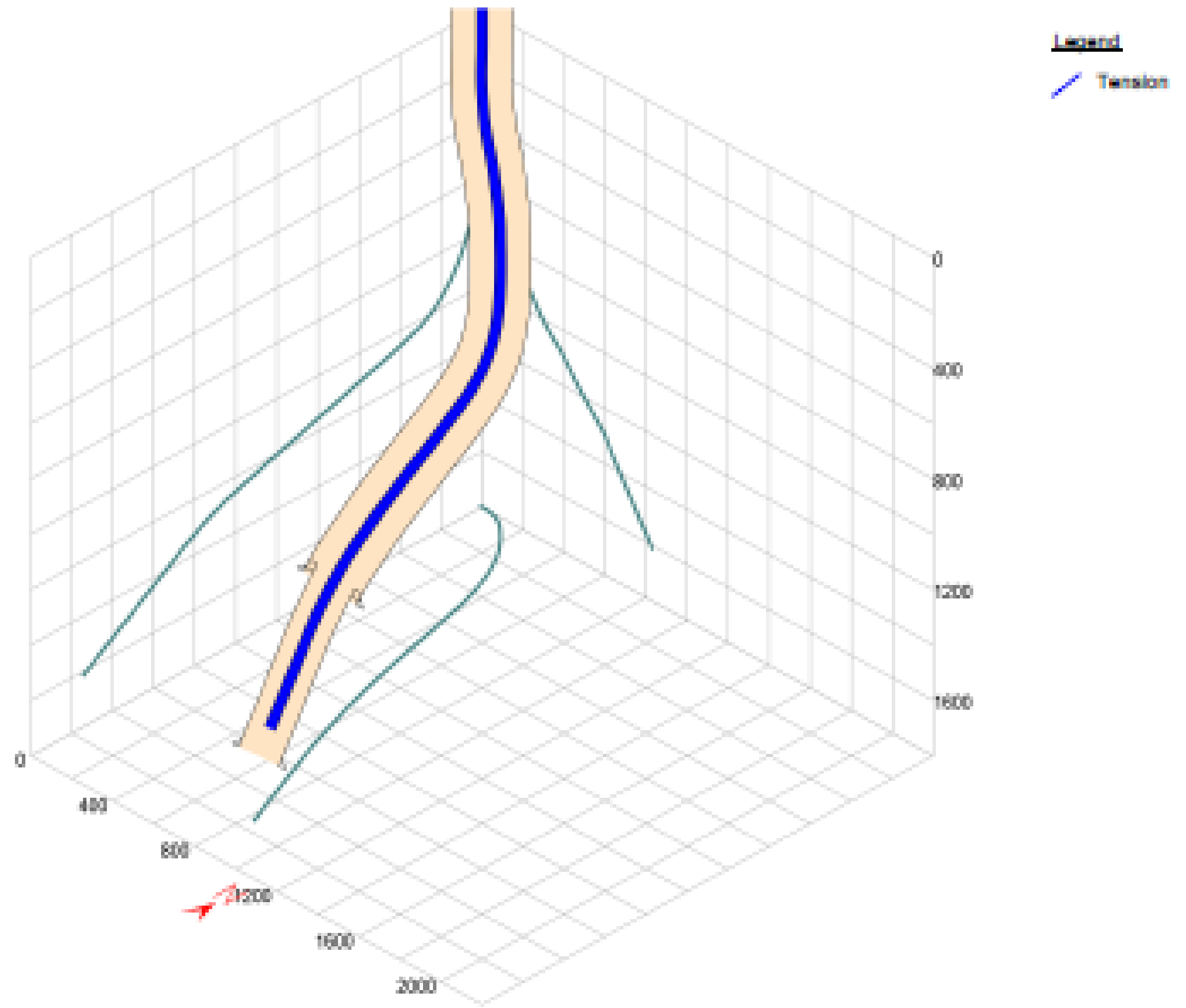


MENAPS-04-22 AUTHORS: Ahmed Abbas. Kerry Daly (Presenter)- EXPRO

Modelling required

Once the Well Geometry and BHA are known,
Torque & Drag Simulation is run to identify the forces at work.

At measured depth of 2870.2 m:	RIH	POOH	
Forces on BHA			
Force on end (user specified)	0	0	lbf
Axial buoyant weight	24327	24327	lbf
Axial weight reduction due to bending	-396	-399	lbf
Wellbore friction	-14477	14609	lbf
Fluid shear drag	-17	17	lbf
Fluid pressure drag	-214	214	lbf
Fluid form drag	-7	7	lbf
Net force on BHA	9216	38775	lbf
Forces on Pipe			
Axial buoyant weight	108289	108289	lbf
Wellbore friction	-40179	89138	lbf
Fluid shear drag	-143	143	lbf
Fluid pressure drag	-264	264	lbf
Fluid form drag	0	0	lbf
Net force on pipe	67703	197833	lbf
Net force below stripper	76919	236608	lbf
WHP force	0	0	lbf
Stripper friction	-500	500	lbf
Force above stripper	76419	237108	lbf



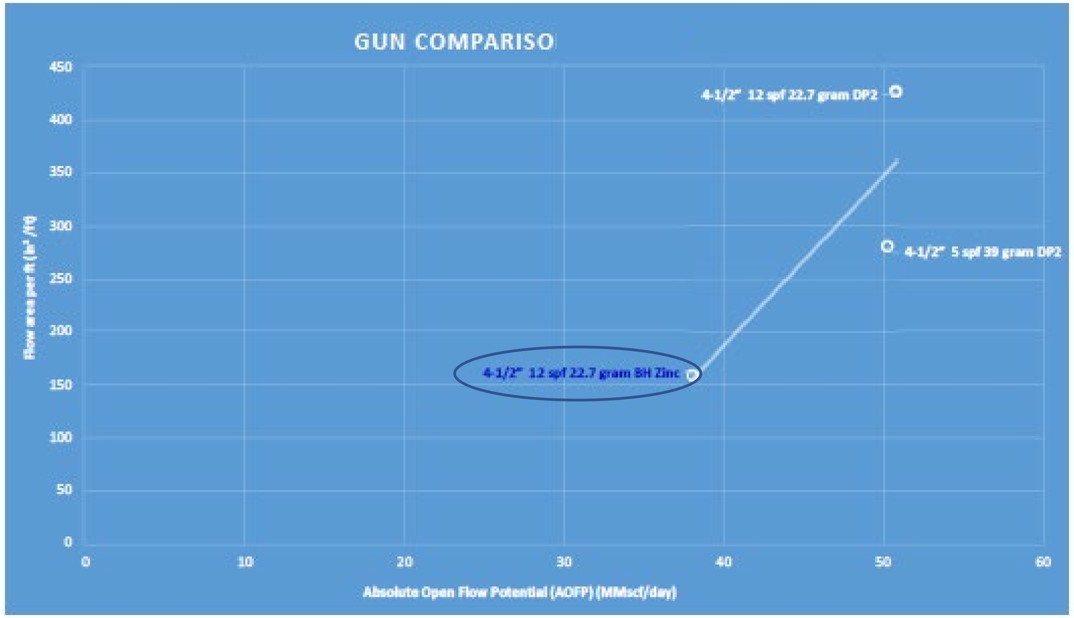
Modelling required

In this case, client requested DUB in a low compressive strength formation with planned sand production. As such,

- Pre-job modelling using SPOT Analysis compared various gun systems based on API RP19B Section 1 performance test data against wellbore and formation parameters.
- Based on results and client decision, 114mm (4.5”) OD gun using low-debris (zinc case) BH charges (22.7 gm RDX) in higher density gun design 39 spm (12 spf) was selected to perforate the well.
- Note: This was not the best performing based on SPOT modelling, but in the end was the client’s choice

	: Shot in 7" Liner		
	4-1/2" 5 spf 39 gram DP2	4-1/2" 12 spf 22.7 gram BH Zinc	4-1/2" 12 spf 22.7 gram DP2
Avg. Formation Penetration (inches)	37.77	4.42	26.10
EHD (inches)	0.47	0.87	0.43
AOF (MMscf/day)	50.21	38.08	50.80
Standard perf flow area (inch^2)	56.14	13.28	35.56
Flow area per ft (inch^2/ft)	280.70	159.30	426.76

Recommended gun system based on Gravel Pack Completion



REF: API 19B Section 1 Test Data

- 114mm (4.5”) OD gun using low-debris (zinc case) BH charges (22.7 gm RDX) in higher density gun design 39 spm (12 spf).
- Test data presented here is analysed within SPOT against wellbore data to generate predicted inflow area.

CERTIFICATION DATA SHEET
PERFORATING SYSTEM EVALUATION, RP 19B; SECTION 1

API FORM 19B

Service Company ____
Gun OD & Trade Name ____
Charge Name ____
Manufacturer Charge Part. No. 2313334 Date of Manufacture 2005-02-09
Gun Type Expendable Hollow Retrievable Gun
Phasing Tested 45/135 degrees, Firing Order x Top down ____ Bottom up
Debris Description NA
Remarks Shot in Fluid / Decentralised

Explosive Weight 22,7 g, HMX powder, Case Material Zinc
Max. Temp. F 400 1 hr 380 3hr 335 24 hr 300 100 hr ____ hr
Maximum Pressure Rating 18.900 psi, Carrier Material Steel
Shot Density Tested 12 spf shots/ft
Recommended Minimum ID for Running ____ in
Available Firing Mode Selective, x Simultaneous
Debris Weight NA g/charge, Debris NA in^3/charge

SECTION 1 - CONCRETE TARGET

Casing Data 7" OD, Weight 32,0 lb/ft. L-80 API Grade, Date of Concrete Test 2005-03-21
Target Data 88,2" OD, Amount of Cement 7606 lb., Amount of Sand 15212 lb., Amount of Water 3946 lb.
Date of Compressive Strength Test 2005-03-23 Briquette Compressive Strength 6800 psi, Age of Target 33 days

Shot No.	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10	
Clearance, in.	0,00	1,30	0,69	0,18	1,59	0,18	0,69	1,30	0,00	1,30	
Casing Hole Diameter, Short Axis, in.	0,75	0,53	0,78	0,71	0,76	0,85	0,63	0,75	0,84	0,71	
Casing Hole Diameter, Long Axis, in.	0,76	0,55	0,80	0,79	0,89	0,90	0,67	0,78	0,85	0,83	
Average Casing Hole Diameter, in.	0,75	0,54	0,79	0,75	0,83	0,87	0,65	0,76	0,84	0,77	
Total Depth, in.	7,09	6,30	8,27	6,30	6,69	lost	7,09	6,69	6,29	6,69	
Burr Height, in.	0,12	0,15	0,16	0,04	0,15	0,09	0,09	0,16	0,11	0,15	
Shot No.	No. 11	No. 12	No. 13	No. 14	No. 15	No. 16	No. 17	No.18	No. 19	No. 20	Average
Clearance, in.	0,69	0,18	1,59	0,18	0,69	1,30	0,00	1,30	0,69	0,18	
Casing Hole Diameter, Short Axis, in.	0,68	0,78	0,74	0,69	0,83	0,68	0,76	0,78	0,68	0,73	
Casing Hole Diameter, Long Axis, in.	0,70	0,78	0,81	0,76	0,84	0,75	0,85	0,89	0,74	0,83	
Average Casing Hole Diameter, in.	0,69	0,78	0,78	0,73	0,83	0,71	0,80	0,83	0,71	0,78	
Total Depth, in.	8,27	8,66	6,69	6,30	7,09	6,30	6,69	7,09	7,09	7,48	
Burr Height, in.	0,08	0,11	0,14	0,08	0,13	0,07	0,11	0,16	0,10	0,13	

Remarks

Cont. On Page 2

WITNESSING INFORMATION

Date of Notice to Intent to Test: 15.02.2005 Witnessed by: Ian Thompson
Other Activities Witnessed: Target Pouring ____ Briquette: Preparation: ____ Testing: ____ Burr Height Measurements: ____ Samples Taken: Concrete: x Casing: x

CERTIFICATION

I certify that these tests were made according to the procedure as outlined in API RP 19B: Recommended Practices for Evaluation of Well Perforators. First Edition, November, 2000. All of the equipment used in these tests, such as the guns, jet charges, detonator cord, etc., was standard equipment with our company for use in the gun being tested, and was not changed in any manner for the test. Furthermore, the equipment was chosen at random from stock and therefore will be substantially the same as the equipment which would be furnished to perforate a well for any operator. The American Petroleum Institute neither endorses these test results nor recommends the use of the perforator system described.

x CERTIFIED BY

____ RECERTIFIED (Company Official) (Title) (Date) (Company) (Address)

CERTIFICATION DATA SHEET
PERFORATING SYSTEM EVALUATION, RP 19B; SECTION 1

API FORM 19B

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Date of Compressive Strength Test 2005-03-23 Briquette Compressive Strength 6800 psi, Age of Target 33 days

Shot No.	No. 21	No. 22	No. 23	No. 24	No. 25	No. 26	No. 27	No. 28	No. 29	No. 30	
Clearance, in.	1,59	0,18	0,69	1,30	0,00	1,30	0,69	0,18	1,59	0,18	
Casing Hole Diameter, Short Axis, in.	0,71	0,71	0,70	0,64	0,76	0,70	0,76	0,73	0,77	0,77	
Casing Hole Diameter, Long Axis, in.	0,86	0,77	0,78	0,74	0,77	0,77	0,82	0,74	0,77	0,85	
Average Casing Hole Diameter, in.	0,78	0,74	0,74	0,69	0,76	0,74	0,79	0,73	0,77	0,81	
Total Depth, in.	6,50	6,30	7,09	5,51	6,69	7,09	7,48	7,87	6,30	6,69	
Burr Height, in.	0,13	0,15	0,06	0,13	0,09	0,19	0,06	0,09	0,09	0,11	
Shot No.	No. 31	No. 32	No. 33	No. 34	No. 35	No. 36	No. 37	No.38	No. 39	No. 40	Average
Clearance, in.	0,69	1,30	0,00	1,30	0,69	0,18	1,59	0,18	0,69	1,30	
Casing Hole Diameter, Short Axis, in.	0,62	0,78	0,80	0,71	0,69	0,77	0,76	0,73	0,72	0,79	0,73
Casing Hole Diameter, Long Axis, in.	0,63	0,83	0,83	0,84	0,85	0,83	0,85	0,73	0,78	0,86	0,79
Average Casing Hole Diameter, in.	0,62	0,80	0,81	0,78	0,77	0,80	0,80	0,73	0,75	0,83	0,76
Total Depth, in.	6,69	5,51	7,87	7,09	lost	6,30	lost	lost	6,30	5,12	6,81
Burr Height, in.	0,04	0,14	0,12	0,22	0,13	0,07	0,07	0,13	0,08	0,10	0,11

Remarks

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Date of Notice to Intent to Test: 15.02.2005 Witnessed by: Ian Thompson
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x CERTIFIED BY

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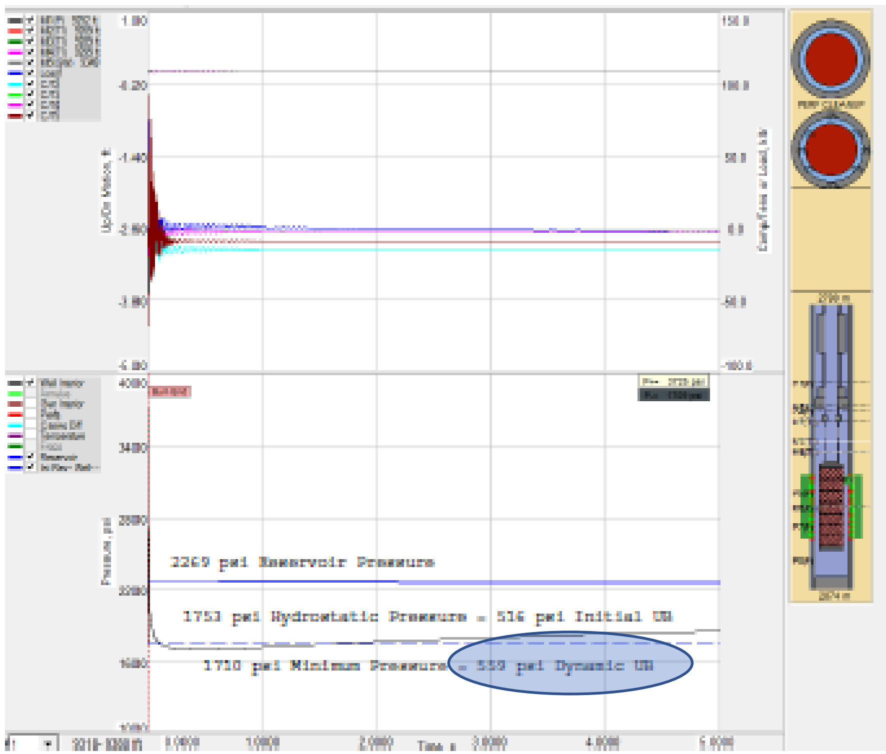
Modelling required

- Pre-job modelling using PulseFrac Analysis compared various Bottom Hole Assembly (BHA) configurations in order to estimate DUB effects after firing the perforating guns.
- Various iterations were performed to properly configure the BHA to match requested DUB pressures.
- This determined the final gun configuration, spacing blanks above and below the loaded interval to create the necessary 0 psi chambers.
- No special equipment was required: No surge chambers, etc. Simply loaded and blank guns as determined by PulseFrac model

Results for Working Region #1: 2,840 ft – 2,859 m



Original design for 500 psi DUB:

- 5m blank gun above
- 19m loaded
- 5m blank gun below

Final design for 300 psi DUB:

- 4.41m blank gun above
- 7m loaded
- 2m blank gun below

Case #1: 4.5" OD Perforating Guns, loaded 12spf 22.7gr (0.95" EH, 6.92" Pen) charges from 2,840 m – 2,859 m (19 m). 5' Safety Spacer above & below loaded guns.

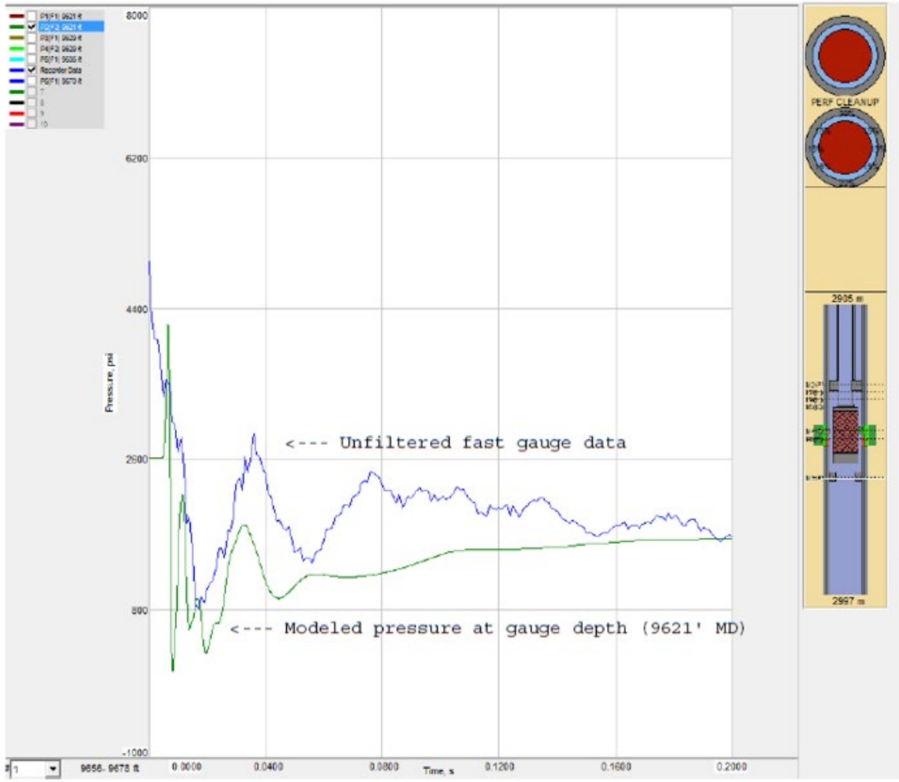
(500psi Static Underbalance Initial Condition)

(Perm=5 mD, Porosity=21%, BHP=2269 psi, BHT=69 C, S=+10.1)

Modelling Verification:

- Post-job PulseFrac model compared actual event data from Fast Gages to determine how much DUB was actually created.
- Final Total Skin=1.0 (desired ≤ 1.0 to match undamaged formation)
- Actual DUB recorded was 796 psi- slightly higher than planned but graphically still a close fit.

Unfiltered Expanded Plot (0.2s)

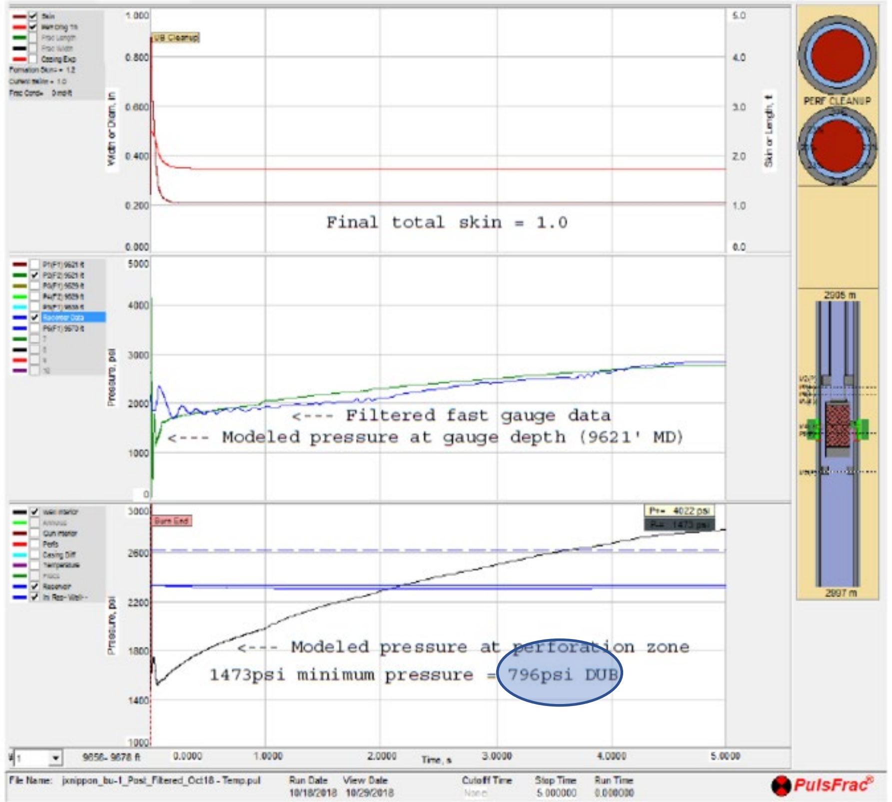


Post Job Fast Data Comparison, First Stage - Lower Zone: 4.5" OD Perforating Guns, loaded 12spf 22.7gr charges from 2,943 m – 2,950 m (7 m). 4.41m Surge Chamber above & 2m below loaded guns.

(300psi Static Underbalance Initial Condition)

(Perm=5.18 mD, Porosity=21%, BHP=2269 psi, BHT=69 C)

Filtered Plot (5s)



Post Job Fast Data Comparison, First Stage - Lower Zone: 4.5" OD Perforating Guns, loaded 12spf 22.7gr charges from 2,943 m – 2,950 m (7 m). 4.41m Surge Chamber above & 2m below loaded guns.

(300psi Static Underbalance Initial Condition)

(Perm=5.18 mD, Porosity=21%, BHP=2269 psi, BHT=69 C)

Offshore Malaysia Production Well Requires Unique Solution to Maximize Production using Minimal Dynamic Underbalance (DUB) for Clean-up in Low Compressive Strength Sand-Producing Formation via Shoot & Pull Tubing Conveyed Perforating (TCP).

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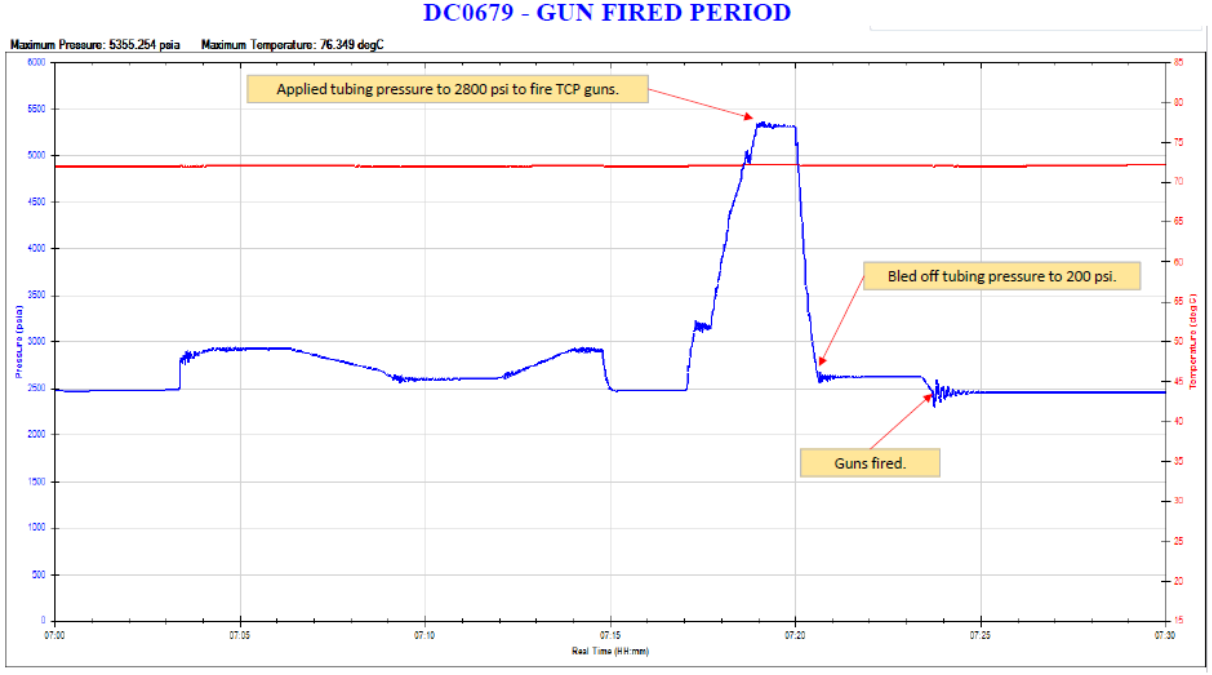
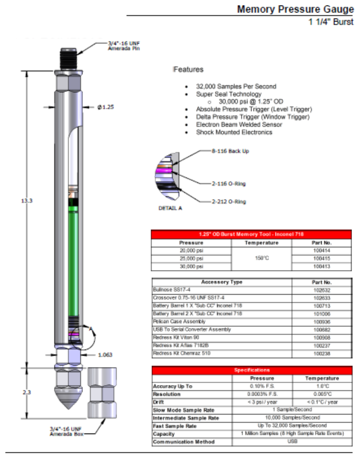
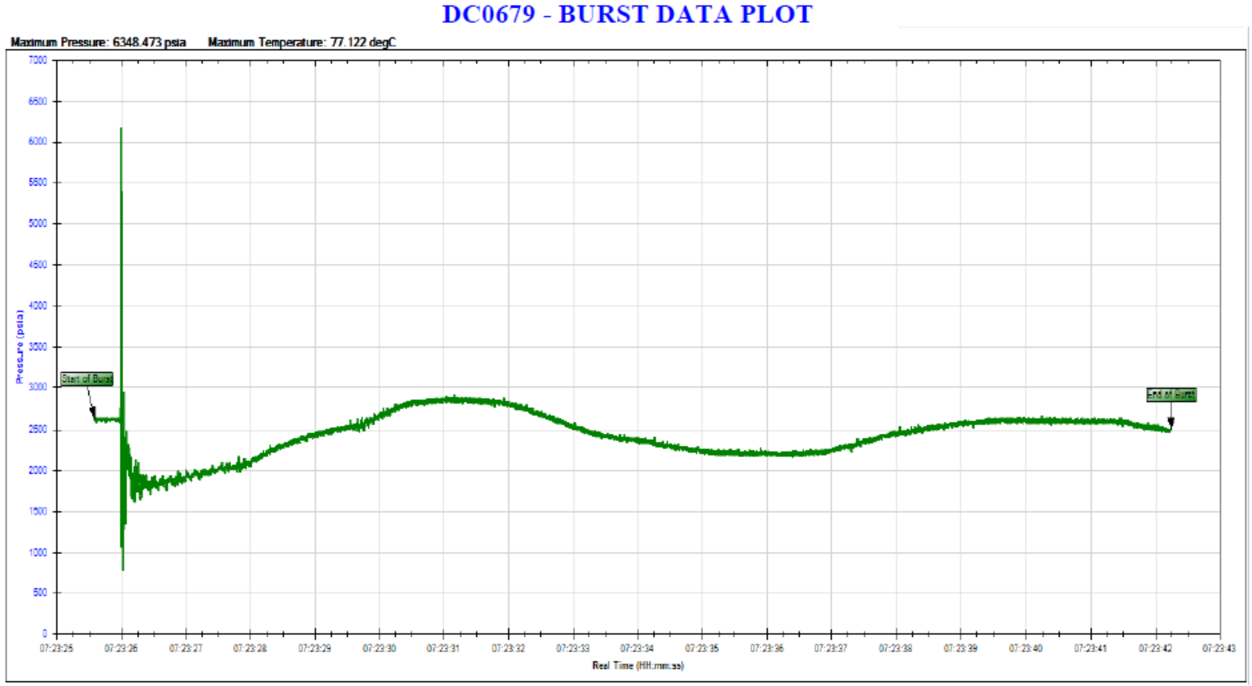
REF: Fast Gauge Data



Perforating/ DUB Event (in seconds)

- Total measured time: 15 sec
- Pre-event: ~ 1 sec
- Gun firing: < 1 sec
- DUB creation returning to zero: ~ 14 sec





Events (in minutes):

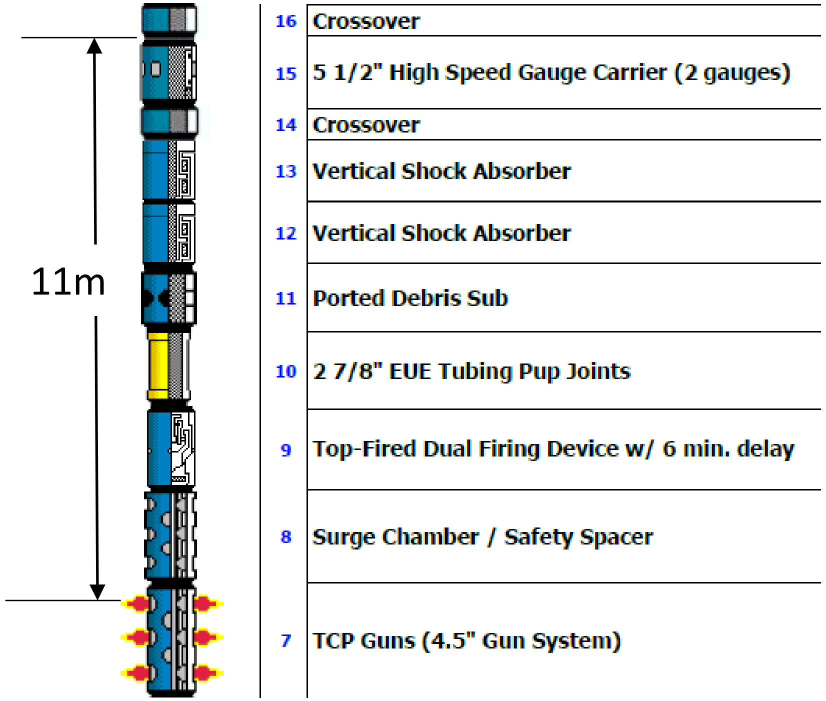
- Pressure up to shear pins to trigger Firing Head with 6-Minute Delay
- While Delay burns, bleed off pressure to establish proper Underbalance
- After UB established, wait a few minutes and then guns fire.
- Perforating event is recorded to be complete > 1 minute

Analysis of Data

- Pre-job models were predicting a similar amount of DUB (500 – 1000psi).
- 300 psi was recommended DUB, not maximum requirement.
- Note: DUB is a transient effect and formation collapse would be based on static (actual) underbalance.

Compare to:

- Fast Gauge pressure of 796 psi not empirically derived but calculated in the final ‘Post-job’ model.
- Actual data is collected from few feet to hundreds of feet away. In this case- 11m
- Several assumptions made to get a match between the collected real data and the fast gauge in the model.
- This produces a modeled average wellbore pressure across the perf interval that corresponds with the empirical fast gauge pressure.



Post-job evaluation of production data:

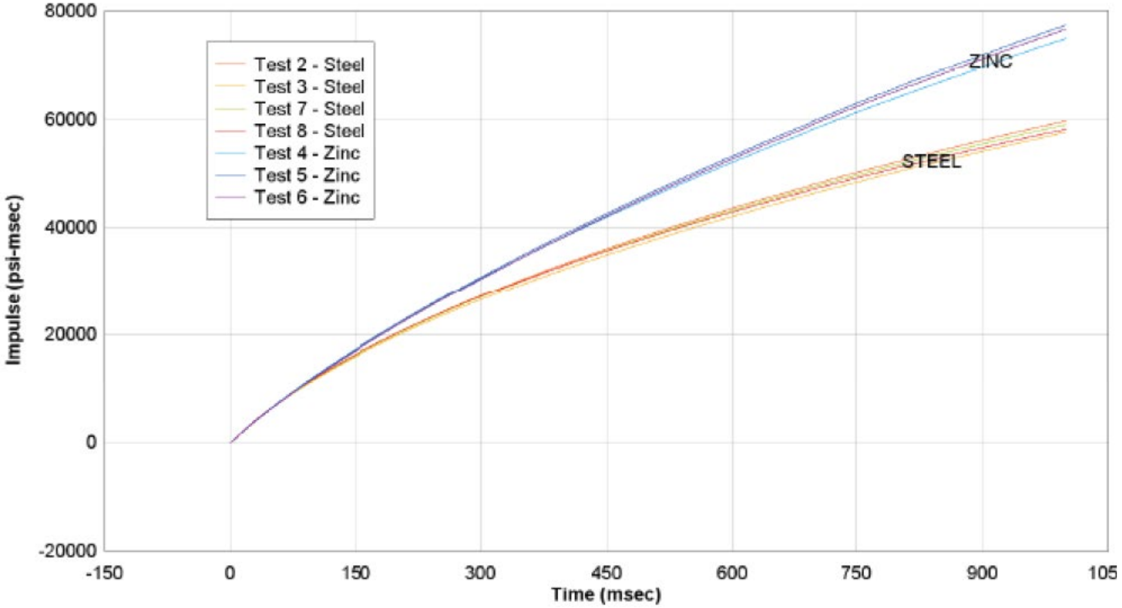
- Graphic plots were not available at time of writing however client confirmed that ~ 6 months after completion:
    - Production objectives were satisfied
    - Production values met their pre-job estimates.

Technical Contributions:

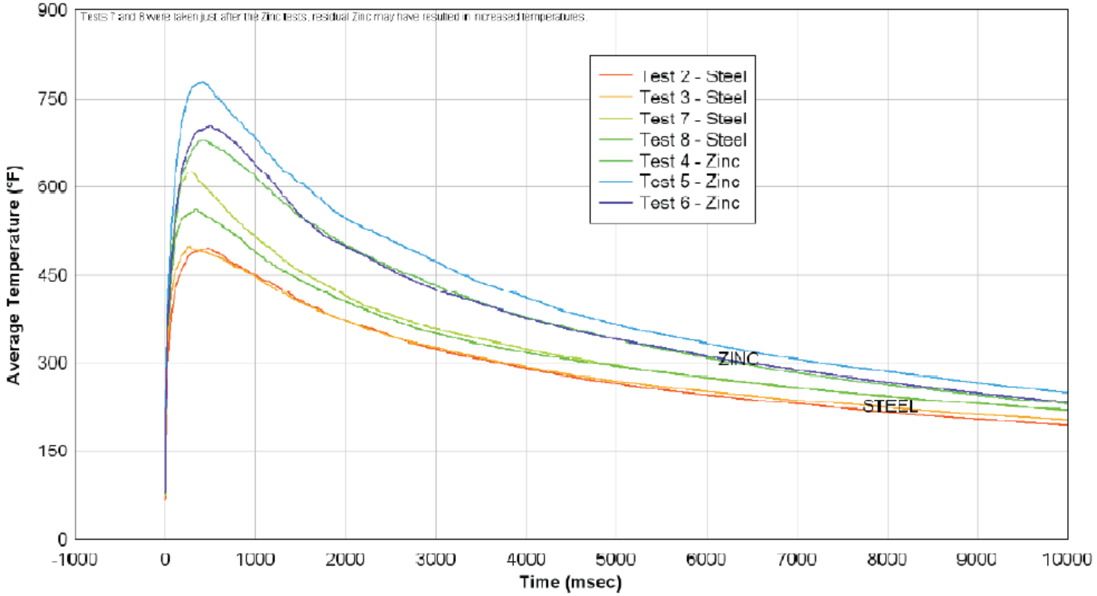
- Use of low DUB in a low compressive strength sand-producing formation is not typical- unique and innovative
- Use of Zinc charges created some challenges that required consideration:

1. Working against the DUB design:

  - Zinc is known to extend the pulse of the perforating event- both in increased time and pressure, which can affect the DUB effects.
  - As such, pre-job PulseFrac modelling was used to compensate for the conditions and properly design the BHA.



With Zinc, Pressure is increased

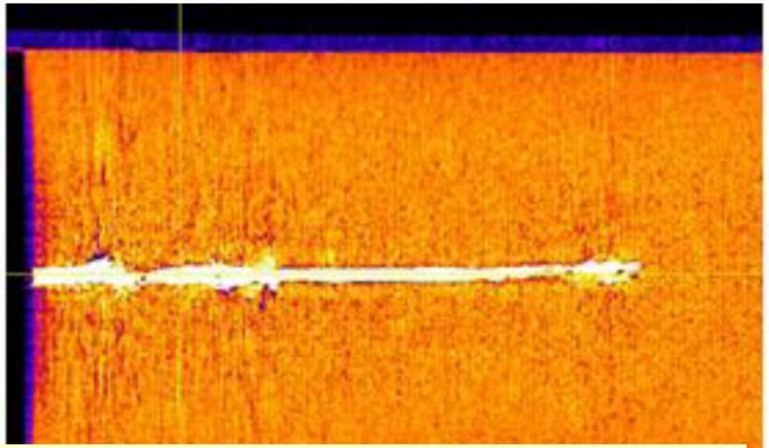


With Zinc, Temperature is increased

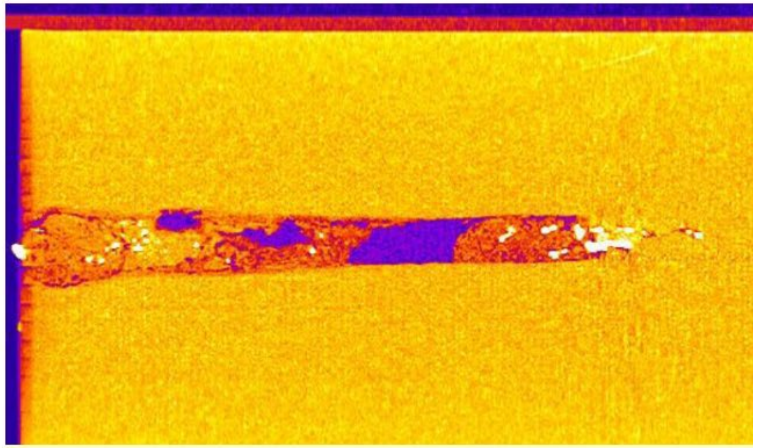
REF: Han, et al, 2010

Technical Contributions (continued):

2. **Working against the DUB design:**
   - Zinc charges in overbalanced conditions are commonly used as a Fluid Loss Control agent, which can line the perforation and limit the flow through it.
   - In the case of secondary Frac Pack operations, where applied surface pressure will be used to increase the tunnel length, then this is an acceptable application.
   - However, if Frac Pack will not be used and instead only Gravel Pack, then if the formation is not properly surge cleaned using DUB technique, the formation damage may reduce hydrocarbon production.
   - It is a sensitive procedure that required proper pre-job modelling to define correct equipment and procedures.



Zinc case, NaBr wellbore fluid
PR 0.15, Overbalance conditions



Zinc case, NaBr wellbore fluid
PR 1.85, Underbalance conditions

REF: Zuklic et al, 2016

Conclusion:

- Dynamic Underbalance (DUB) is a viable completion technique which utilizes the differential between higher formation pressures and lower wellbore pressures.
- If not controlled, DUB can damage the formation from excessive surging, potentially collapsing perforations and thereby reducing production.
- For this reason, most DUB jobs are limited to high compressive strength formations which do not produce sand, and use deep penetrating charges. In our case however, the client requested DUB in a low compressive strength formation with planned sand production.
- As a result, Expro performed several types of modelling and evaluations to confirm that the equipment and DUB was appropriate to deliver a successful job with long-term production:
    - Pre-job Torque 7 Drag, evaluating Wellbore Geometry to ensure BHA was able to withstand forces it would encounter.
    - Pre-job SPOT model compared various gun systems. Based on results, 114mm (4.5”) OD gun using zinc BH charges (22.7 gm RDX) at 39 spm (12 spf) was selected to perforate the well. This was not the best option presented but was chosen by client.
    - Pre-job PulseFrac model compared various configurations to estimate DUB after gun firing. Iterations were performed to properly configure BHA to fit client’s DUB pressures. The BHA had 4.41m of blank, 7m of loaded, and 2m blank to generate 0 psi chambers for DUB.
    - Post-job PulseFrac model compared to actual Fast Gage data to determined fit/accuracy of the model.
        - While Fast Gauge DUB was slightly higher (796 psi vvs 300psi), it still created a good fit to PulseFrac model and generated Skin=1
    - Post-job evaluation of production data ensured that objectives were satisfied against pre-job estimates.

Modelling is key to our all of our DUB jobs. In this case, it provided confidence ensuring we had the proper equipment and procedures in place to successfully complete this project. Based on that, we minimized DUB to surge-clean the perforation while not damaging the low USC formation to maximize production for our client.

Acknowledgements:

Thank you to all for attending, the MENAPS Committee for selecting us, and Expro management for the opportunity to present this subject today

References:

1. Nurul Fadzil et al, "Maximizing Injection Performance Through Fit-for-Purpose Dynamic Underbalance Perforation Using Unconventional Gun System in Offshore Well, Sarawak, Malaysia. " Paper presented at the IADC/SPE Asia Pacific Drilling Conference and Exhibition, virtual, 8 June, 2021. DOI: 10.2118/201061-MS

2. Han, C.. , Du, Michael H., and Bob Ference. "Effect of Shaped Charge Case Materials on Perforating Guns." Paper presented at the International Oil and Gas Conference and Exhibition in China, Beijing, China, June 2010. doi: 10.2118/130477-MS

3. Zuklic, S., Myers, B., & Satti, R. (2016, February 24). Field Application Study of Zinc Based, Low Debris Perforating Charges. Society of Petroleum Engineers. doi:10.2118/178934-MS

Thank You!

Q&A