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Geothermal

GEOTHERMAL 2023

Realising the Ambition

USING UNDERBALANCE TCP TO PROMOTE PERFORATION CLEAN-UP TO OPTIMIZE WATER INJECTION AND GEOTHERMAL PRODUCTION IN NETHERLANDS

Presented by:

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Map View of Netherland's Greenport Westland-Oostkand area

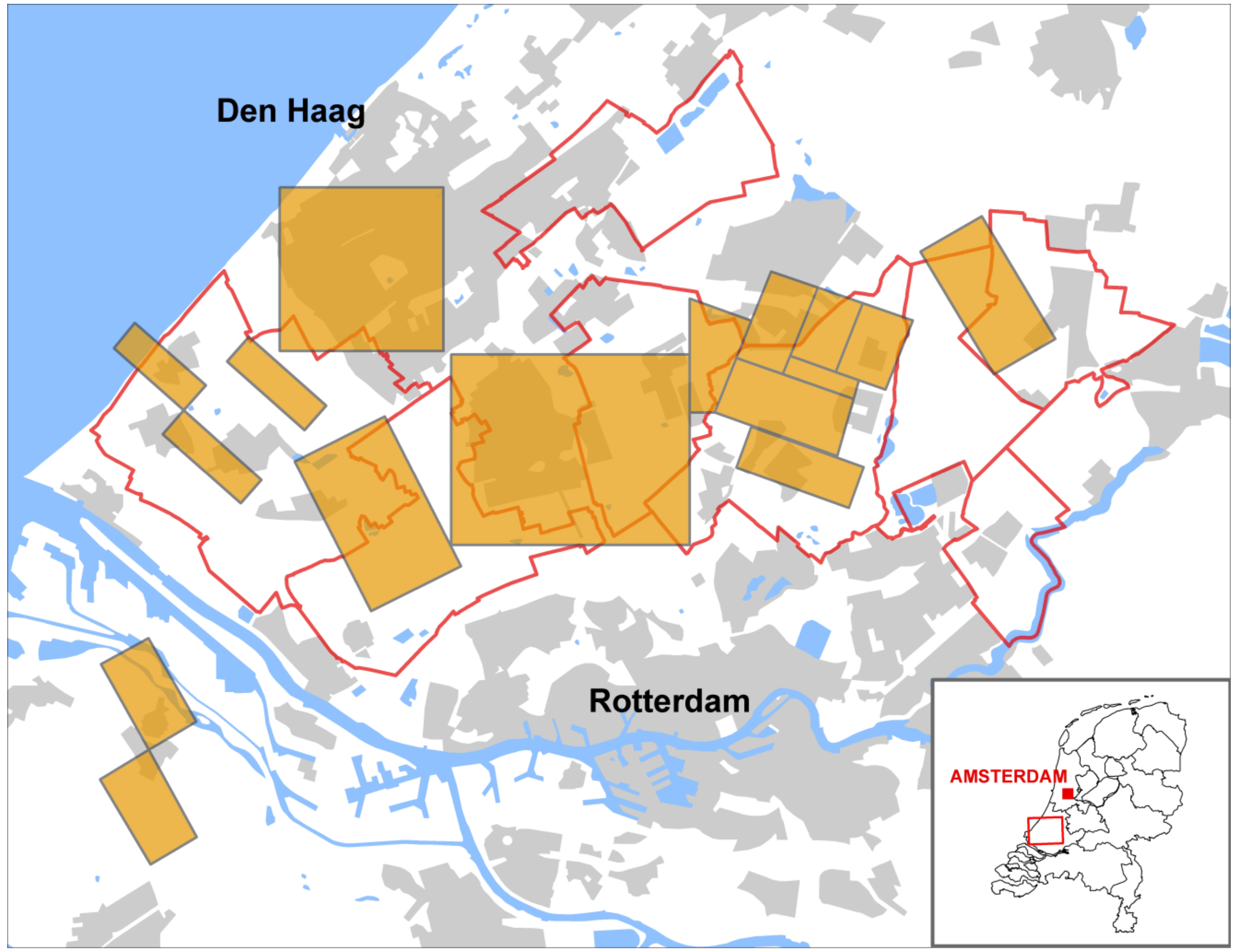

Fig. 1: Van Leeuwen, W. et al, 2019 [1]

Project Overview:

- Geothermal district heating project near Maasdijk, NL [Fig 1, 2].
- Masterplan comprises of a total 153 doublets spread over 170 km2 area
- Two sand targets: Delft & Alblasserdam
- Potential to provide 25% of Greenport's greenhouses with heat for 30 years
- Previous wells experienced sand production and integrity challenges
- Original plan to perforate on one continuous string of Tubing Conveyed Perforating (TCP) guns with Static/ Dynamic Underbalance (DUB) technique
- Expro analysis showed potential risk of 1) gun misfire, and 2) weight/ shock load concerns
- Agreed solution to perforate each zone selectivel using "reactive" perforating charges on top interval

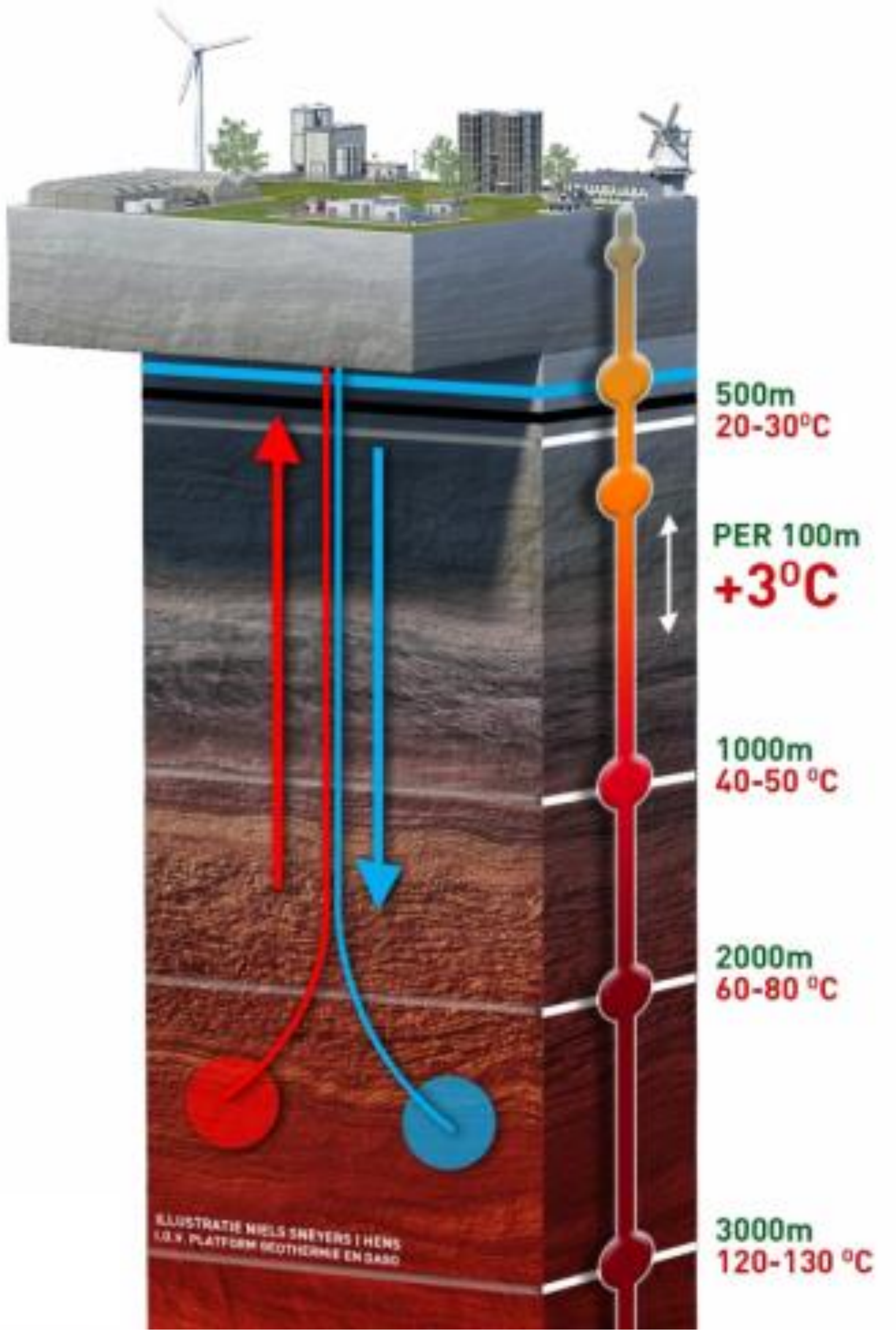

Figure 2: Stichting Platform Geothermie, 2018 [2]

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Project Parameters:

- Expro was awarded a ten-well TCP project for this Geothermal district heating project;
  - This project was divided into five pairs of wells (doublets)
  - Target sandstones
    1) Delft- shallower, cleaner, thinner (~50m/ 164 ft)

       ~150m/ 492 ft gap in between.
    2) Alblasserdam- deeper, less clean, thicker (~150m/ 492 ft),
  - Challenge 1 – Protect Glass Reinforced Epoxy special lined casing during intervention
  - Challenge 2 - Provide uniform wellbore underbalance at the time of firing for optimal perforation tunnel cleaning across the entire perforating interval
  - Challenge 3 – Ensure long bottom hole assembly (BHA) could be successfully and safely deployed, fired, and retrieved on Coiled Tubing
  - Challenge 4 – Manage risk of two independent rig set-ups being used, which required different lifting, handling, risk assessment, and personnel competencies and training.
  - Challenge 5 – Execute efficiently to tight timelines around an active drilling project preventing any costly downtime and penalties.

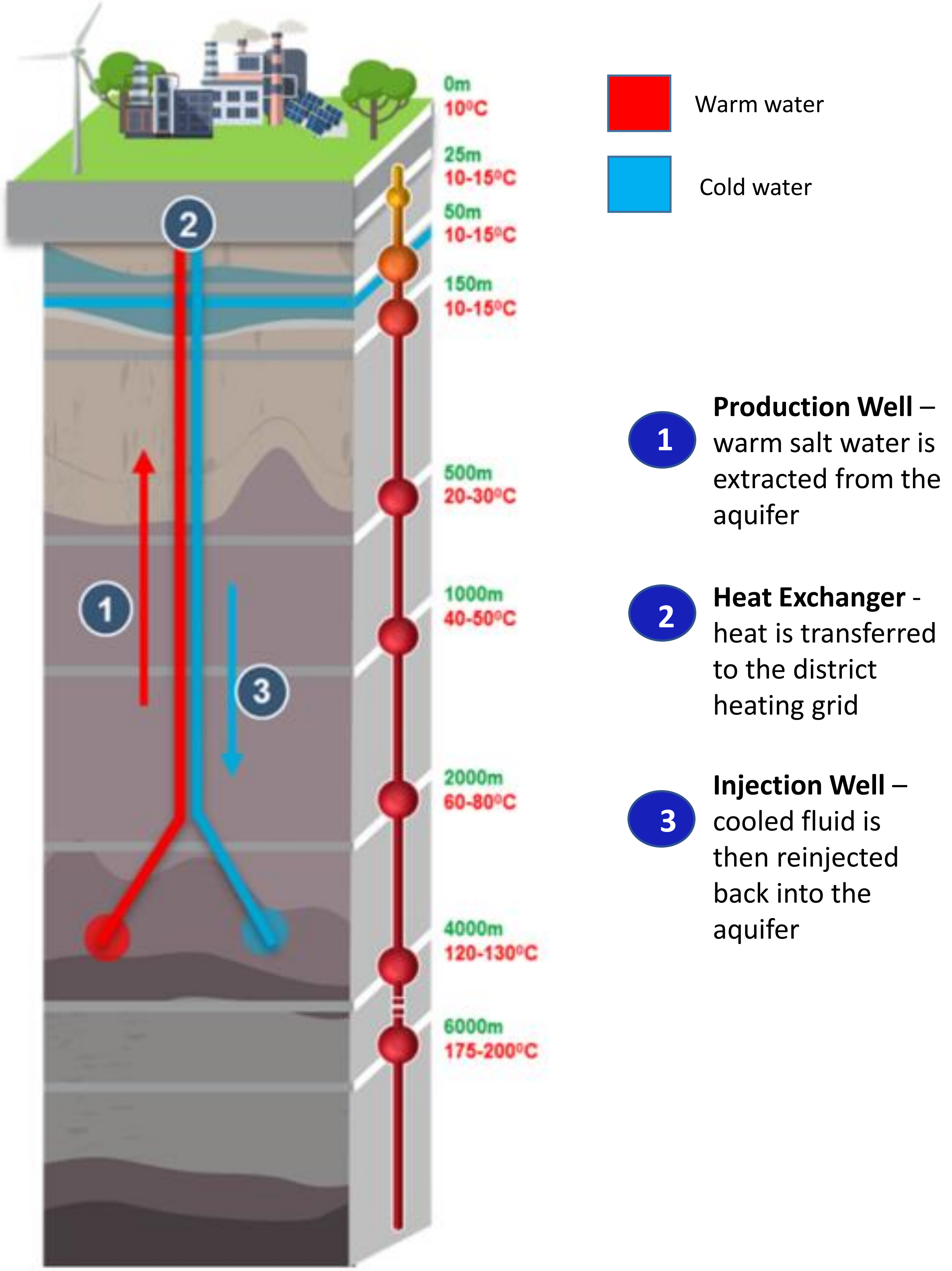

Figure 3: https://allesoveraardwarmte.nl/ [3]

Reservoir Properties (1- Van Leeuwen, W. et al, 2019):

- Since 2007, long history of geothermal production from Greenport Westland-Oostkand area [Fig. 1]
- The well configuration is based on a well spacing between production and reinjection wells to ensure thermal breakthrough occurs only after certain years. In order to extract maximum heat, this spacing takes into account variations in reservoir thickness and temperature.
- In this area, adequate temperate is present at formation depths (Geothermal gradient: T=0.028*d+11)[Table 1]
- Potential transmissivity of Delft- highest potential in area to act as geothermal reservoir [Table 2]

Key Concept:

- **Thermal breakthrough**: The lifetime of a geothermal system ends when the water extracted from the production well reaches a certain minimum temperature as a result of the cold water injected through the infiltration well (Target= 30 years)[Table 3]

Starting Points	KNNSB	SLDND
Flow rate (m^3/h)	150	150
Equivalent full load hours (h)	5,000	5,000
Initial temperature (° C)	45-70	70-75
Injection temperature (° C)	40	40
Porosity (-)	0.19	0.23
Thickness (m)	25-90	25-90
Volumetric heat capacity [$MJ/(m^3*K)$]	2.5	2.6
Desired lifetime of doublet	30	30
Thermal retardation factor [-]	3.3	2.8

Table 1: Delft Sandstone Properties [1]

Member	p10	p50	p90
Berkel Sandstone	709	22	1
Delft Sandstone	211	37	6

Table 2: % Probabilities of transmissibility [1]

	Berkel Sandstone Member	Nieuwerkerk Formation
HIP [TJ]	200,950	506,800
Heat extracted (masterplan) [TJ]	73,500	274,300
Percentage of HIP [%]	37	54
Doublets	39	114
Surface greenhouses [ha]	189	714

Table 3: Analytical results of Geothermal Project
Note: HIP= Total Amount of present heat [1]

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Challenge #1: Protect Glass Reinforced Epoxy special lined casing during intervention

Challenging conditions:

- 1.08 Specific Gravity Salt Water being used- highly corrosive over time [Salinity ~10.8%, 9.01 lb/gal]
- Produced water rate ~75,000 barrels/day
- Large 9 5/8" Casing
- 30-year completion life design
- Special lined casing with Glass Reinforced Epoxy (GRE) was used to preserve the integrity of the wellbore for an expected 30-year life.

Remedy

- To ensure well longevity, special roller connectors were designed to protect the GRE lined casing [Fig. 4,5]
- The efficient collaboration between the Client, Company, and outside experts was essential for the effective design, delivery, and implementation in a timely manner.

Fig. 4- Roller Sub Design:

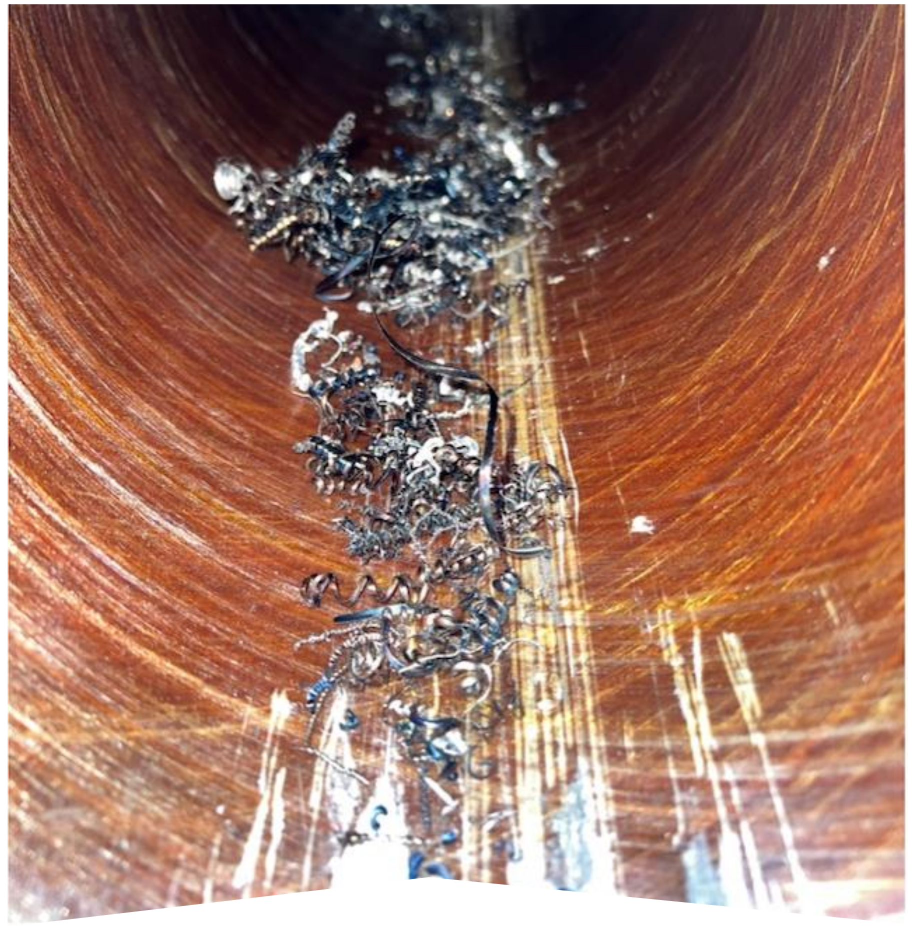

Fig. 5- Drag Test Results

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Challenge #2: Provide uniform wellbore underbalance at the time of firing for optimal perforation tunnel cleaning across the entire perforating interval

Remedy:

- Expro specializes in TCP due to its ability to create and clean long sections of perforating interval at one time.
- Explosive jet charges create holes in the gun body, holes in the wellbore casing, and perforation tunnels in the formation.
- DUB allows higher pressure formation fluid to surge-clean the Dperforations into lower pressure evacuated guns (0 psi)[Fig. 6].
  - DUB is a timed event:
  - First guns fire
    - Completed in µsec
  - Next DUB occurs
    - Completed in msec through secs
- Auto-Vent Firing Head system (Absolute Pressure) was selected ad fit-for purpose for this application.

Dynamic Underbalance (max surge into wellbore/ max cleaning)

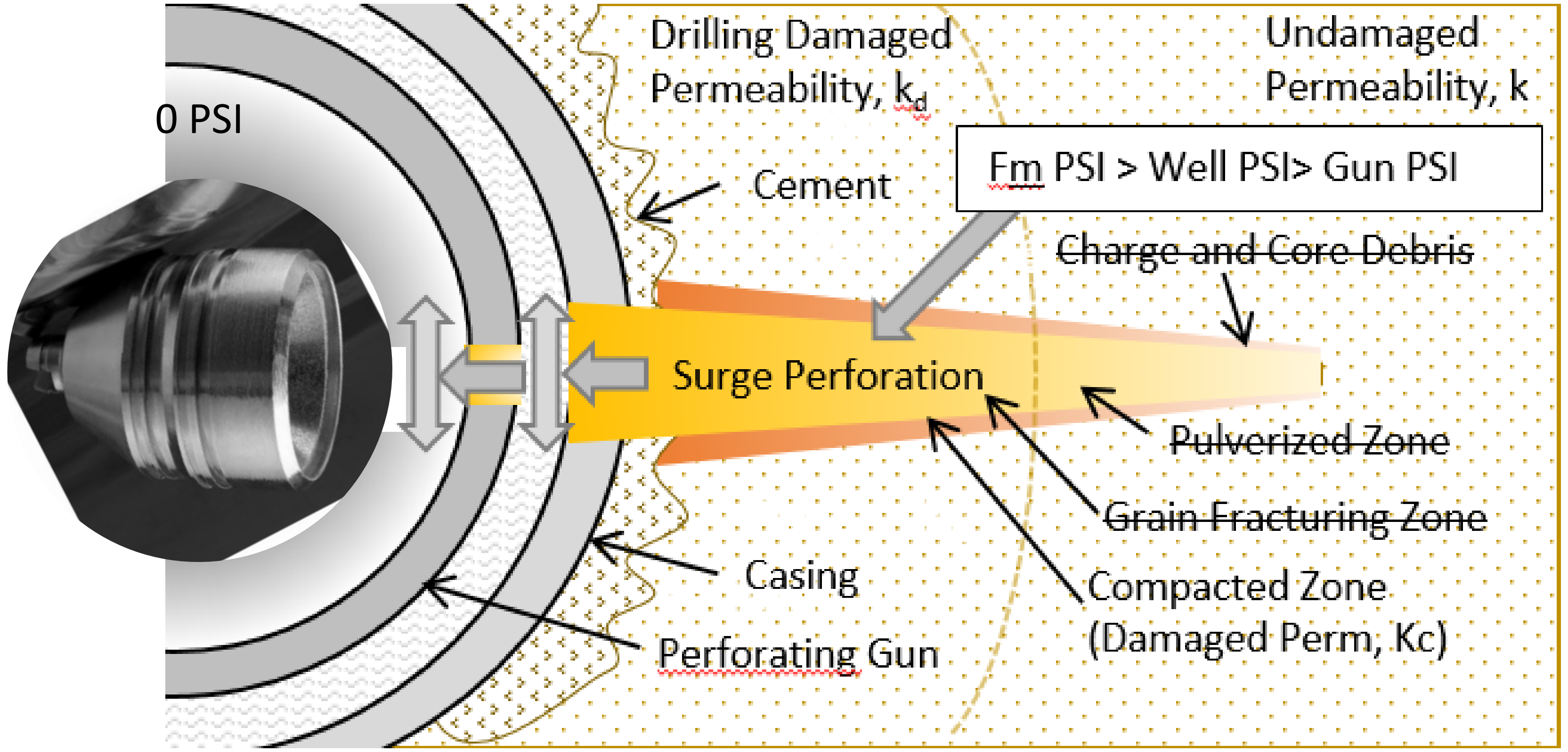

Fig. 6- Fadzil et al, 2021 [4]

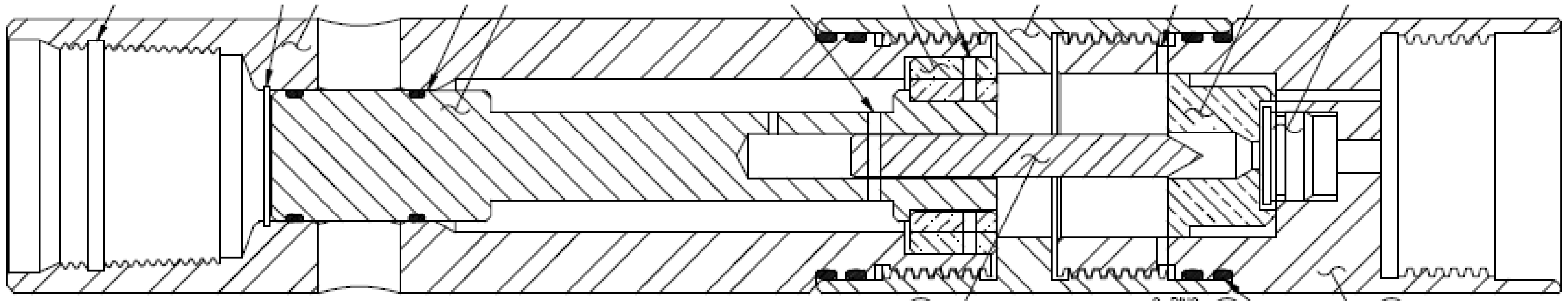

Fig. 7- Proprietary Auto-Vent Firing Head Assembly

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Challenge #3: Ensure long bottom hole assembly (BHA) could be successfully and safely deployed, fired, and retrieved on Coiled Tubing

- Running long intervals (~150m/ 49 2ft) of large (114 mm/ 4.5 in OD) high-shot density (39spm/ 12spf) perforating guns conveyed on small Coiled Tubing (50.8 mm/ 2.00 in OD) with small (38.1 mm/ 1.50 in AMT) threads of low tensile strength (42,000 lbs)

Remedy

1. To determine if the long bottom hole assembly (BHA) could be successfully deployed, fired, and retrieved on Coiled Tubing, Company's Reservoir Engineering team performed shock modelling (PulseFrac) to ensure this could be accomplished [Fig. 7, Tables 4,5]

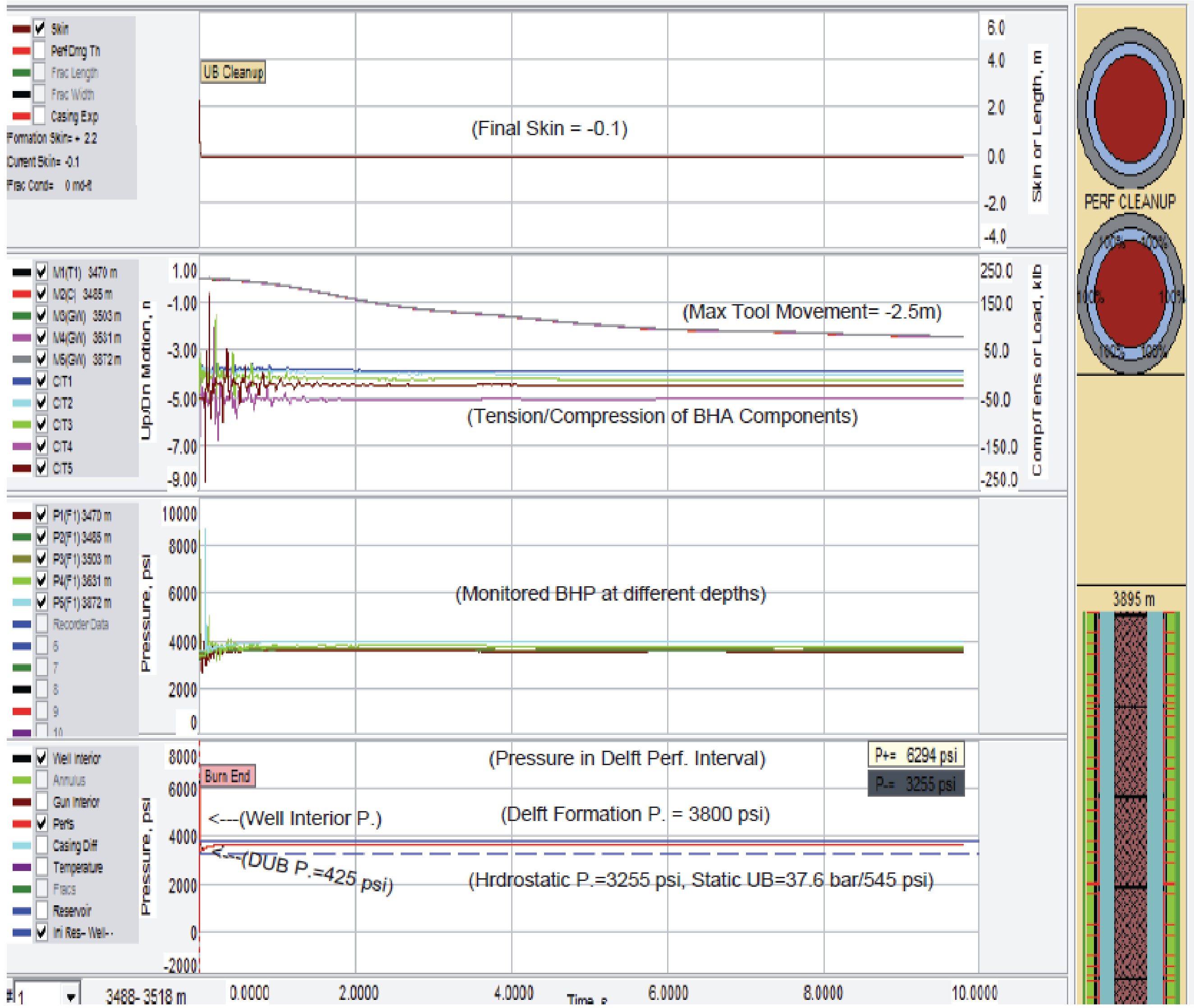

Fig. 8- Modeling Results showing no failure points

1. Delft Sand: Wellbore fluid level at 550m, Hydrostatic Pressure = 224.4 bar (3,255 psi), Static Underbalance (UB) = 37.6 bar (545 psi)

Static UB (psi)	DUB Created (psi)	Final Skin Factor	Max Tool Movement (m)	Max Pressure (psi)	Min. Pressure (psi)
545	425	-0.1	-2.5	6,294	3,255

Table 4

2. Alblasserdam Sand: Wellbore fluid level at 550m, Hydrostatic Pressure = 246.4 bar (3,574 psi), Static Underbalance (UB) = 29.6 bar (429 psi)

Static UB (psi)	DUB Created (psi)	Final Skin Factor	Max Tool Movement (m)	Max Pressure (psi)	Min. Pressure (psi)
429	313	-0.1	-2.5	4,328	3,574

Table 5

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Challenge #3 (continued): Ensure long bottom hole assembly (BHA) could be successfully and safely deployed, fired, and retrieved on Coiled Tubing

- Running long intervals of large high-shot density perforating guns conveyed on small Coiled Tubing with small threads of low tensile strength

Remedy

2. With Client's consent, to reduce the weight and shock load, split the perforation intervals into two runs, however this created a new challenge which needed to be addressed- see #3a [Fig. 8,9]

Note: Gun Systems selected:

- For Injectors:
  1. Lower Alblasserdam- 150m, 114mm/ 4.5in OD, 39spm/ 12 spf, Deep Penetrating (DP) charge
  2. Upper Delft- 50m, 114mm/ 4.5in OD, 39spm/ 12 spf, DP charge (reactive)
- For Producers:
  1. Lower Alblasserdam- 150m, 114mm/ 4.5in OD, 39spm/ 12 spf, Good Hole (GH) charge
  2. Upper Delft- 50m, 114mm/ 4.5in OD, 39spm/ 12 spf, DP charge (reactive)

Challenge #3a: For second run, since the wellbore now has open perforations where well pressure = formation pressure, no formation cleaning possible.

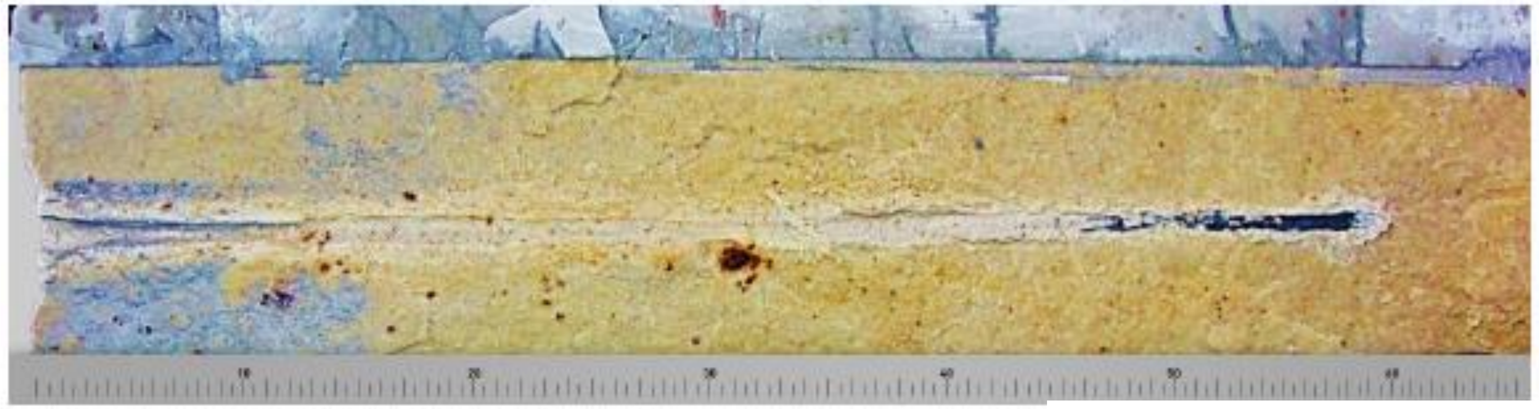

Fig. 9- DP or GH system

1st Runs:
- Standard DP or GH charges used
- Knowing there was debris & perf tunnel plugging, used DUB to surge clean to remove debris and crushed zone.

Fig. 10- Reactive liner system

2nd Runs:
- Well has open perforations and now at balanced pressure condition, so DUB not possible.
- Instead, used Reactive Liner DP charges, which provide a cleaning/ opening of perf tunnel like DUB.

Third party provider- Perforating Gun Systems [6]

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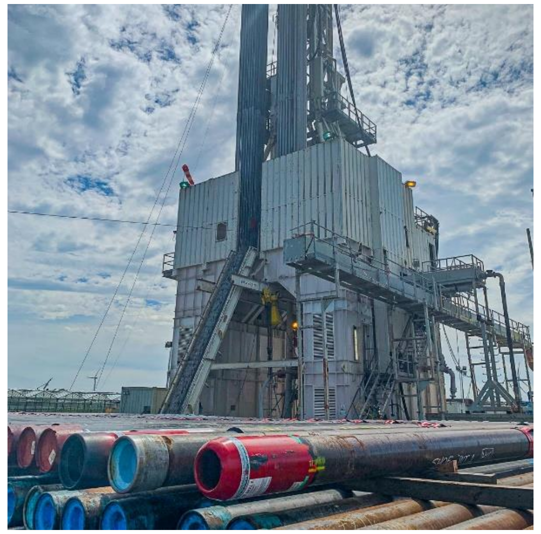
Fig. 11- Land drilling rig



Challenge #4: Manage risk of two independent rig set-ups being used, which required different lifting, handling, risk assessment, and personnel competencies and training.

- Two set-ups being used:
    1. Standard land drilling rig (lifting with rig equipment- hoists and blocks)[Fig. 11]
    2. Rigless using Coiled Tubing Tower and Work Platform (lifting with crane truck and CT unit] [Fig. 12]

Remedy

- Company had trained/ competent personnel able to perform on both set-ups
- Company had full suite of equipment (proprietary or 3rd party) suited to safe pickup, deployment, retrieval, and laydown [Fig. 13]

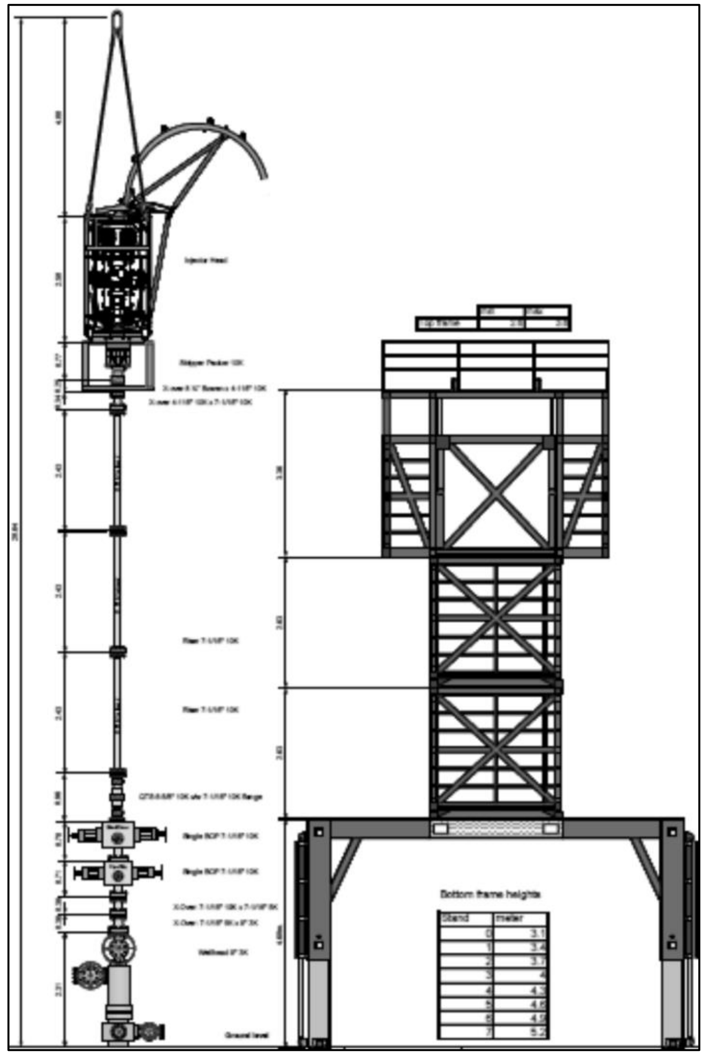


Fig. 12- 3rd party Coiled Tubing BOP/ Lubricator/ Work Platform [5]

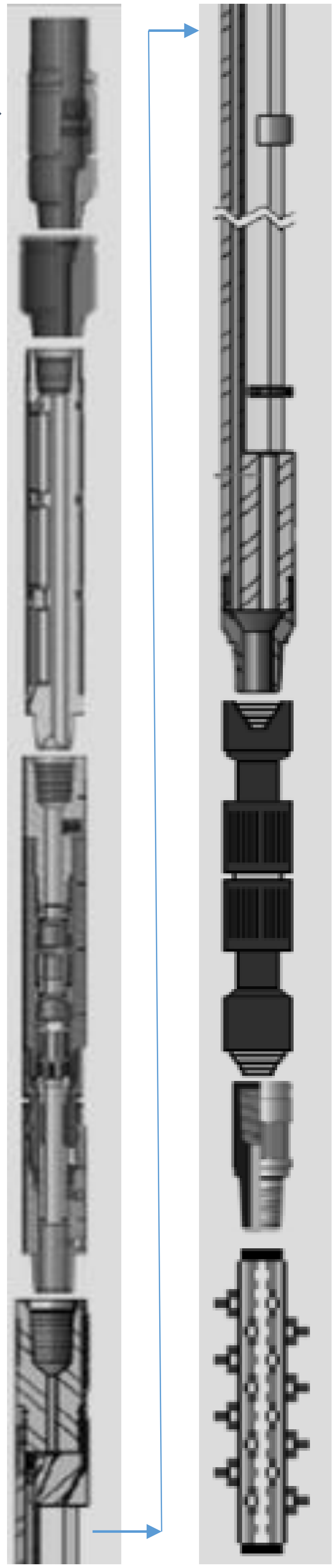


Fig. 13- 3rd party Coiled Tubing BHA- (same for both setups)

Challenge #5: Execute efficiently to tight timelines around an active drilling project preventing any costly downtime and penalties

- Company had to work within tight timelines around an active drilling project to prevent delays.

Remedy:

- Several separate companies were involved in delivery of different aspects of the project.
  - Key was integrated project management solution led by Company, which ensured information was conveyed clearly and completely.
- Established relationships with key suppliers were critical as several companies expedited deliveries and adapted schedules to meet very tight delivery times.
- Deep personnel pool of employees and consultants was tapped for blanket coverage, then in-country, project-specific training was held so that all potential personnel were ready on Day 1 [Fig. 14, 5,16]

Fig. 14- Company personnel inspecting firing head assemblies during in-country training

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Value to the Client

- The Client benefited from the efficient application of tried-and-tested completion technology and expertise from the oil and gas industry to increase productivity for this geothermal project, boosting energy security and assisting energy transition initiatives
- To assure this project’s successful completion, Company supplied an integrated project management solution, offering technical know-how, supply chain coordination, and operational excellence
- Injection and production results are being further analyzed to determine the effectiveness of gun systems selected to optimize the BHA assemblies used in these wells going forward

Fig. 15-View of Netherlands Infrastructure visible from rig floor

Acknowledgement

Thank you to all for attending, the SPE Geothermal Aberdeen Committee for selecting us, our suppliers and personnel that made this project successful, and our Company management for the opportunity to present this subject today.

References

1. Van Leeuwen, W., Buik, N., Gutierrez-Neri, M. Lokhorst, A., Willemsen, G., (2019, April 25-29), Proceedings World Geothermal Congress 2010, Bali, Indonesia : Subsurface Spatial Planning for Geothermal Heat Production in Greenport Westland-Oostland, the Netherlands, *IF Technology, Postbus 605, 6800 AP Arnhem, the Netherlands*.
2. https://allesoveraardwarmte.nl/
3. Stichting Platform Geothermie (2018, May): Master Plan Geothermal Energy in the Netherlands: A broad foundation for sustainable heat supply, : www.geothermie.nl
4. 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
5. 3rd party provider information- Coiled Tubing BOP/ Lubricator/ Work Platform
6. 3rd party provider information- Perforating Gun Systems

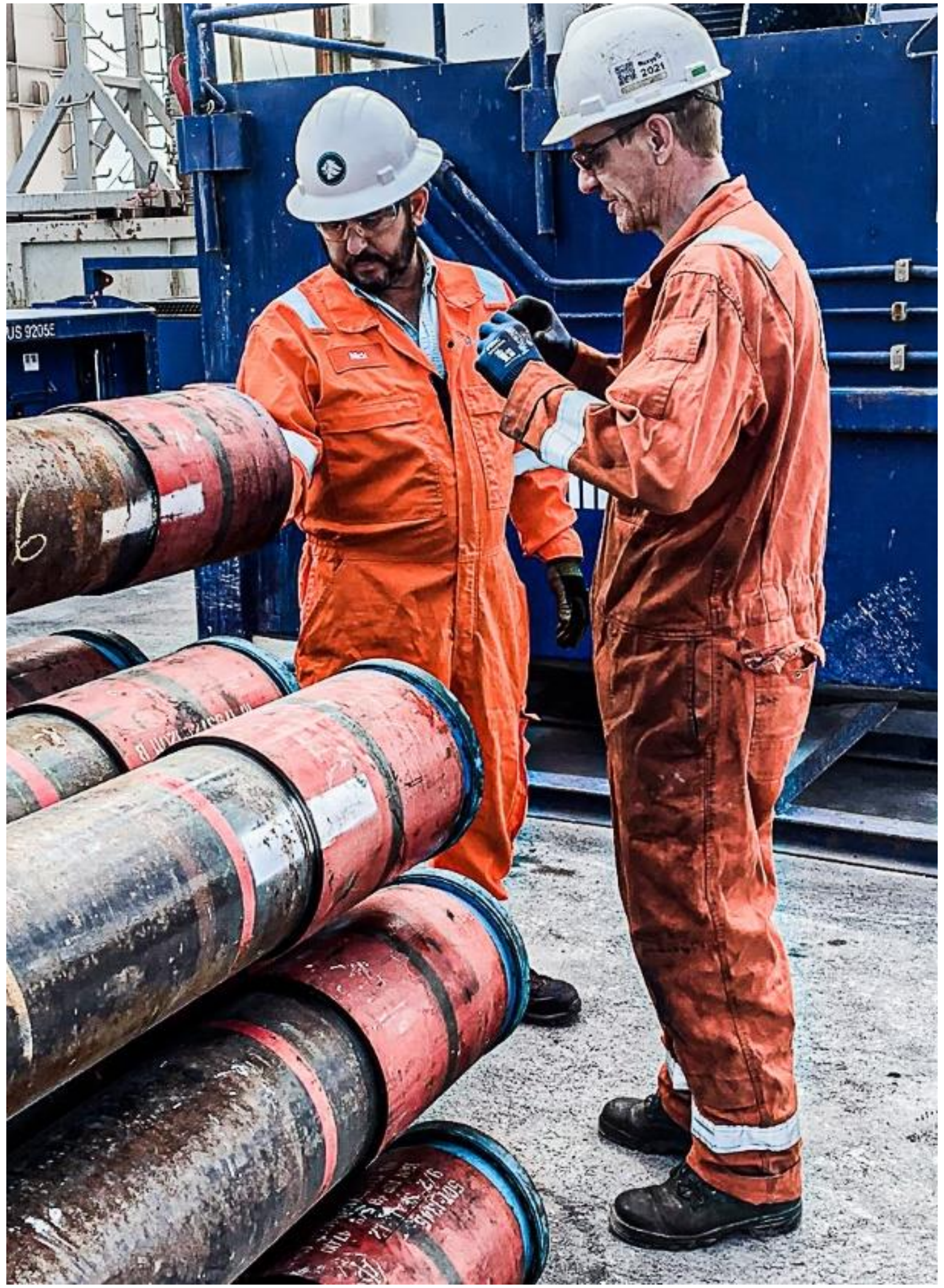

Fig. 16- Company Personnel inspecting GRE-lined casing during Rig Visit

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Thank you

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