The First Application of Autonomous Outflow Control Devices in a Water Injection Well in Norway

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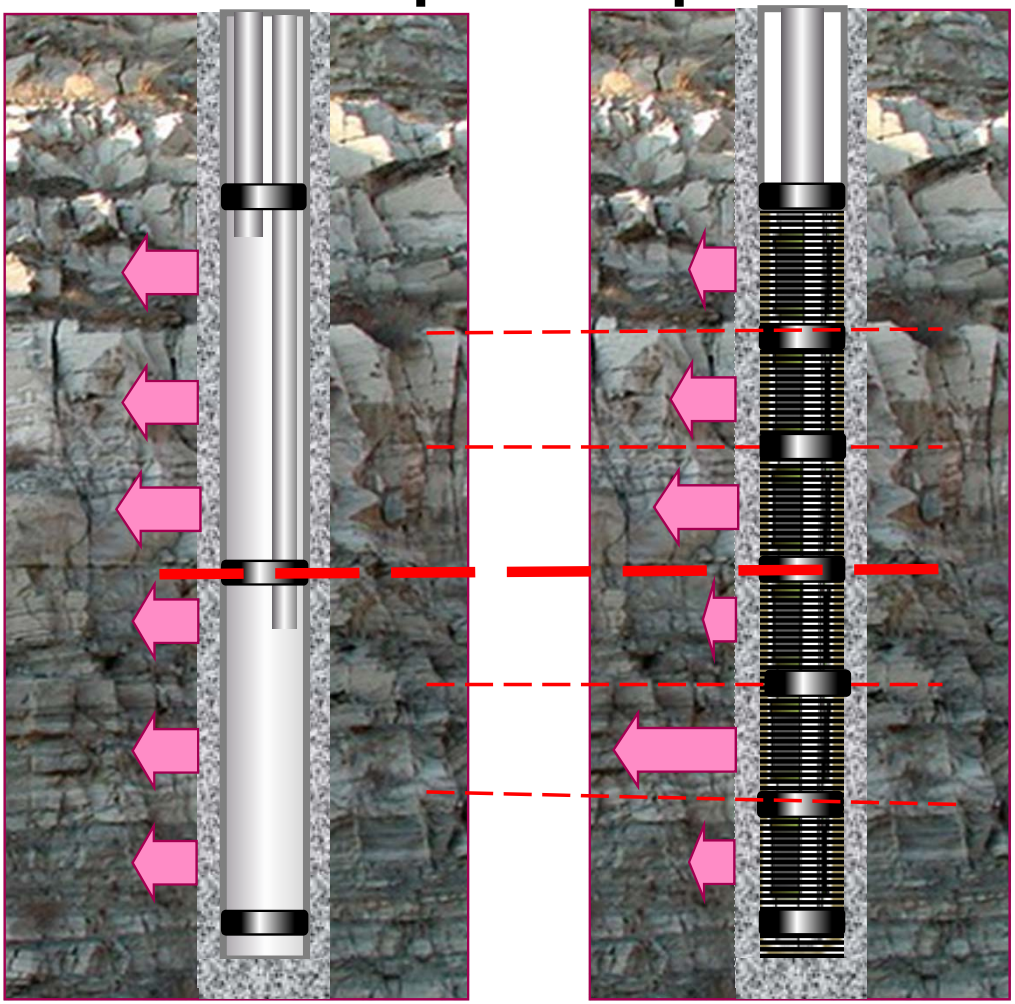
TENDEKA
RESULTS ACROSS YOUR RESERVOIR

From Mutiple Completions to Single Advanced Completions

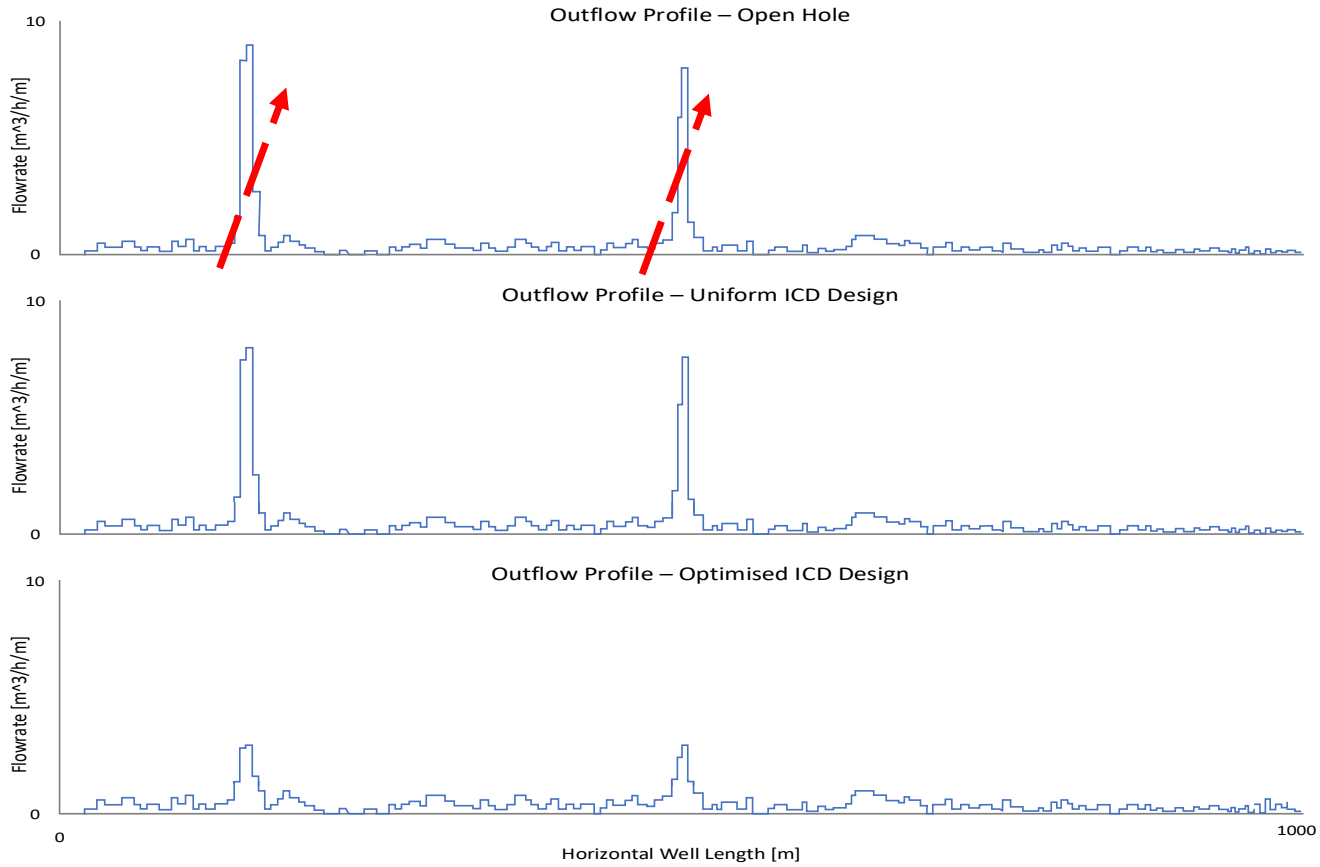


- **Objectives**
  - Permit higher resolution control to multiple layers
  - The outfluxes profile not to be only dependent to heterogeneity of rock at each section of well
  - Ensure proportional distribution of water injection along full length of wellbore and between laterals
  - Respond to dynamic changes in fluid injection
    - Fracture growth
    - Thermal fracture initiation
    - Matrix impairment, plugging
    - Unexpected variations in fluid displacement
    - Breach in Containment

- **Solutions**
  - Advanced Completions
    - Flow Control Devices: FCDs, AFCDs, ICVs
    - Zonal isolation: Packers, seal bores

OUTFLOW PROFILE COMPARISON

The Conventional Techniques



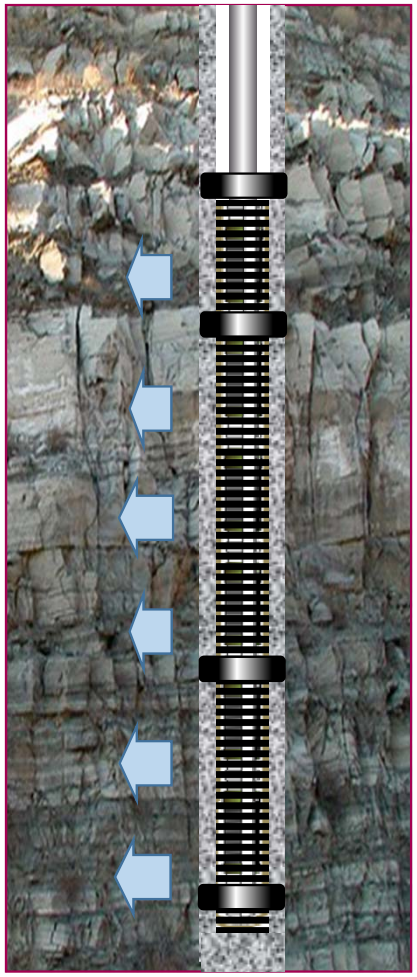
BAREFOOT/SAS

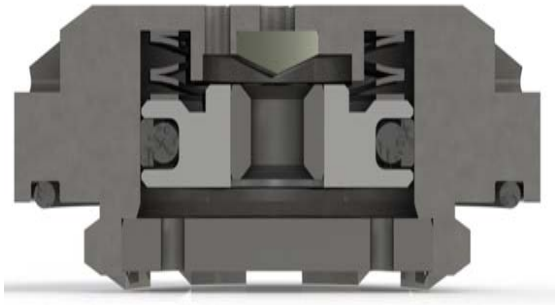
SAME ICD SIZE ACROSS COMPLETION

ICD 10X SMALLER AREA AT FRACTURES

FLOFUSE™; AUTONOMOUS OUTFLOW CONTROL DEVICE

Rate Limiting Flow Control Device





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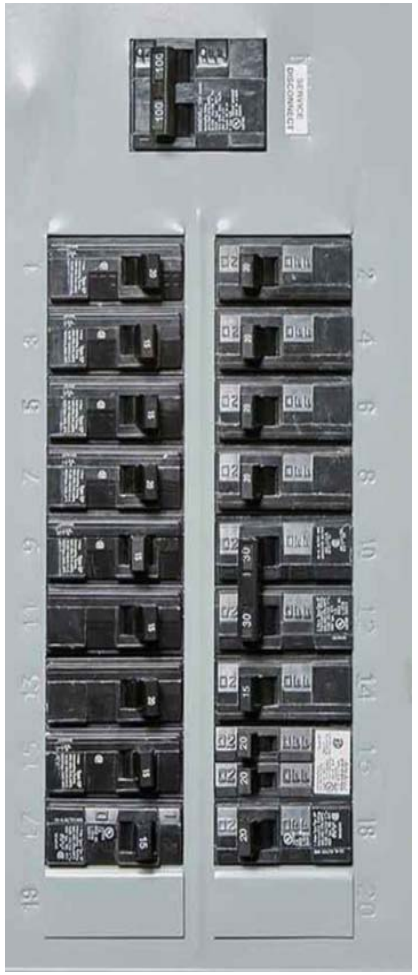
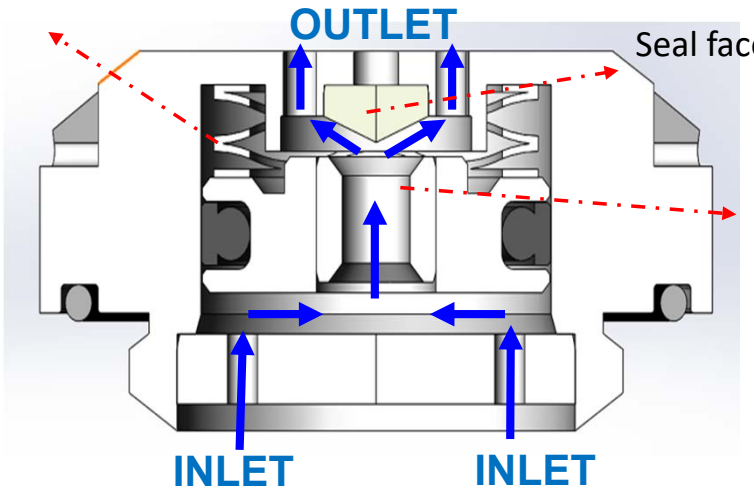


The valve provides a rate limit to prevent excessive fluid injection into the thief/fracture zones thereby enabling distributed or matrix injection.

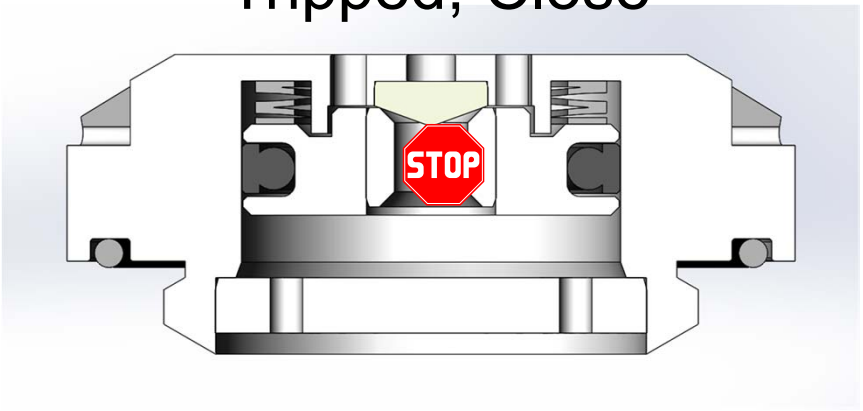
THE FIRST AUTONOMOUS OUTFLOW CONTROL DEVICE

FloFuse™ Design and Operation

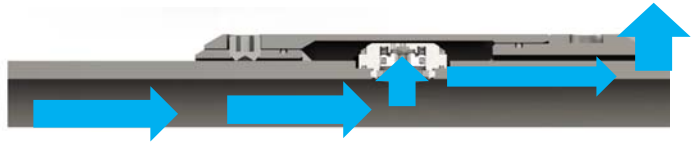
Open to Flow



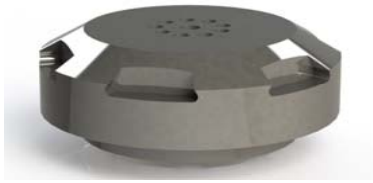
Tripped, Close



- The well is segmented into multiple zones with one or more FloFuse valves within each zone.
- The valve is mounted into the basepipe or screen section.
- Majority of fluid passed through FloFuse valves.
- Bypass valves (size from 1.5mm to 10mm) are to enable injecting a minimum rate to each zone.



FloFuse



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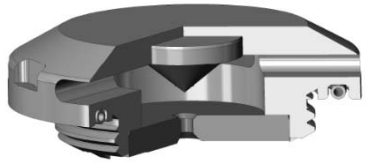
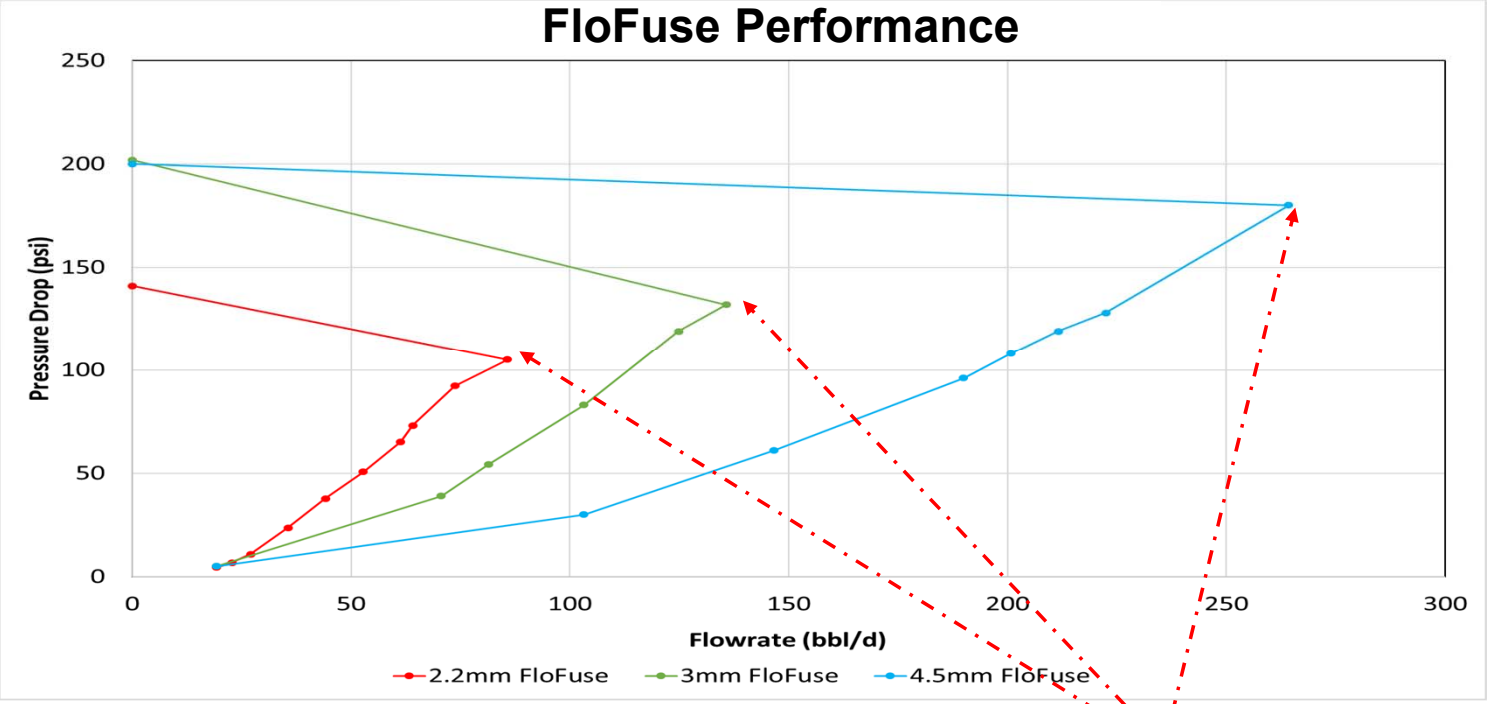
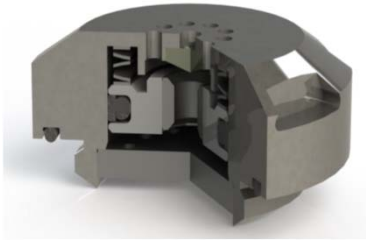
Bypass valve



FloFuse Performance





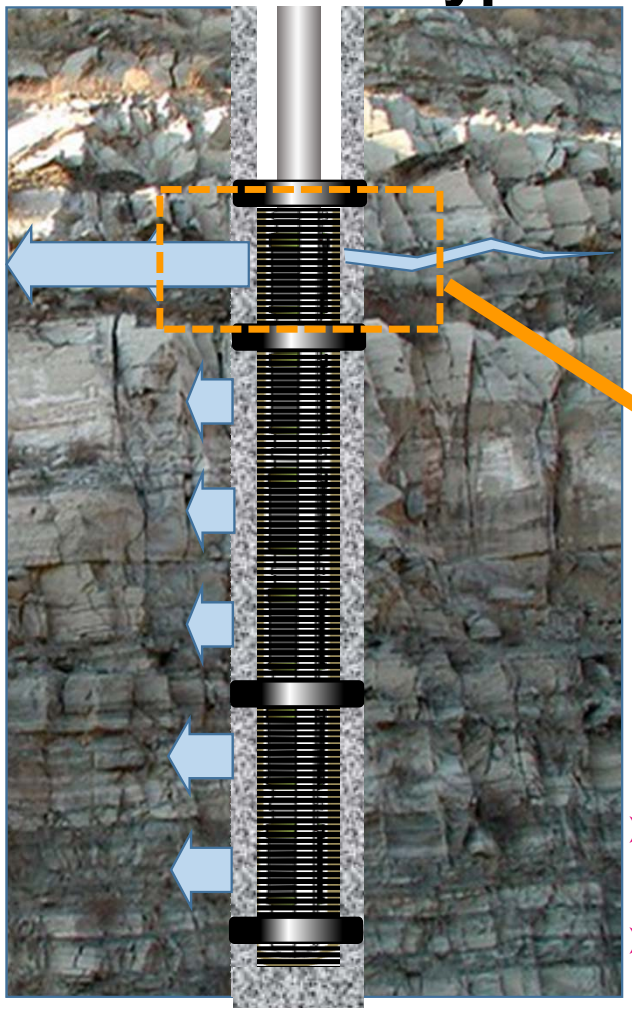
$$\partial P = \left(0.5 * \frac{\rho}{Cd^2A^2}\right) Q^2$$

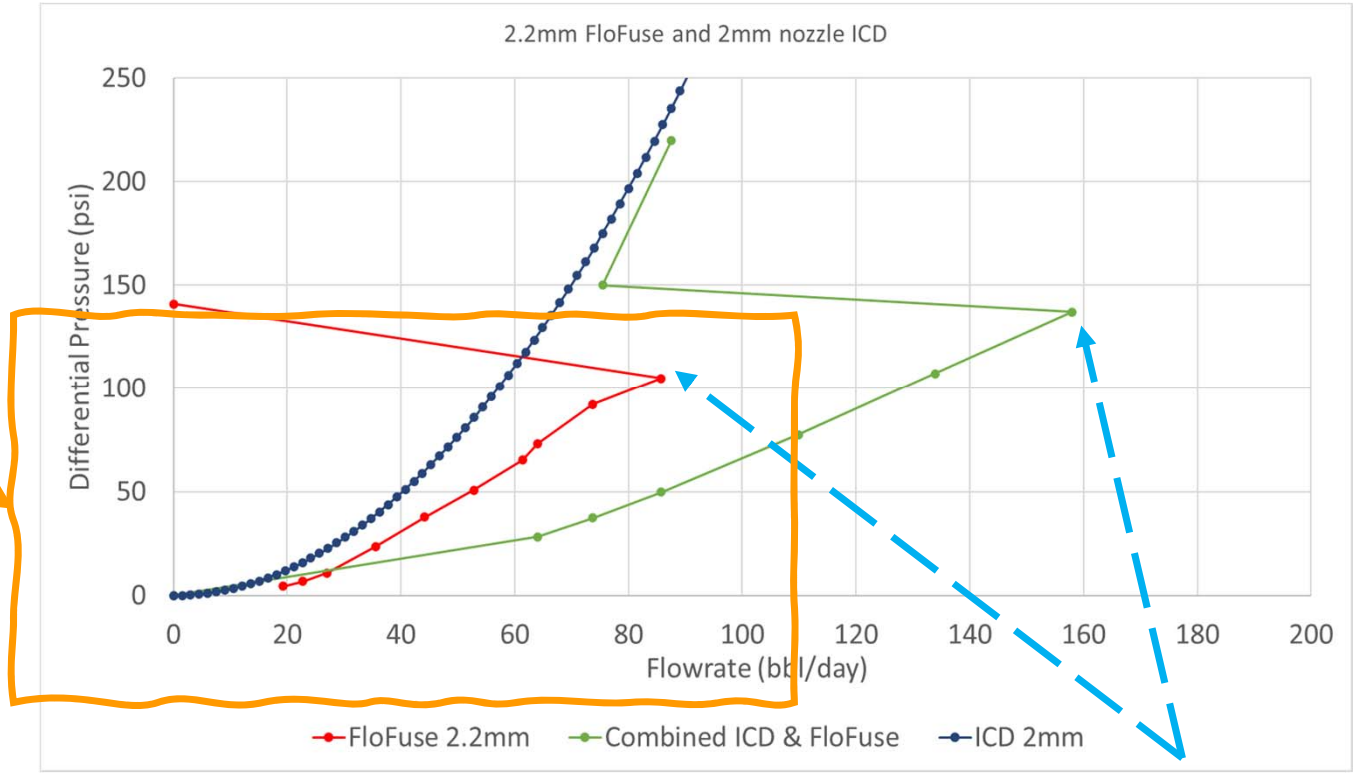
Tripping Pressure (Rate)

Tripping Pressure (Rate) could be modelled and designed for each application if required

COMBINED PERFORMANCE

FloFuse + Bypass ICD Valve



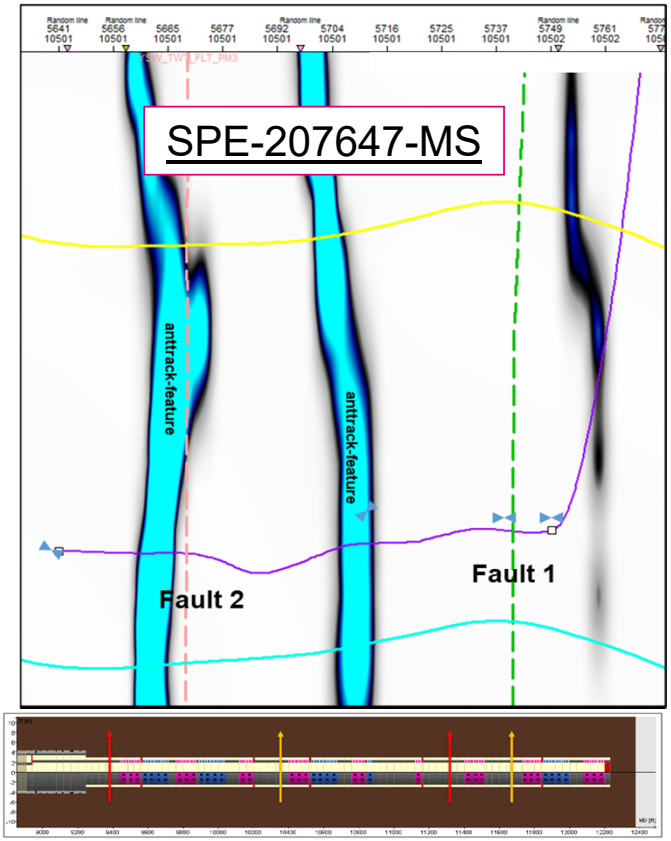


- With a less imposed initial pressure drop compared to conventional ICDs, the autonomous valve could manage water injection much more efficiently
- The valve reduces risk of poor conformance due to complex fracture network development and dilating/propagating fractures.

WORLDWIDE EXAMPLES

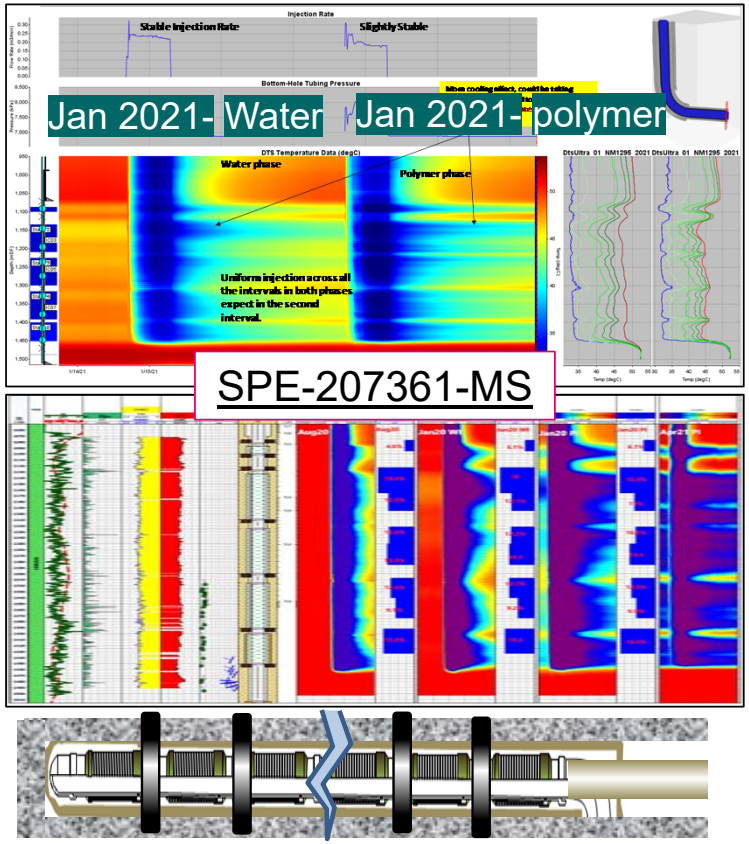
FloFuse Application

- ADNOC Injection wells
- **Design Objective**: Control faults/fractures



Achieved: 42% less injection in thief zones

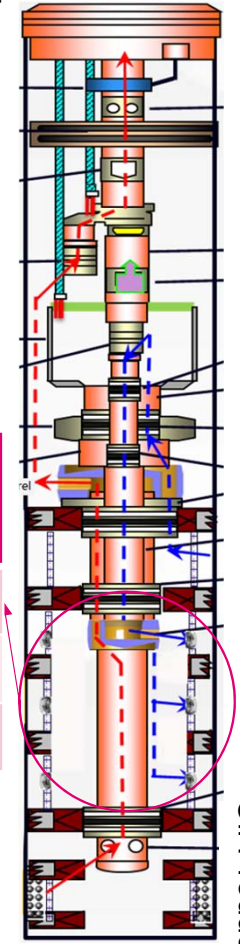
- PDO water/polymer injection wells
- **Design Objective**: Control a prescribed outflow



Achieved : 92% of the planned conformance

- China water injection well in Triple Operation well
- **Design Objective**: Control a prescribed outflow

Zone	Relative Injectivity (%)	Target Injection, (Relative %)
A	(75%)	25%
B	(9%)	23%
C	(16%)	52%



The initial applications have been successful and a dozen wells are planned around globe now.

IVAR AASEN

Ivar Aasen Field

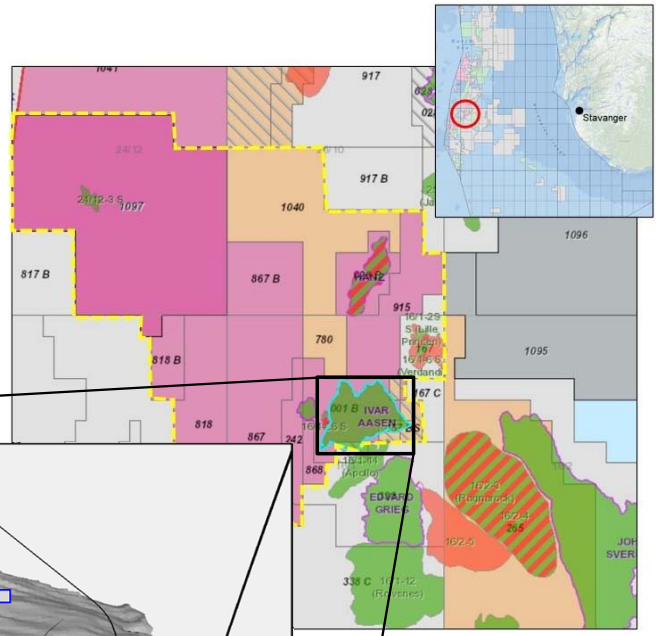
Overview

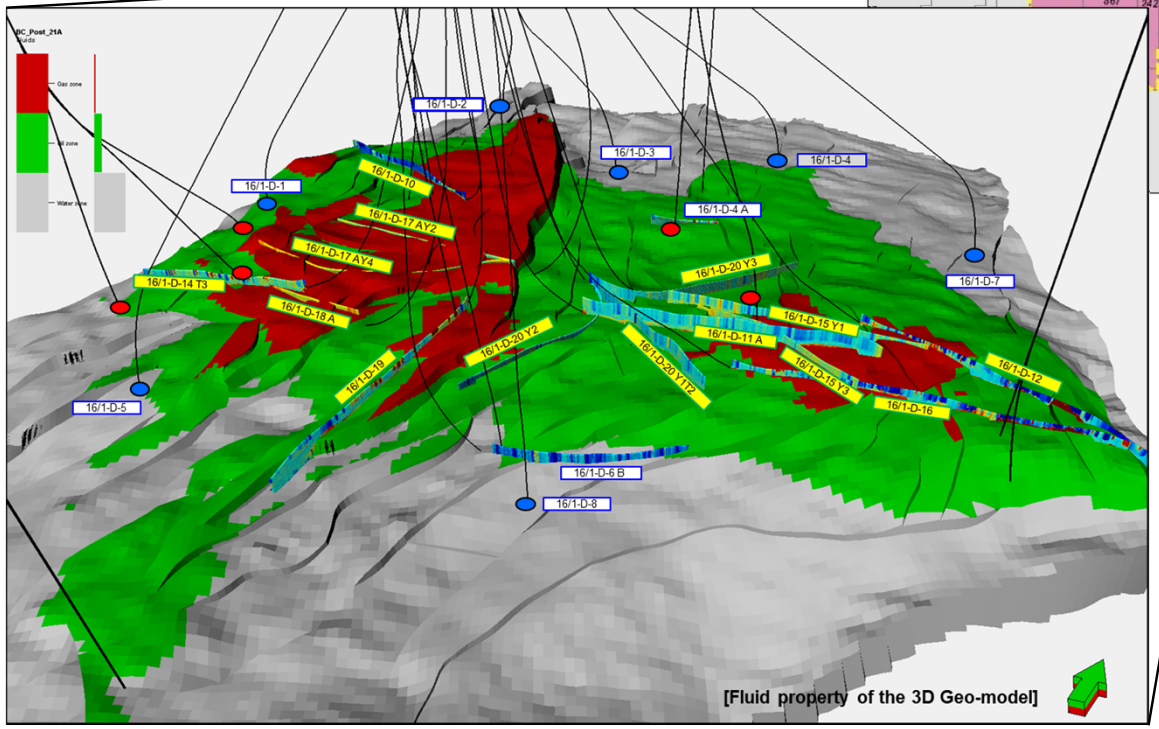
Highlights

- Oil and gas cap
- Approx. 60 x $10^6 Sm^3$ Oil eq. in place
- 11 horisontal producers
- 8 injectors on the flanks
- 5 data wells («geo-pilots») drilled prior the development wells (2015)
- Triassic and Jurassic sandstone reservoir

Drainage strategy

- Horizontal producers – spread out
- Water injectors located at the flanks
- Reservoir depletion strongly supported by water injection
- Pushing the oil towards the producers

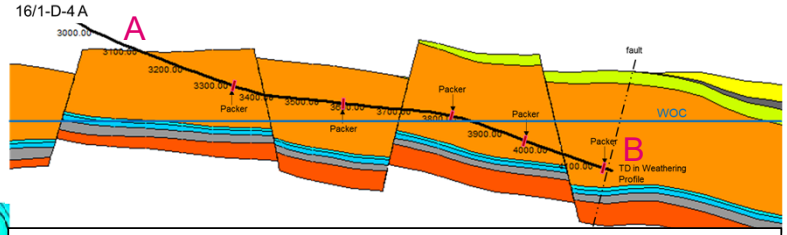




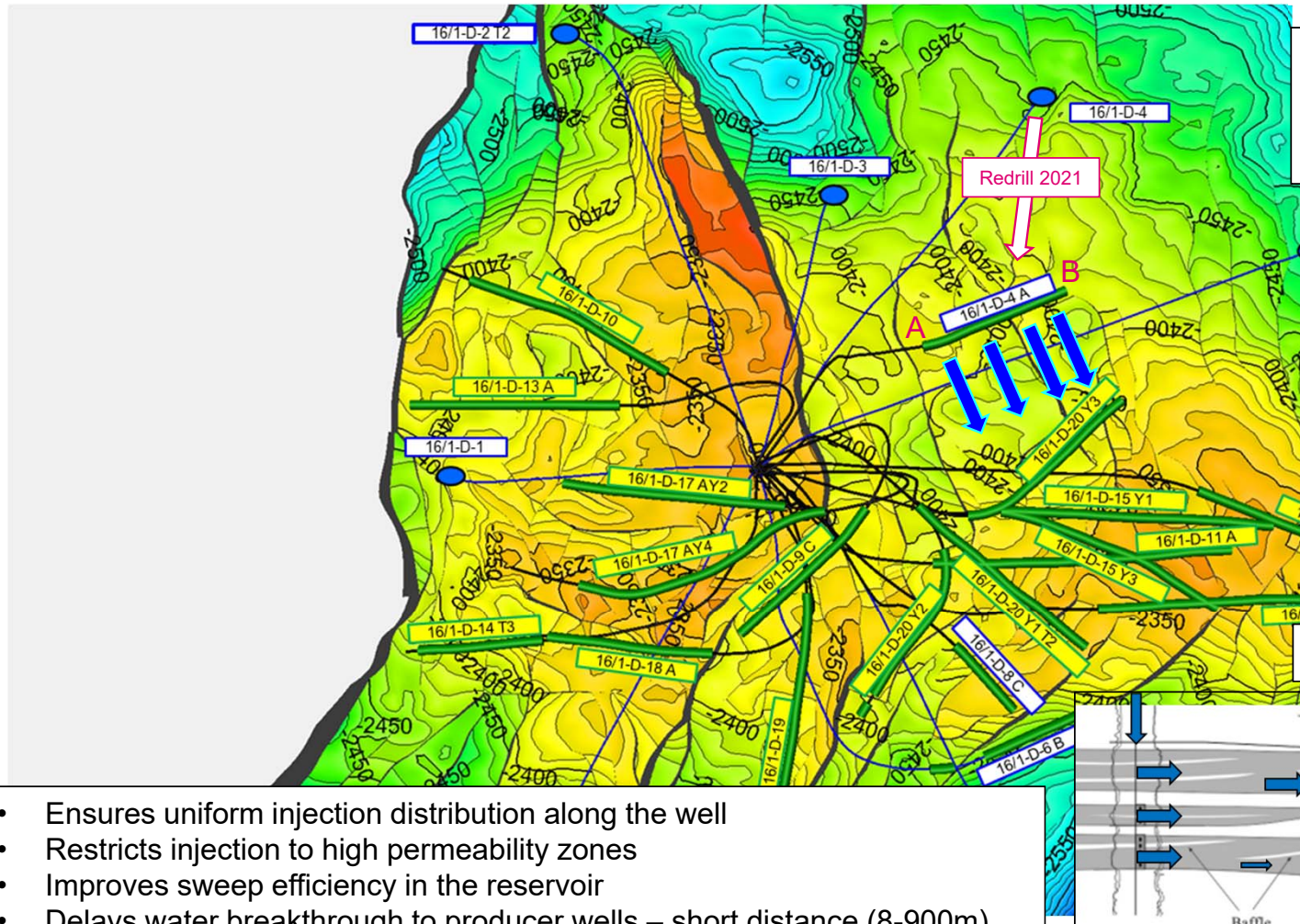
Geo-pilots Water injectors 16/1-D-xx Producers

OBJECTIVE & MAIN SET UP

Objective of D-4 A injector

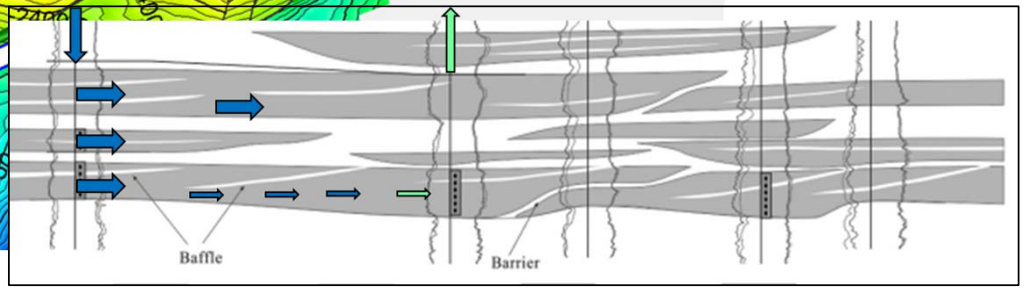


FloFuse in combination with FloExtreme valves were introduced to mitigate some of the identified **RISKs**



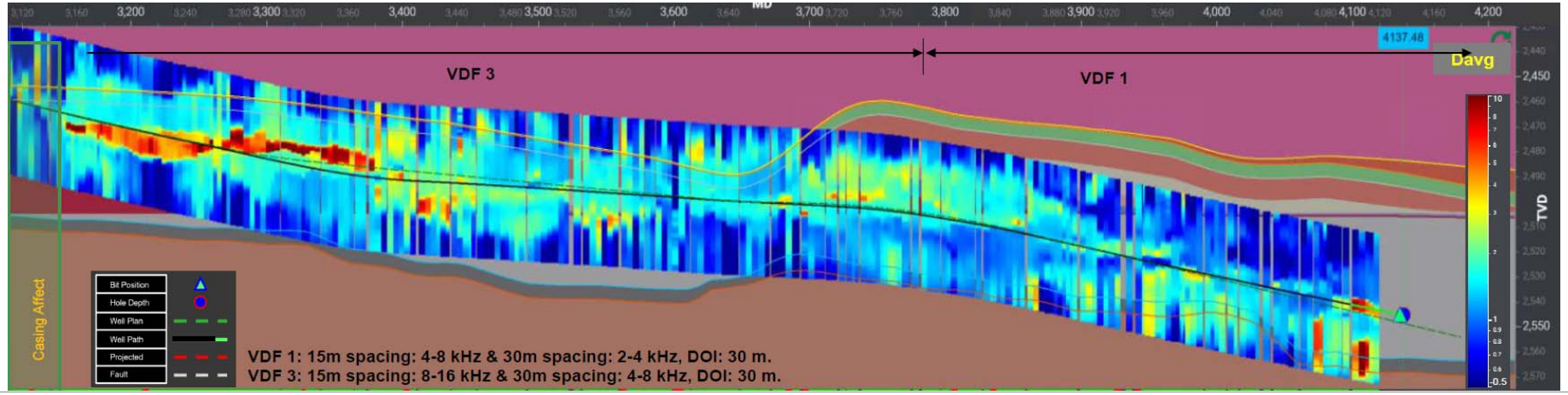
- Ensures uniform injection distribution along the well
- Restricts injection to high permeability zones
- Improves sweep efficiency in the reservoir
- Delays water breakthrough to producer wells – short distance (8-900m)

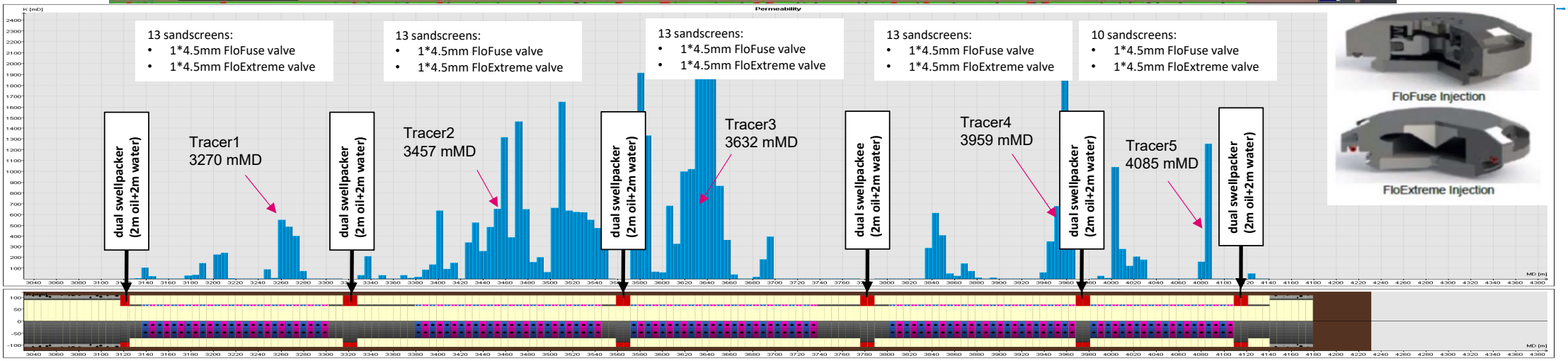
Fluvial channel – low connectivity in general



OBJECTIVE & MAIN SET UP

Permeability Distribution and Real Time EarthStar®Inversion

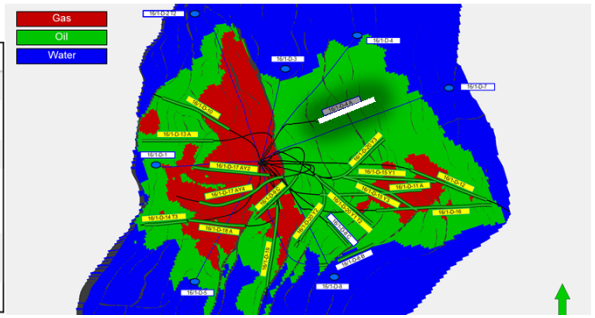




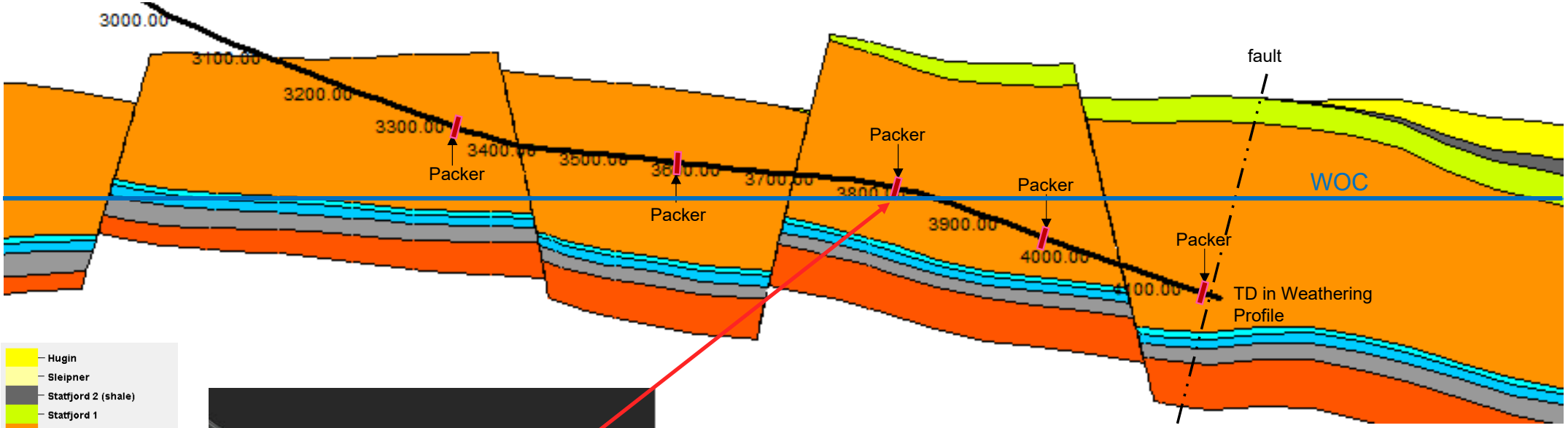
OBJECTIVE & MAIN SET UP

16/1-D-4 A

Well name:	16/1-D-4 A		
Well type:	Horizontal water injector		
Reservoir completion:	Stand alone screens with Tendeka Flofuse and FloExtreme valves, swell packers		
Injection start:	20. Nov. 2021		
Injection status:	Water (m3/d)	BHP(bar)	Choke (%)
June 2023	Approx 1000	382 (limited, Shmin cap-rock)	15
Interventions:	Oct-Nov2021: CT N2 assisted clean-up, Installed plug with flapper, CT N2 start-up May 2023: ILT		
Data acquisition:	Nov. 2017: Clean-up tracers. Reservoir tracers injected May 2022		



16/1-D-4 A



- Hugin
- Sleipner
- Statfjord 2 (shale)
- Statfjord 1
- Skagerrak 2
- Upper Weathering profile
- Lower Weathering profile
- Skagerrak 1
- Alluvial fan

After clean-up, a plug with a flapper were installed in well @ 3760 m MD

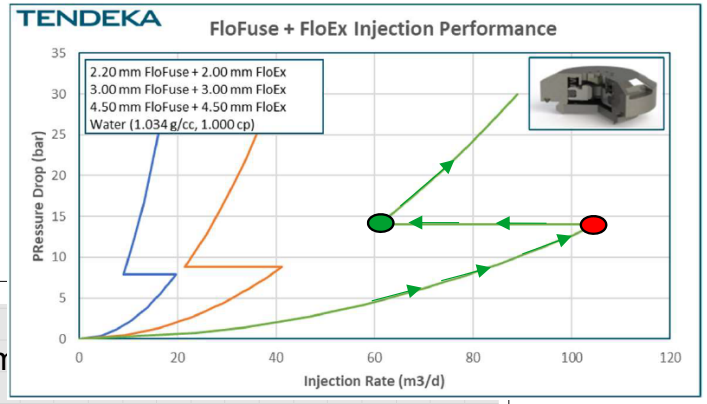
wellbore

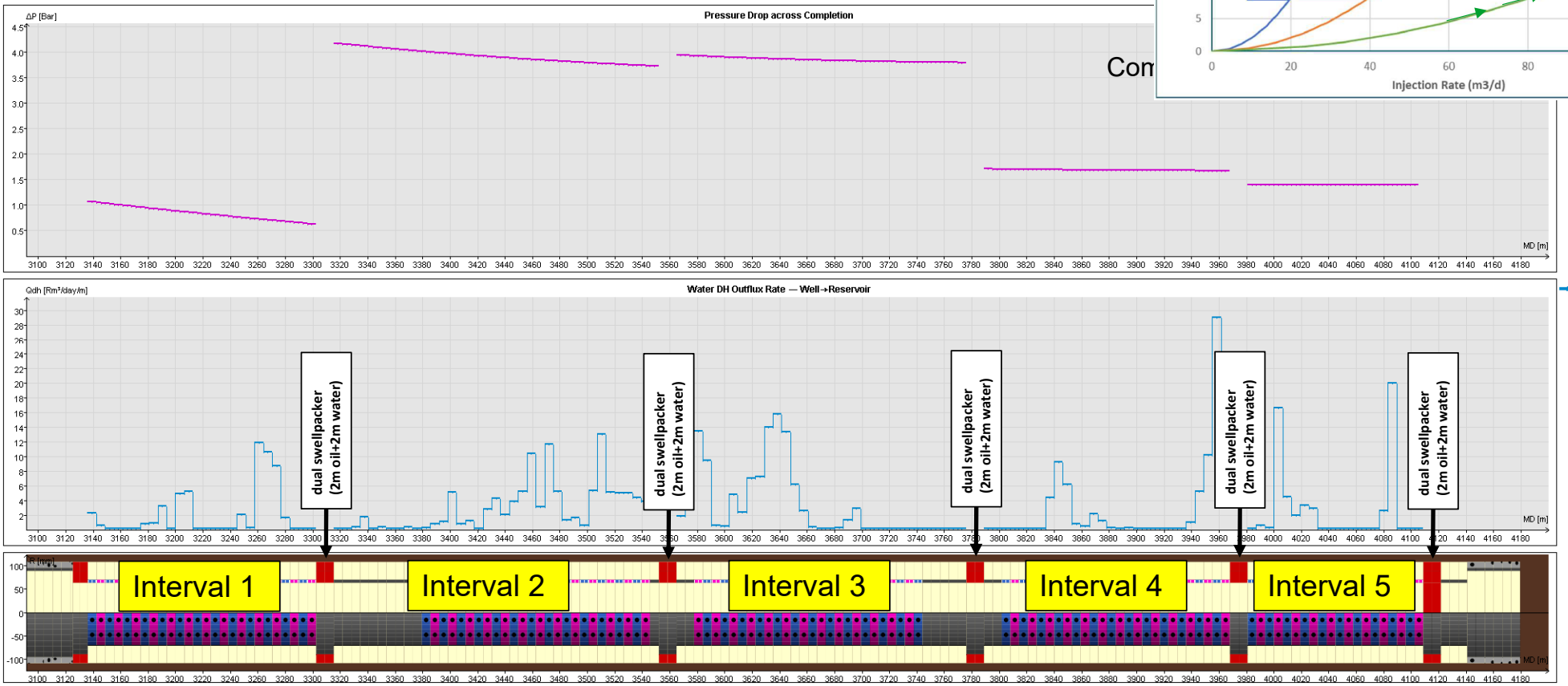
Z-scale:3

OBJECTIVE & MAIN SET UP → EXPECTED INJECTION PERFORMANCE

Injection profile and pressure drop across completion

Injection at 2500 m³/d (assuming equal pressure thus injection in all 5 zones)



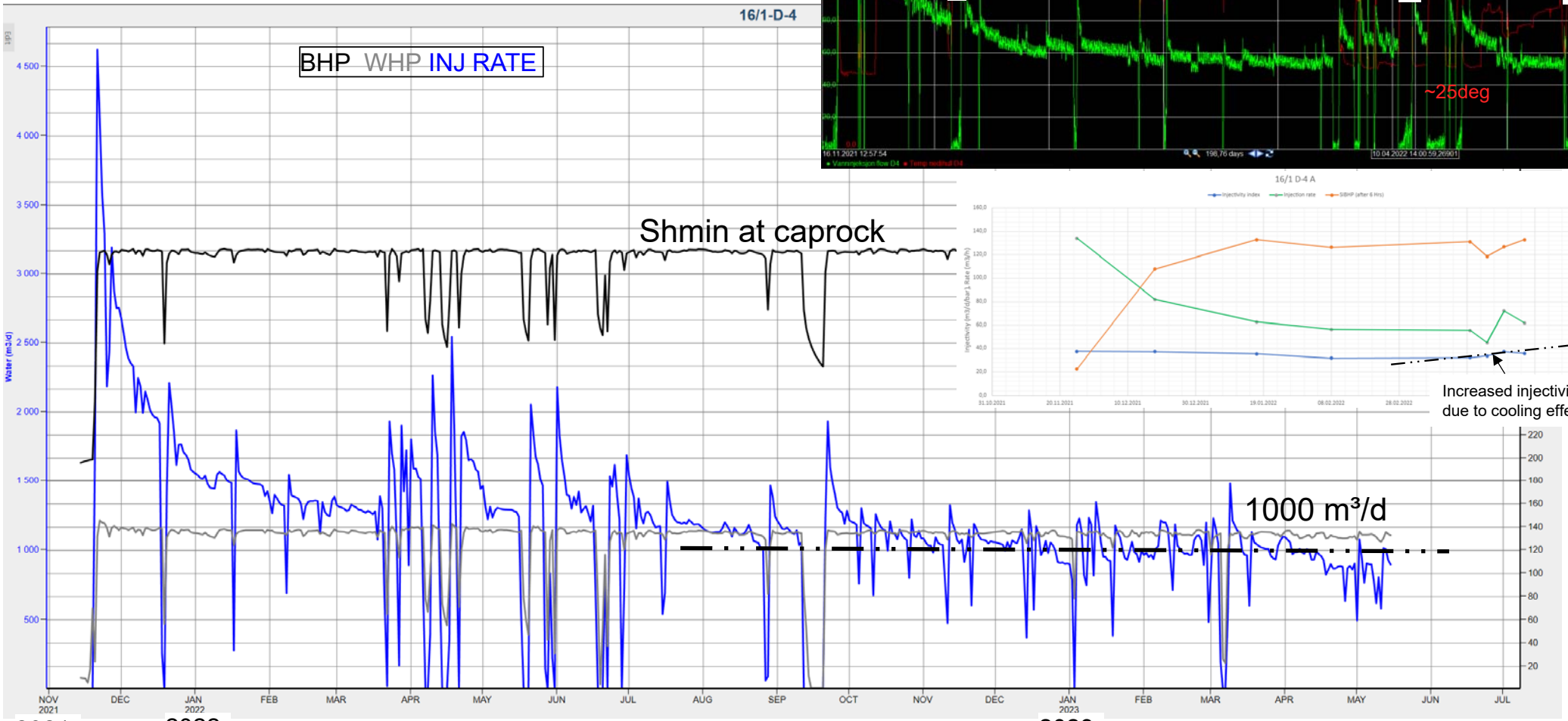


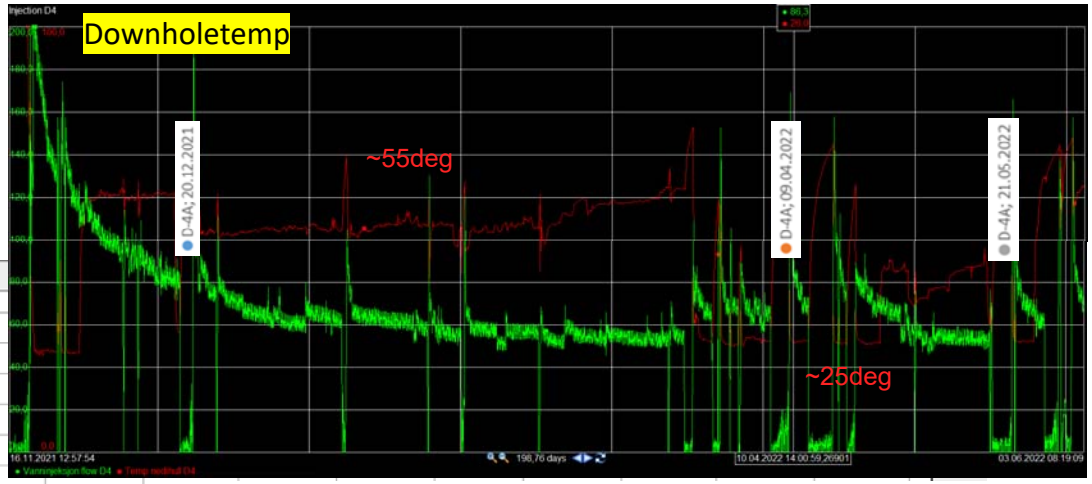
Cd=0.85 for the FloExtreme and 0.62 for the FloFuse

D-4 A INJECTION PERFORMANCE

D-4A Water injector

Current rate 1000 m³/d - Limited to 382 bar @ BHP *(Shmin at caprock)*



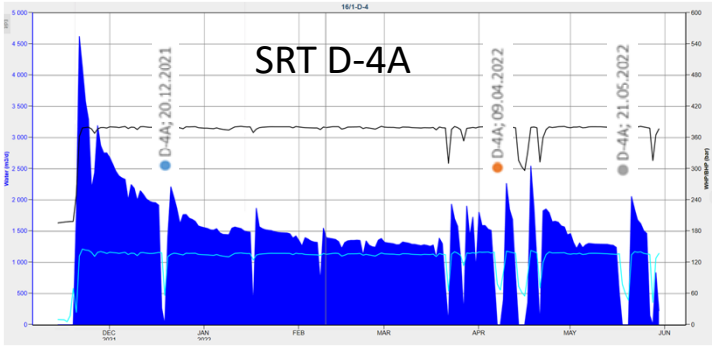


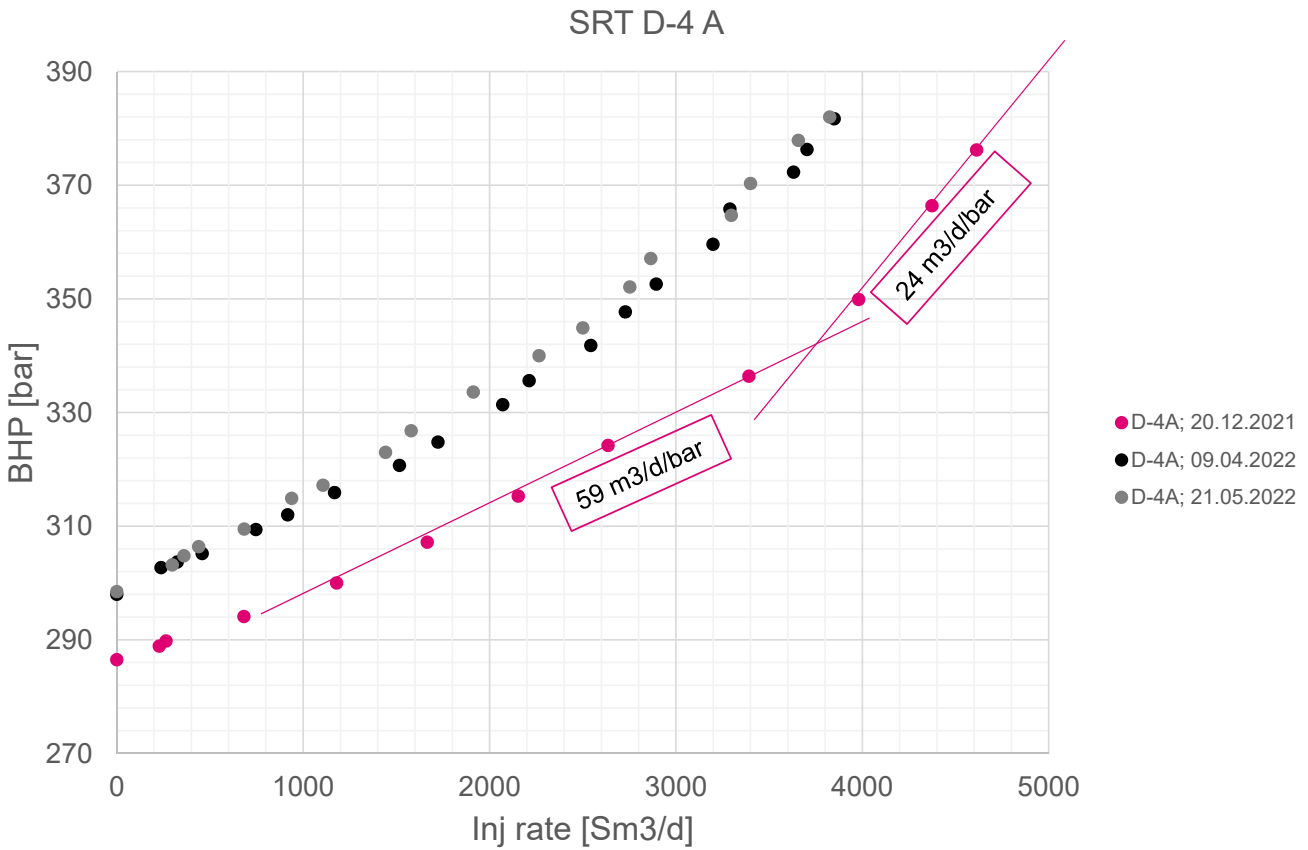
D-4 A INJECTION PERFORMANCE

Step Rate Test D-4 A

Observations:

- Increased reservoir pressure over time
- PLT indicates injections in all zones
- **Significant breaking point on SRT 20.12.2021.**
  - In line with welldesign
- Some changes in incremental injectivity for these.
  - Reduced by time
- Some, "opposite" behaviour for these breaking points. Can this tell us anything about injectivity / pore pressure buildup in our 5 intervals?

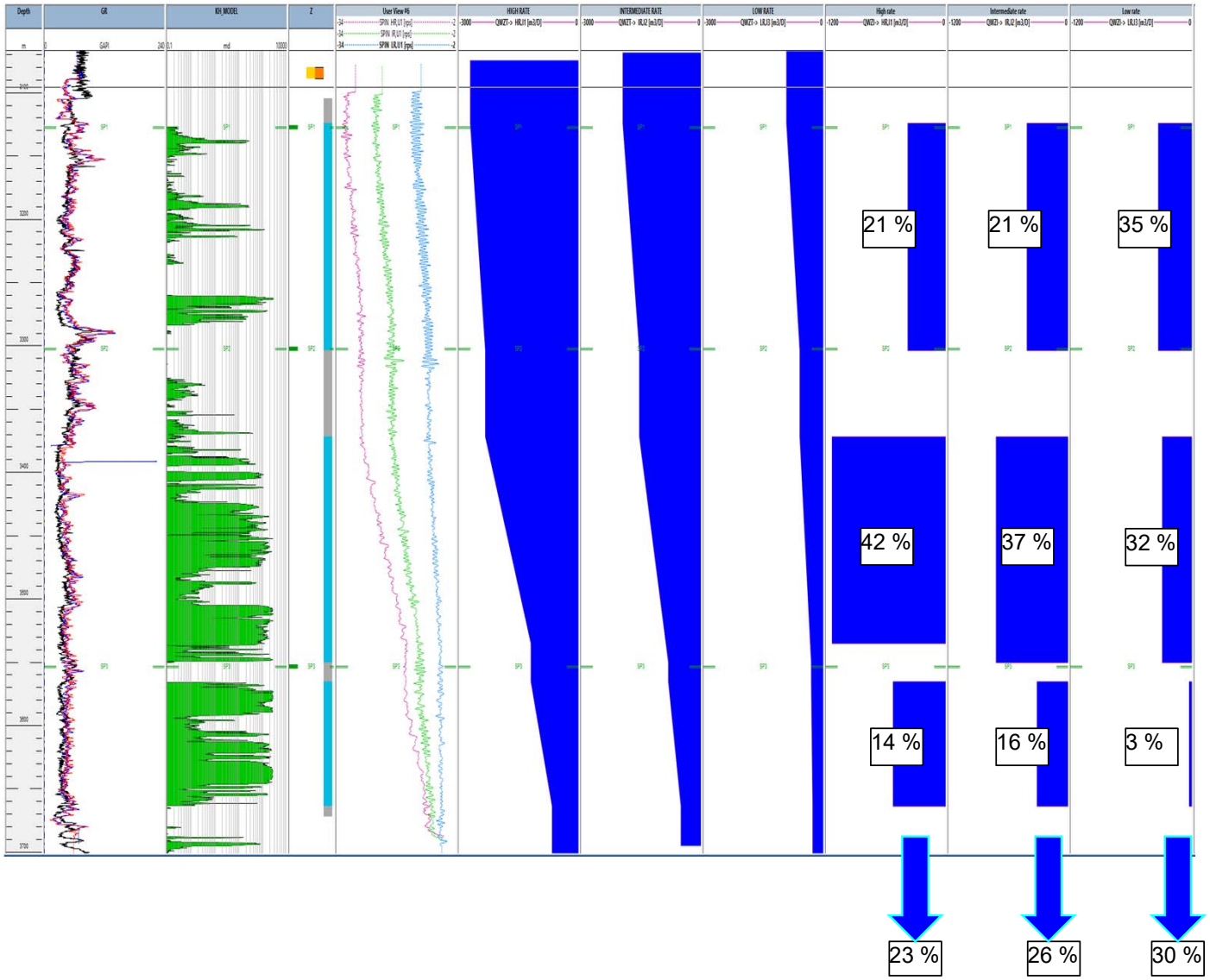




Injection Logging 2022*

- Injection logging indicated flow through all Tendeka valves
  - Based on spinner raw data
    - high rate (2800 m³)
    - low rate (1000 m³)
    - mid rate (2000 m³)
- ILT indicated outflow along all completed interval
  - 25-30 % injection contribution through plug
- More uniform outflow distribution at low rate for each swell packer interval (as compared to high and intermediate rate)
  - Uncertain low rate on interval 3560 m MD to 3660 m mMD. Could be as high as 8 % based on down pass.
- Relatively similar outflow distribution at high and intermediate rates
- MF caliper data showed GRE tubing to be in good condition

* Interpretations based on up pass logging

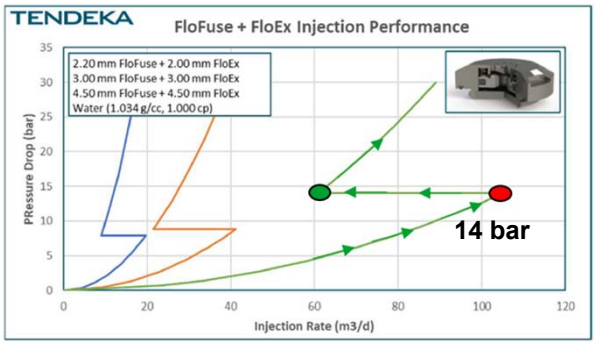


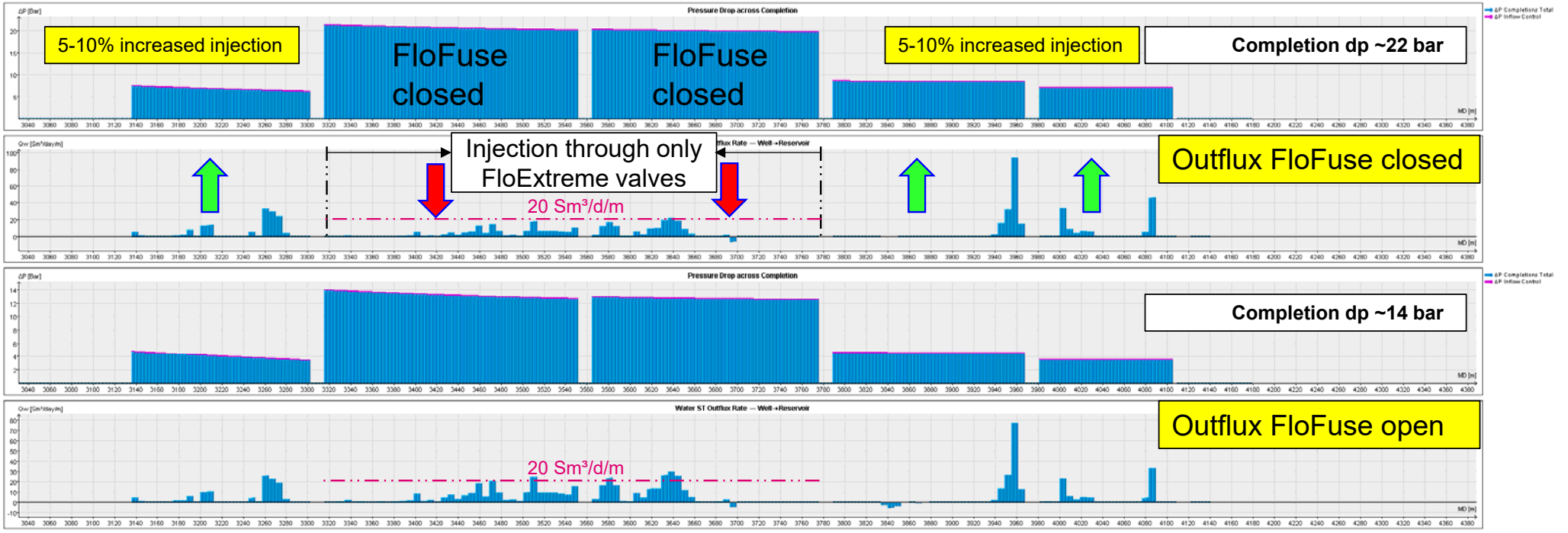
NETOOL MODEL

Injection profile

Injection at high rate – trigger rate of FloFuse

Significant breaking point on SRT @3800 Sm³/d



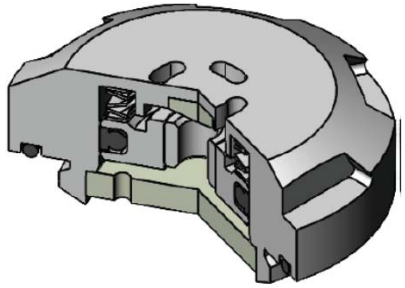


NETool setup: 1 ICD and 1 FCV per joint, ICD+ FCV makes it easier to close many FCV simult.
Cd=0.85 for the FloExtreme and 0.62 for the FloFuse

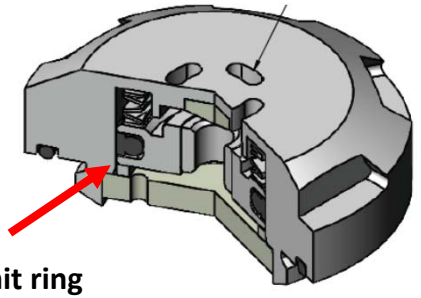
SUMMARY & WAY FORWARD

Flofuse without Check Function in Future Wells

- **D-4A was completed with FloFuse with Check Function**
- **This feature may limit back flow and/or cleanup capacity**
- **Forward wells on Ivar Aasen will be completed with the Non-Check Version to allow for high well clean-up rates.**



Flofuse - Regular
Piston can backstroke and close for production (check valve)



Flofuse – Without Check
Piston has a stop ring allowing for flow in both directions.

Summary & way forward

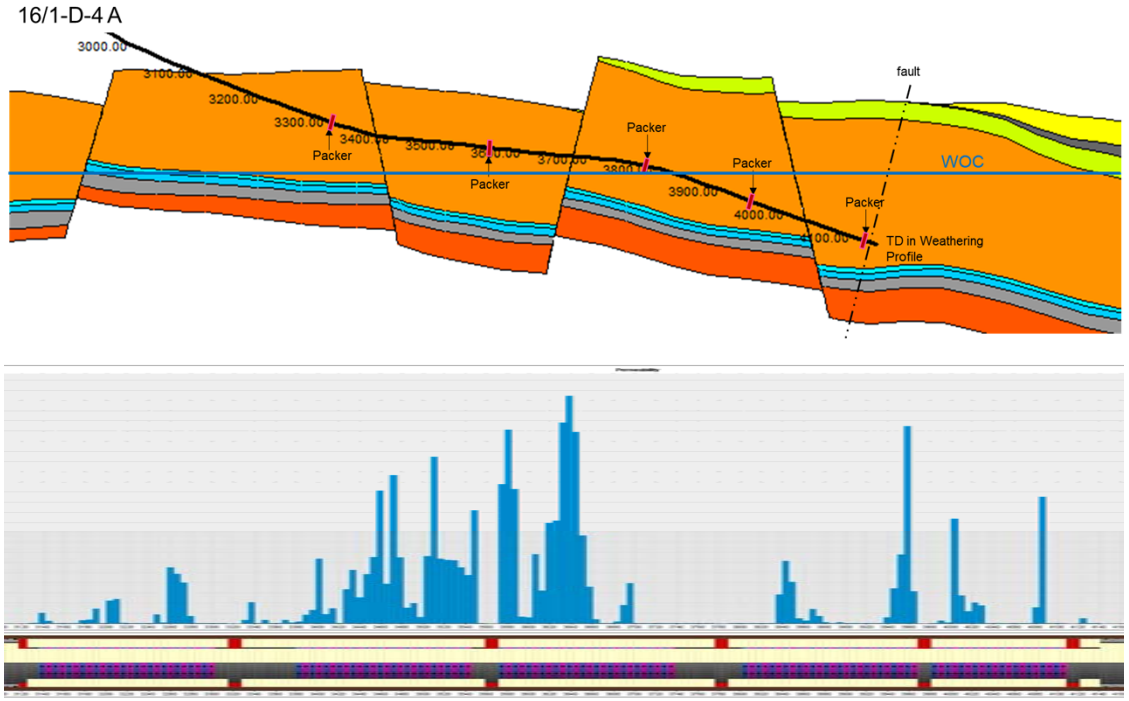
- **Trendlines observed in step rate tests**
  - Same qualitative behaviour
  - Related to “fuse” of valves?

- **“First” breaking points seems to occur at a low rate**
  - Indication of most of injection in one zone at low rate
  - Indication of some of valves within a zone is “fusing”

- **Well intervention June 2022 – Primary objective**
  - Data acquisition to evaluate outflow distribution in well
  - Evaluate effect of Tendeka valves

- **History matching of observed data (ILT) in NETool / Eclipse**

- **FloFuse installed as part of lower completion solution in 2 hybrid IOR 2022 campaign wells on Ivar Aasen!**



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