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Primary funding is provided by

The SPE Foundation through member donations and a contribution from Offshore Europe

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Designing Optimal Wells with Inflow Control Technology

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AkerBP

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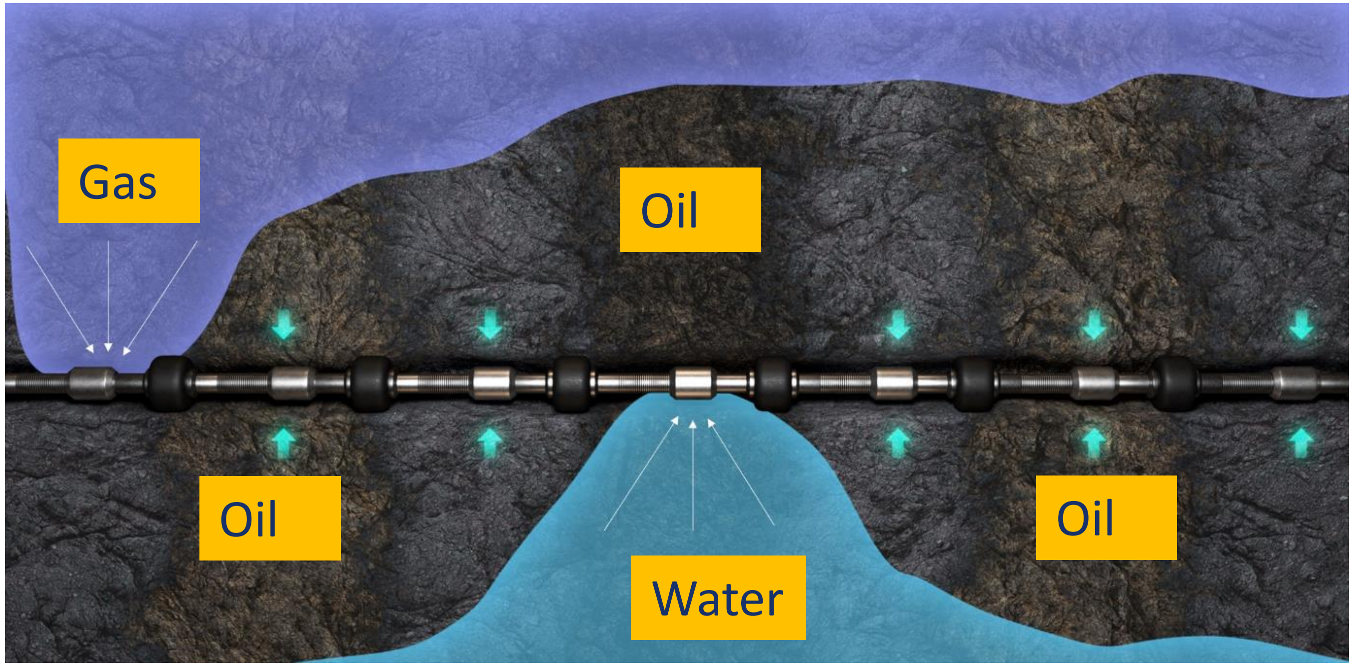
Motivation

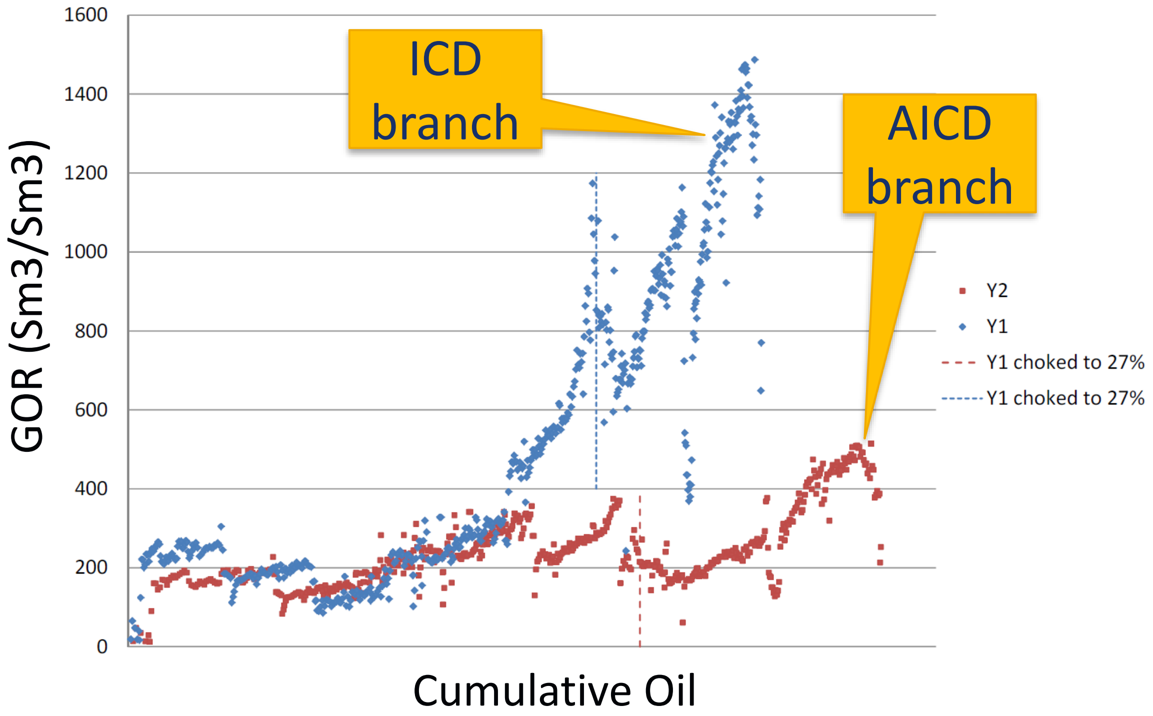
- Better oil recovery
- Less unwanted fluids (water, gas)
  - Reduced energy usage and CO_2 emission
  - Other environmental benefits
- Much pioneering work done by others
  - Brekke and Lien (1994; SPE-24762-PA)
  - Mathiesen et al. (2011; SPE-145737-MS)

Long horizontal production well with sand screens and inflow control technology (ICT)

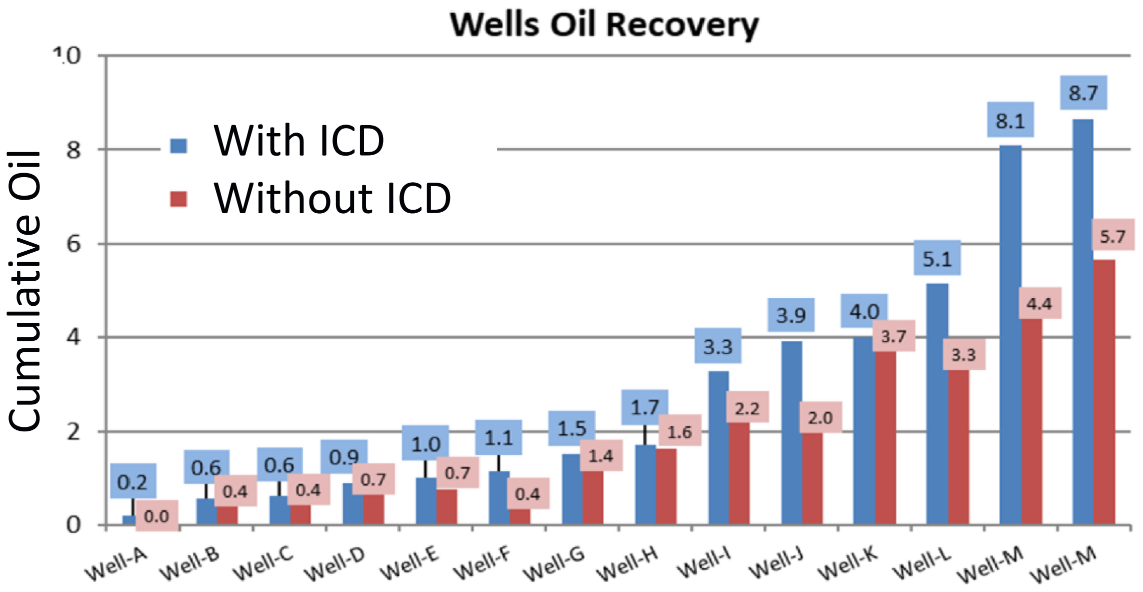


Taghavi et al. (2021) - OTC-31239-MS

Motivation: Value creation examples



Troll field – thin oil rim - offshore Norway
(Halvorsen et al., 2012; SPE-159634)



Onshore United Arab Emirates
(Emegano et al., 2020; SPE-202847)

Outline

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1. Understand reservoir and well objectives
2. Understand ICT and chase improvements
3. Mathematical model of ICT
4. Pre-drill well design study
5. Optimise well design during execution
6. Well surveillance (tracers++)
7. History match
8. Learn and improve

- A step-by-step recipe
  - Applied for more than 40 horizontal branches
- Summary
- Q&A

Understand reservoir and well objectives

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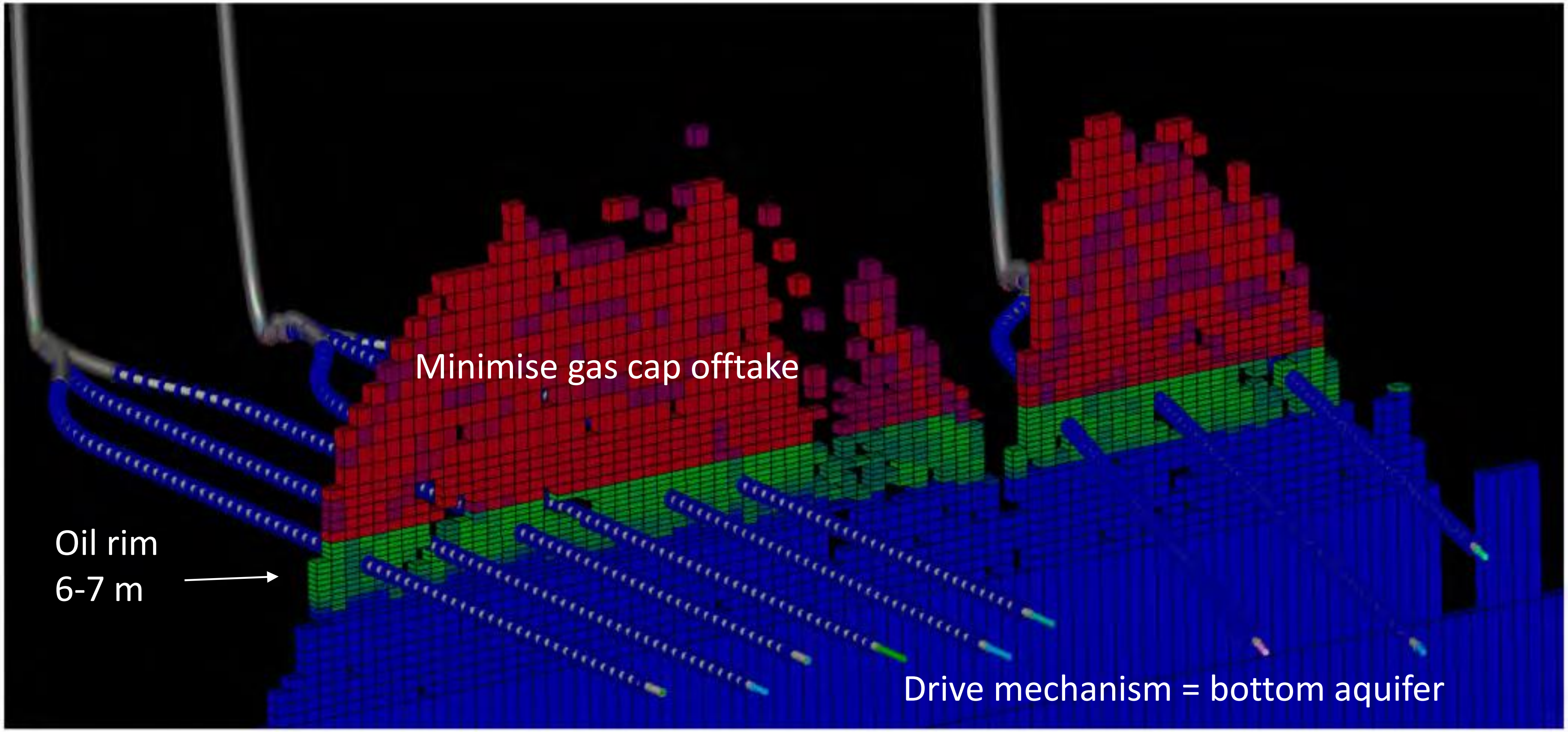
Reservoir

- Expected permeability
- Zonation or segmentation
  - Key for zonal control possibility
- Sand stability – will annulus stay open?
  - Key input and often uncertain
- Drive mechanisms, pressure support
- Expected fluid contacts

Well objectives (examples)

- Maximum oil recovery
- Gas rate < limit
- Water rate < limit
- ICT pressure drop at wanted level at the design rate
- Inflow along well proportional to potential reserves along well
- Operational constraints: Flow-check, injection needs,…

Example: 2023 development

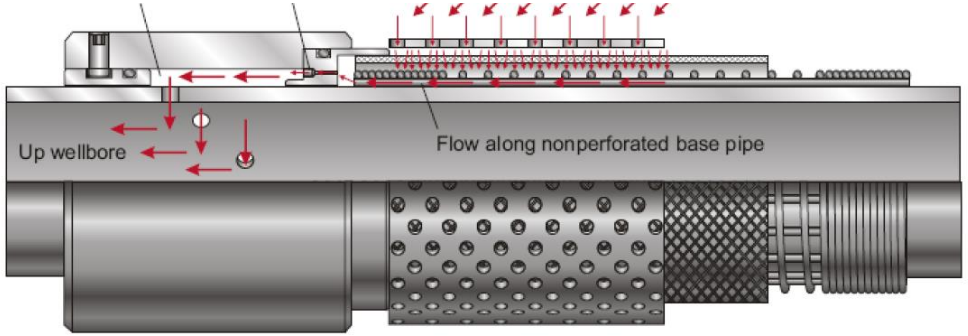


Taghavi et al. (2021) - OTC-31239-MS

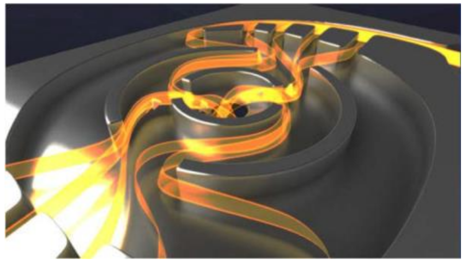
Understand available technology

Technology:

- Active operated flow control valves
- Inflow control technology (API)
  - Type 1: An ICD with no moving part, nozzle ICD etc.



Type 2N: Autonomous Inflow Control Devices (AICD) with no moving parts

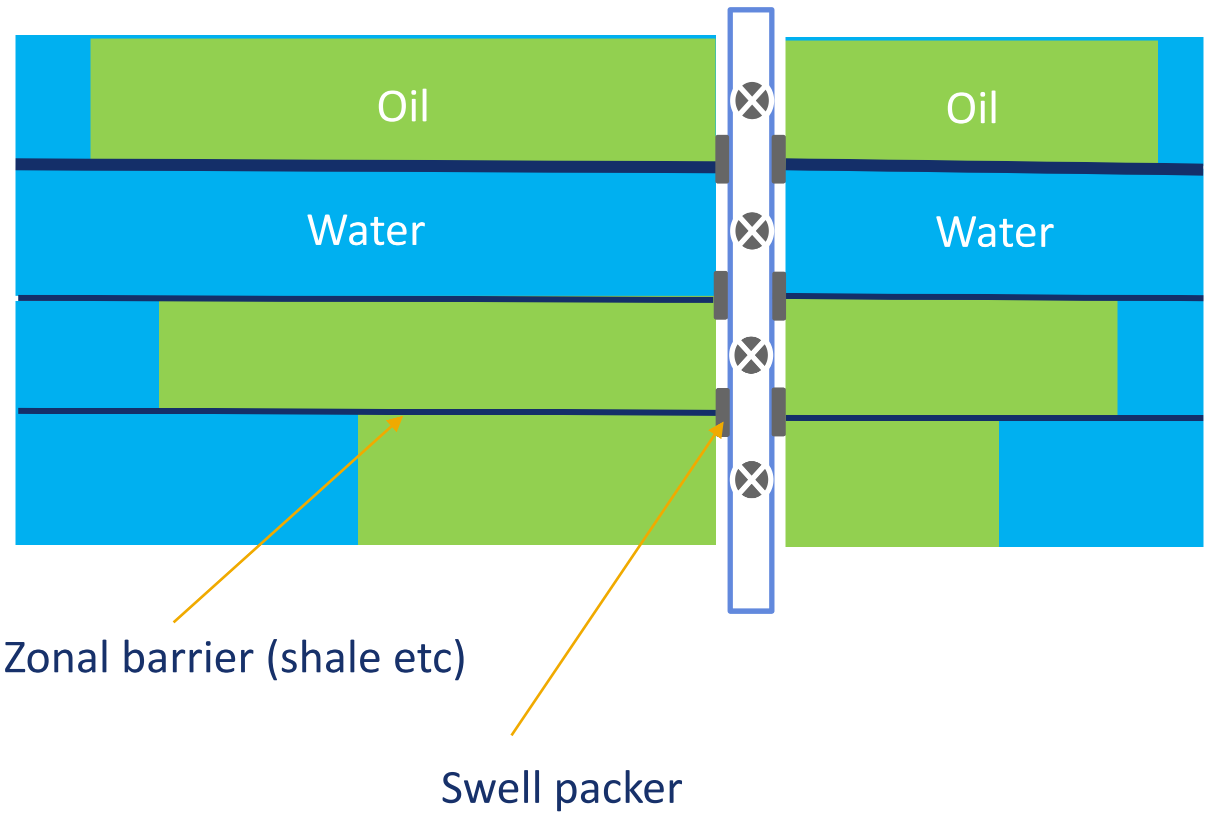


Type 2M: Autonomous Inflow Control Devices (AICD) with moving parts

Aadnoy and Hareland (2009) SPE-122824; Garcia et al. (2009) IPTC-13863
Least et al. (2013) SPE-167379; Langaas et al. (2018) SPE-187288-PA
Langaas et al. (2023) SPE-214342-PA

Zonal isolation

- For wells with open annulus (outside sand screens) zonal isolation is of key importance
- Well zonation needs to build on any extensive reservoir barriers or zonation
- Swell packers are commonly used



Chasing improvements

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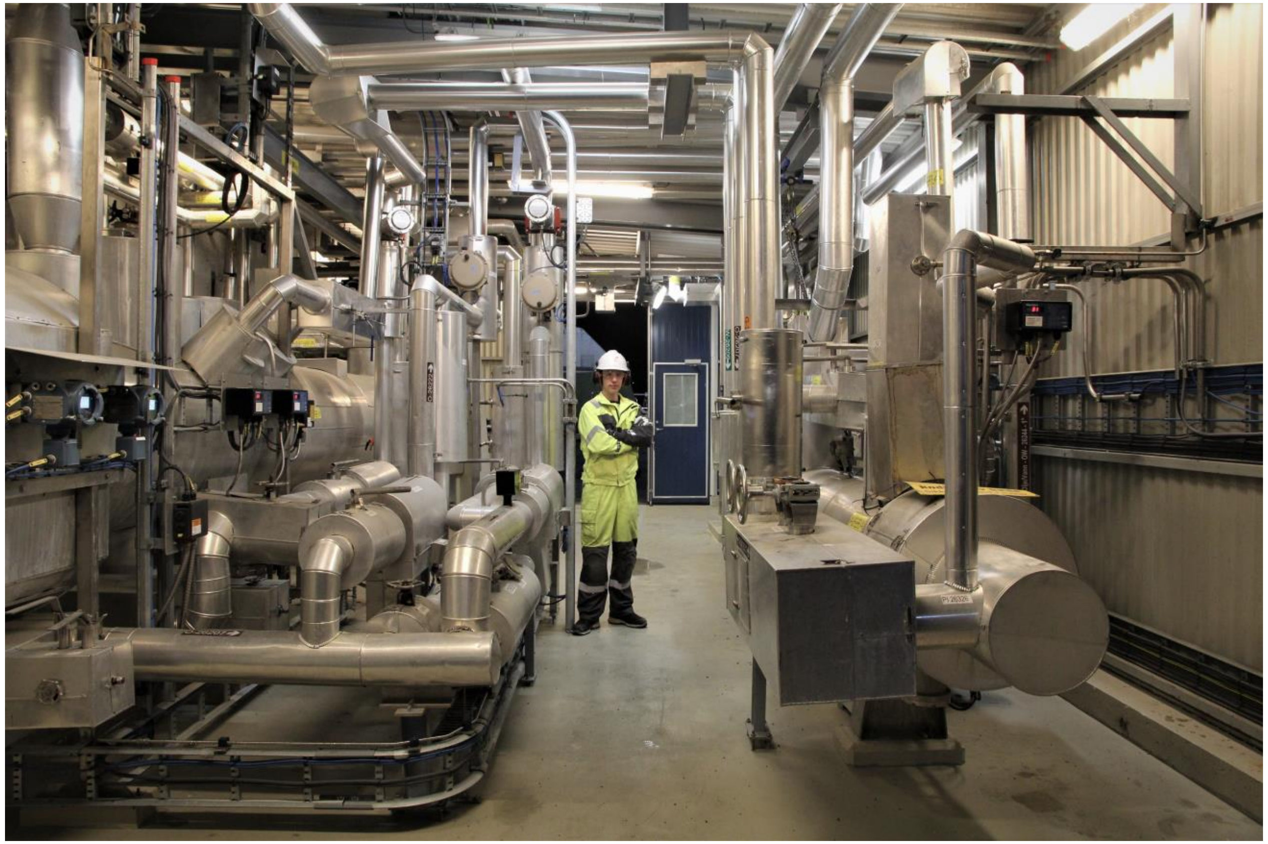
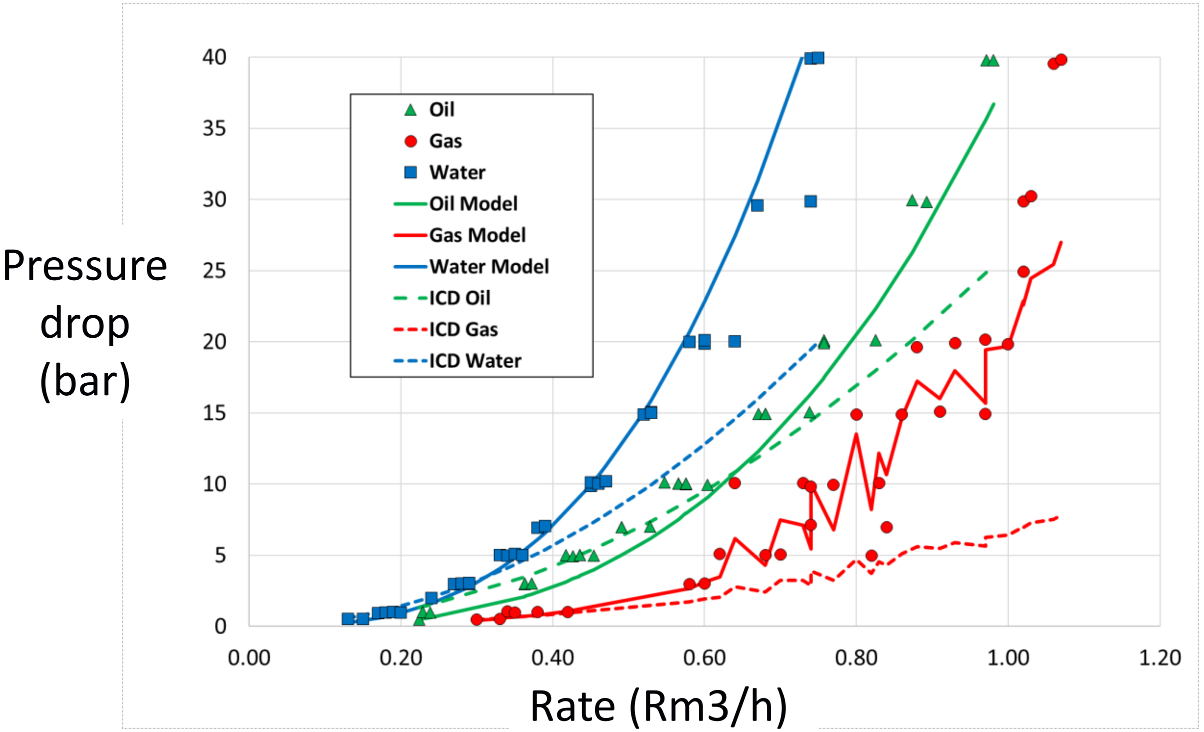
- AICD testing performed ~yearly at Equinor's lab facility
- Full scale test @ reservoir conditions
- 1 m^3 reservoir oil needed!
- Share results openly with vendors

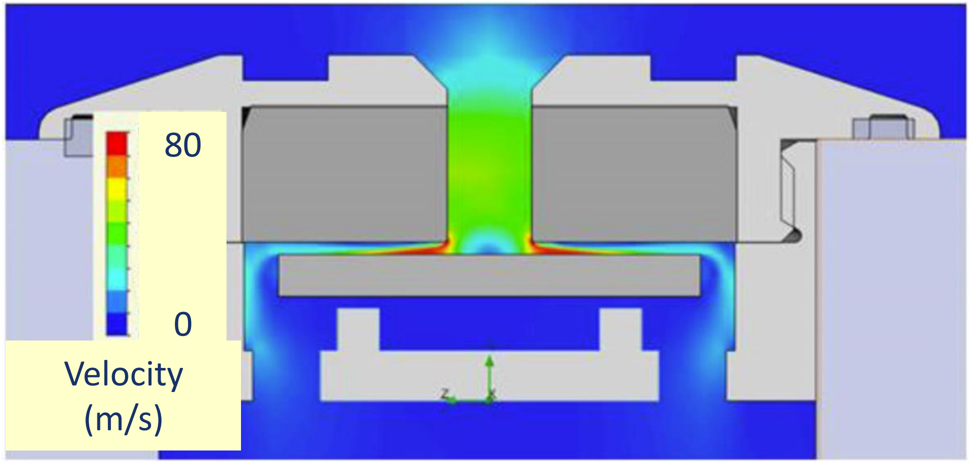


AICD reservoir condition test facility in Norway (Photo: Equinor)

Floating disk AICD

- Test 2015 (0.84 cP oil, 0.46 cP water)
  - Better gas and water choking

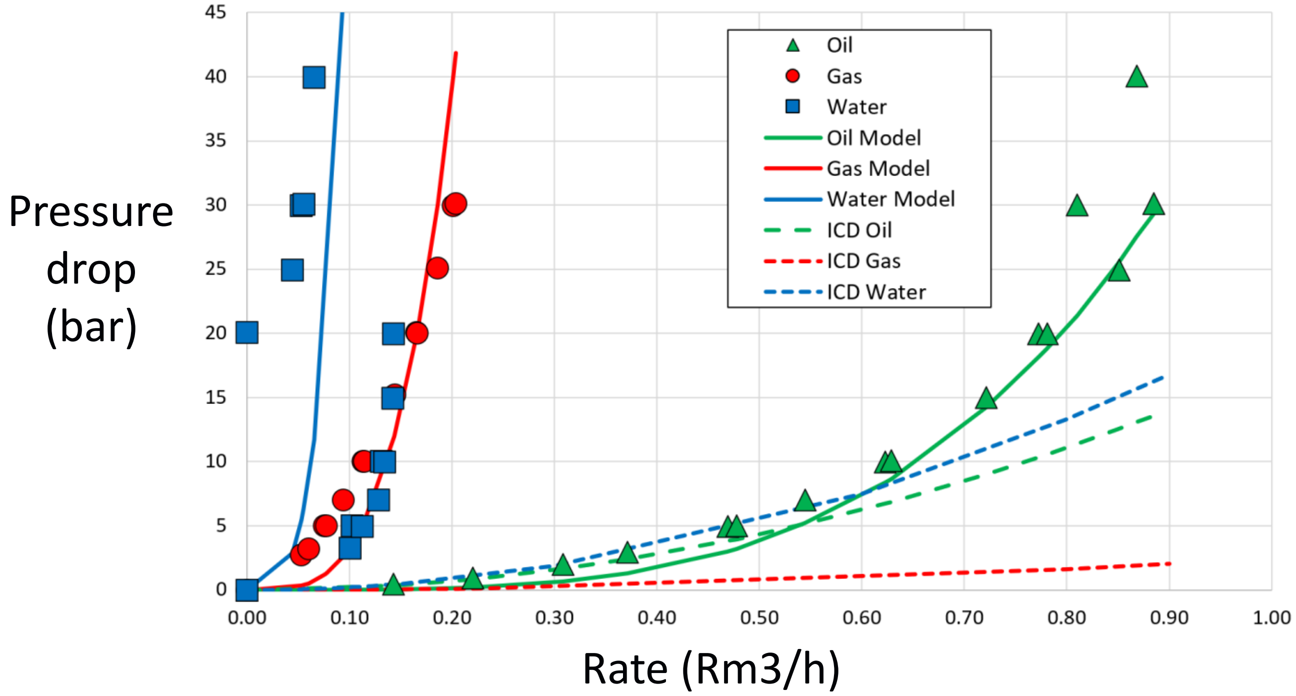


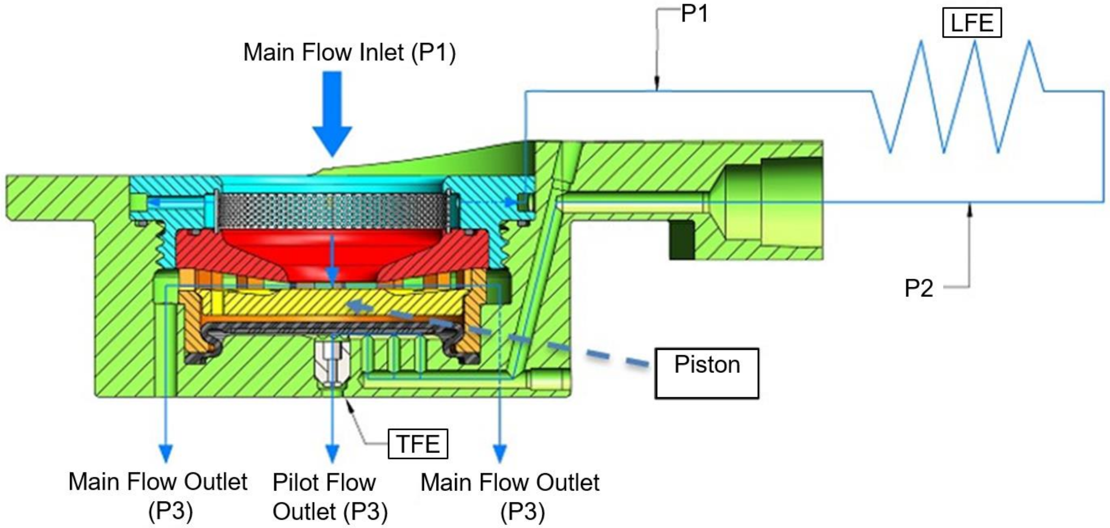


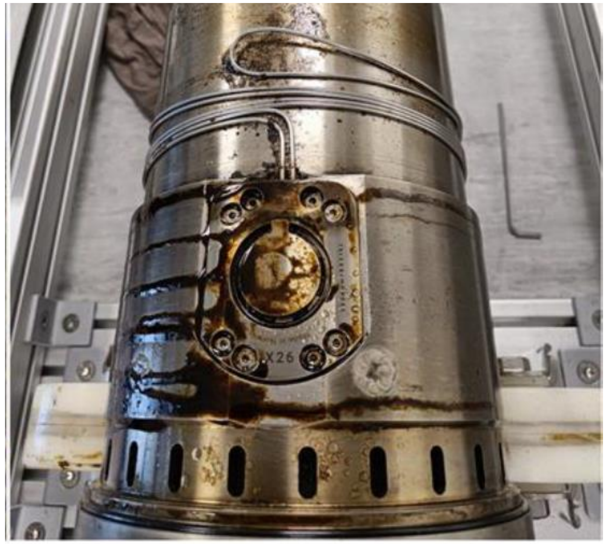
Voll et al. (2014) SPE-171149-MS and Langaas et al. (2018, 2020) SPE-187288-PA, SPE-200719-MS

Autonomous inflow control valve

- Test 2022 (5.6 cP oil, 0.66 cP water)
  - Much better gas and water choking







Langaas et al. (2023) SPE-214342-PA

Mathematical model of ICT

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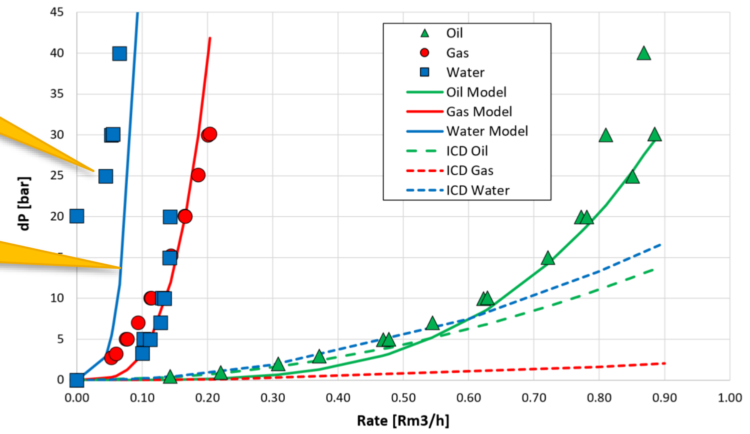
- One device/valve is tested in the laboratory
  - Single phase performance tests
  - Multi-phase performance tests
- Need mathematical model to quantify impact

Measurement

Mathematical Model



The “AICD equation” is commonly used

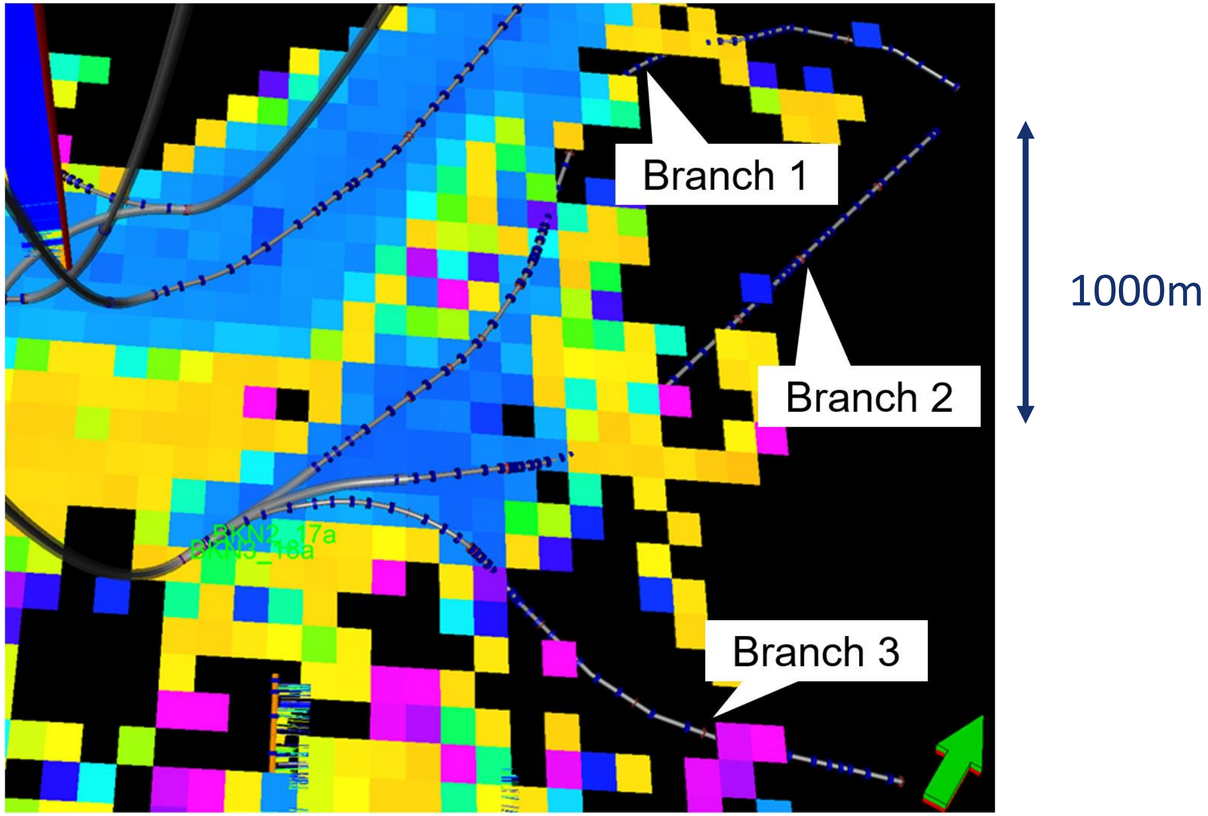
$$\Delta p = \left(\frac{\rho_{\text{mix}}}{\rho_{\text{cal}}}\right)^{z} \left(\frac{\mu_{\text{cal}}}{\mu_{\text{mix}}}\right)^{y} \rho_{\text{mix}}\, a \left(\frac{q}{q_{\text{cal}}}\right)^{x}$$

Δp	Pressure drop (Pa)
ρ	Fluid density (kg/m3)
q	Volumetric rate (m3/s)
a	AICD strength (Pa*m^3/kg)
µ	Viscosity (Pa*s)
x, y, z	Numbers (dimensionless)

Mathiesen et al. (2011) SPE-145737; Langaas et al. (2023) SPE-214342-PA

Pre-drill well design studies

- Dynamic reservoir models best
- Steady state inflow model to QC and finetune design
- Understand what technology is optimal
- Establish lower completion strategy and base design
- Order equipment
  - Keep some flexibility for optimisation

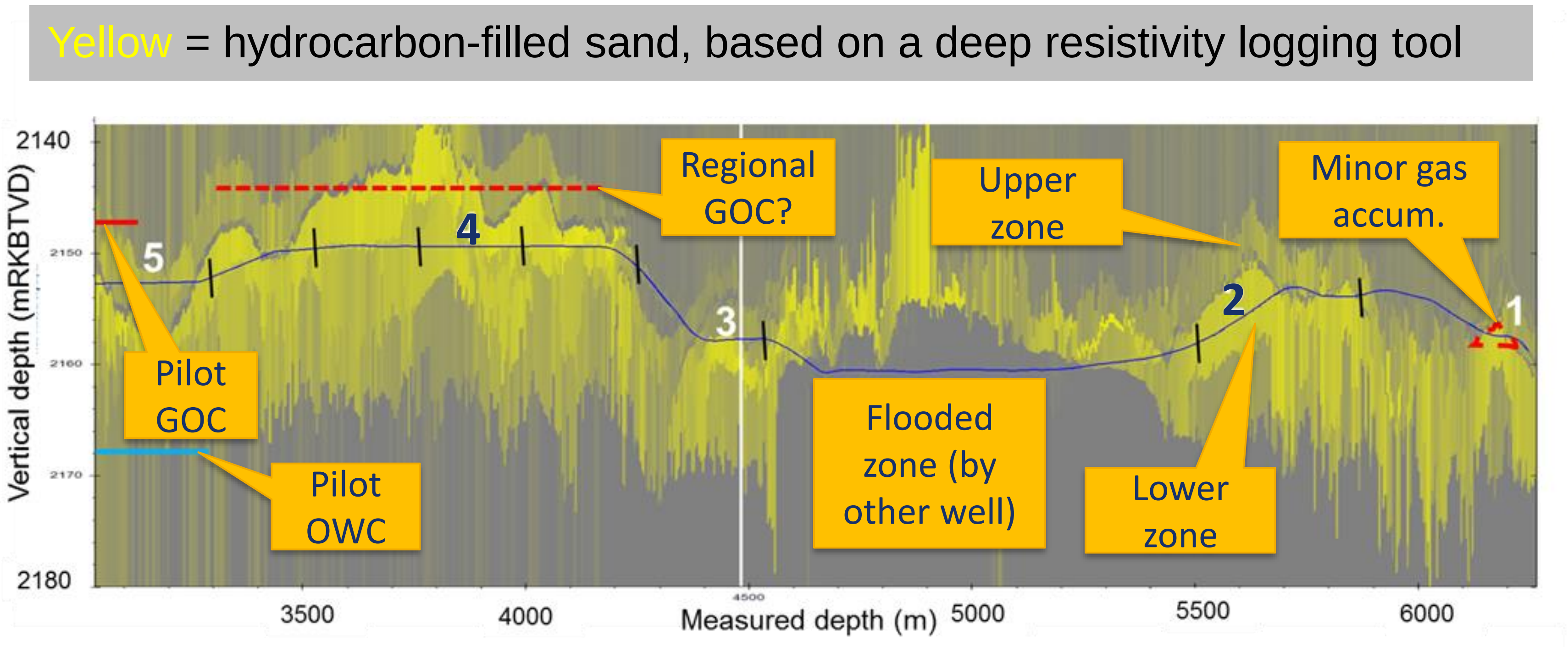


Full field 3D dynamic model and a designed MLT-3 well. Saturation in grid at heel well depth after 12 years production (warm colours = remaining oil)

Langaas et al. (2018) SPE-187288-PA

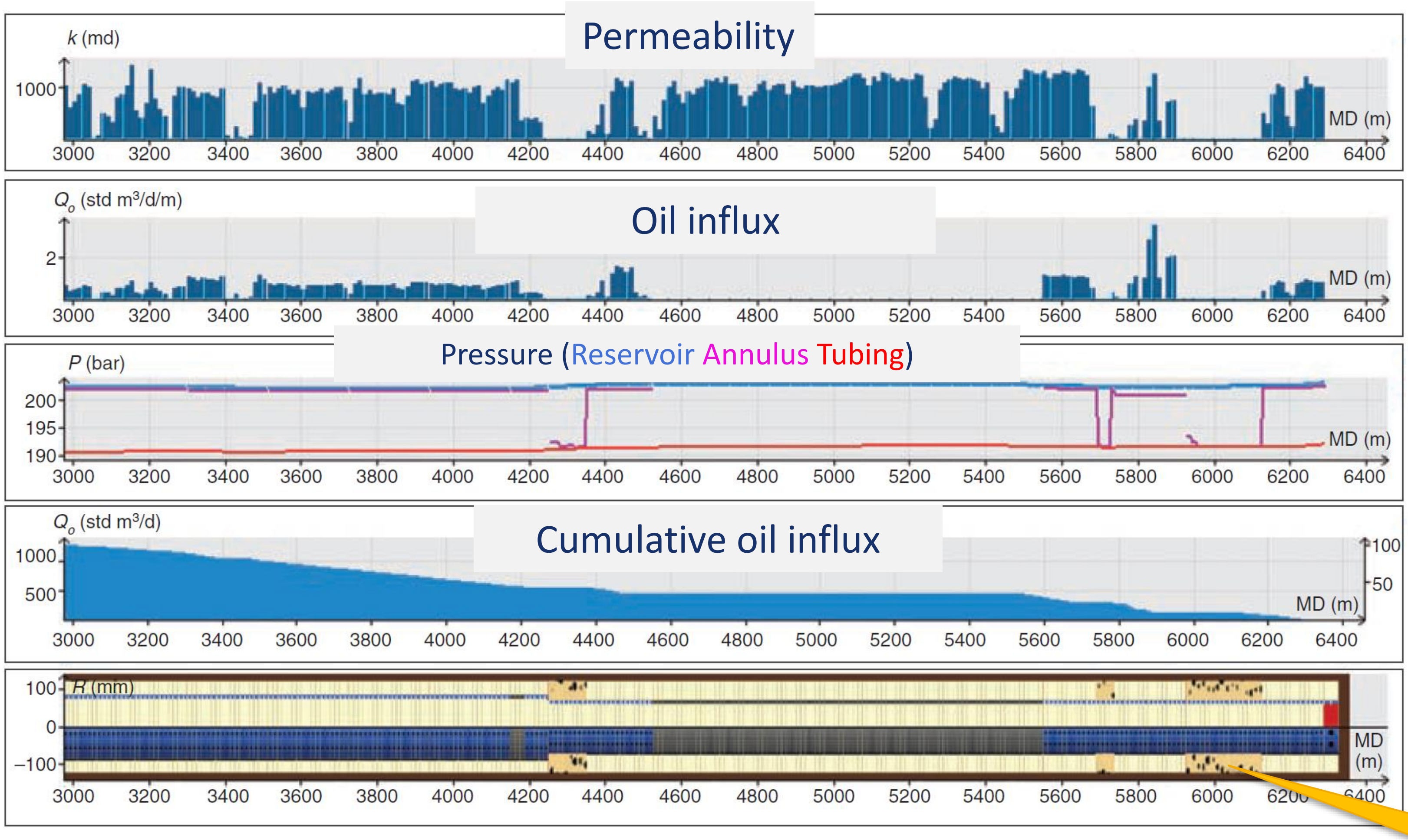
Optimise during execution

- Update reservoir understanding during drilling
- Understand
  - Fluid contacts
  - Reservoir pressure
  - Permeability
  - Zonation
  - Potential reserves along well
  - …



Langaas et al. (2018) SPE-187288-PA

Update model during execution



- Update steady state inflow model
  - Update permeability estimate
  - Adjust swell packer position, blank sections, (A)ICT strength - to get wanted inflow
  - Check pressure drop at design rate
- Typical deadline ~12 h after drilling complete
  - high value creation hours $$

Shale creep assumed - impacts zonal inflow

Langaas et al. (2018) SPE-187288-PA

Optimise well design during execution

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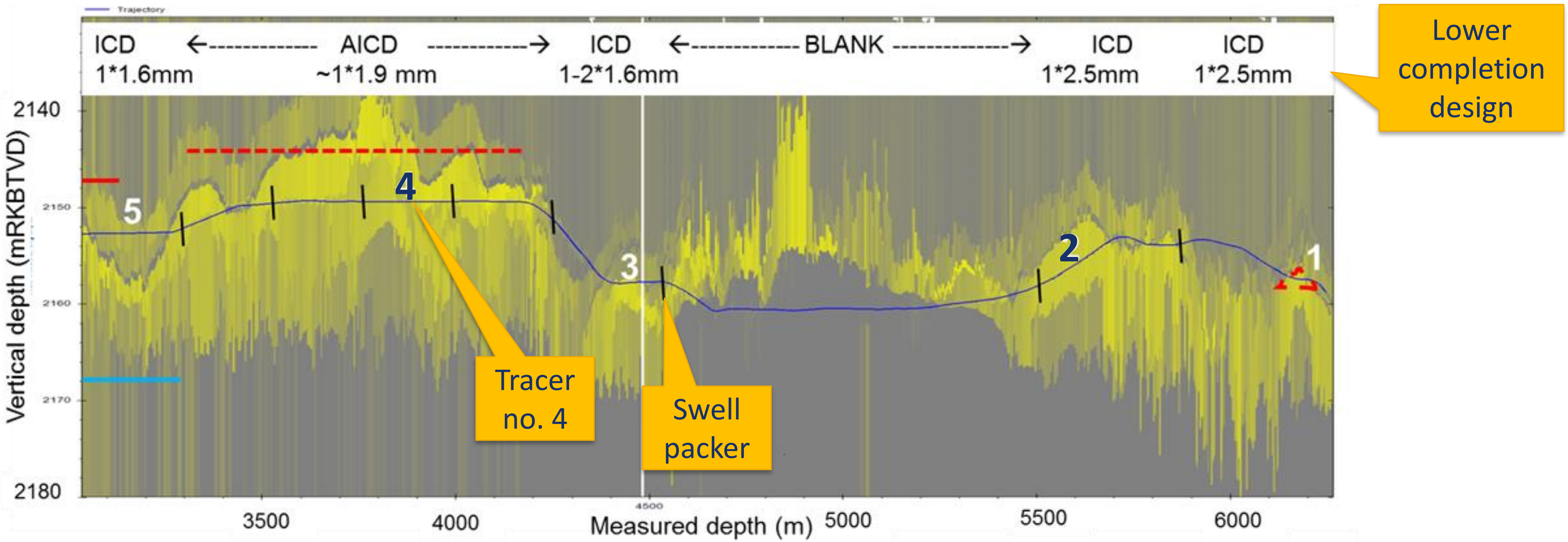
Good visualisation of updated design is key for integrated team clarity



Langaas et al. (2018) SPE-187288-PA

Well surveillance

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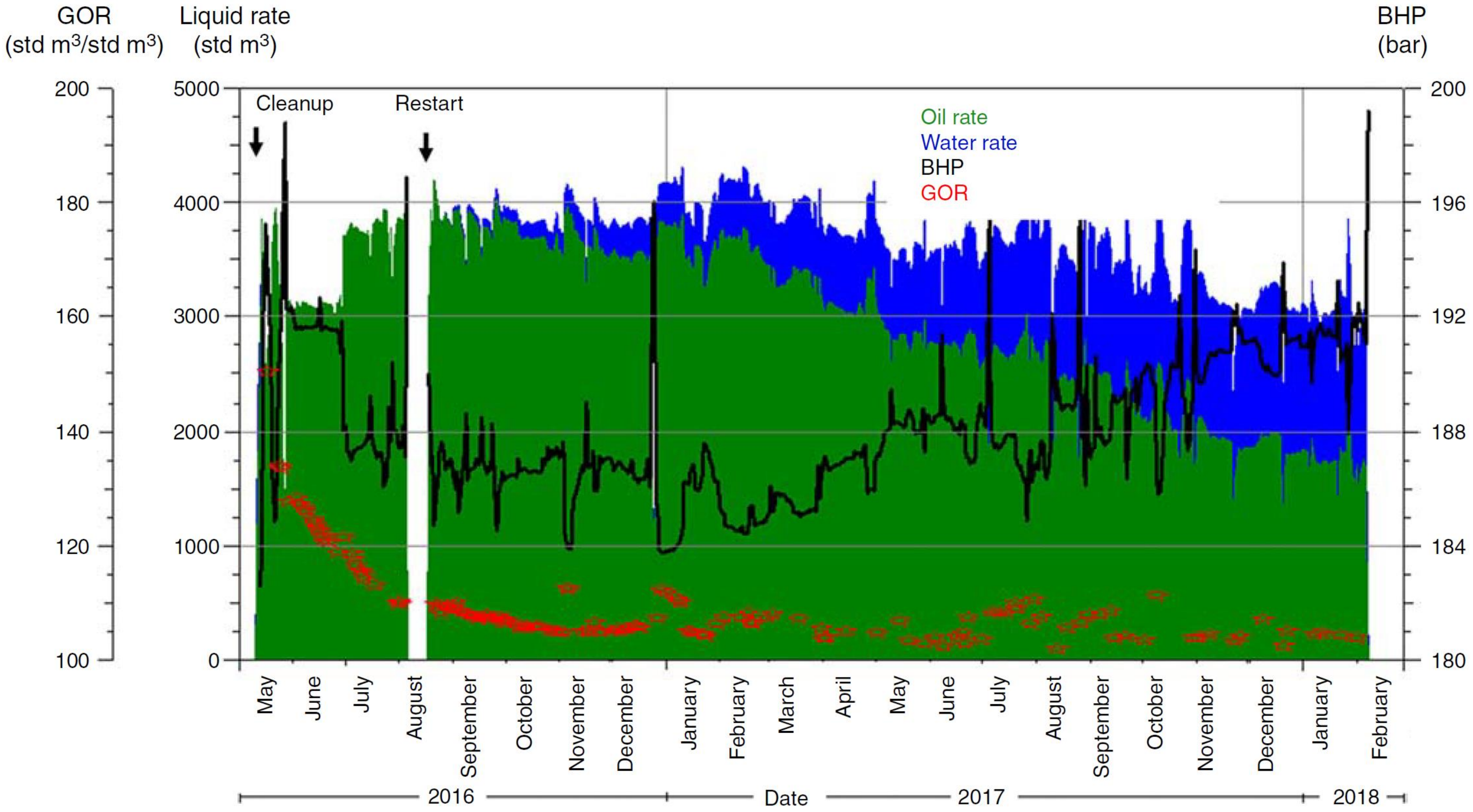
- Pressures
- Rates
- Production logging (PLT)
- Tracers
  - Confirmation of clean-up
  - Influx estimates (restart)
  - Continuous monitoring



Langaas et al. (2018) SPE-187288-PA

Tracers: Restart (to estimate influx)

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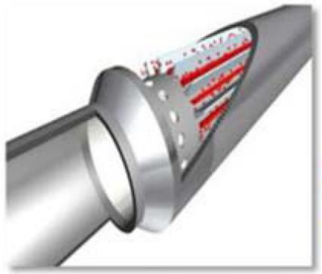
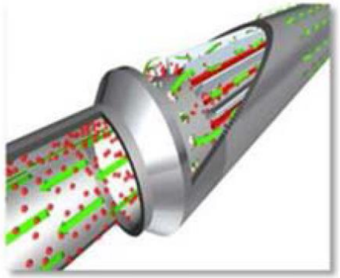
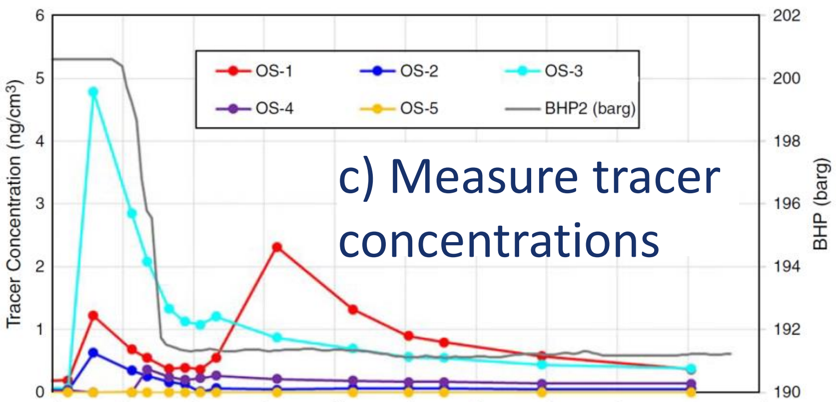
a) Shut-in:
Tracer cloud
builds up

b) Restart:
Production through
tracer cloud



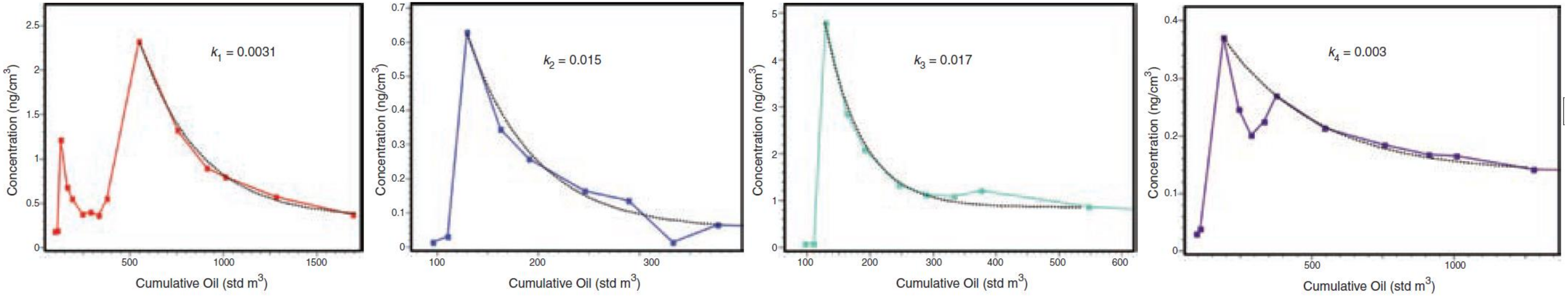




c) Measure tracer concentrations

Time (hh:mm)
02:00
14:00

d) Exponential decay fit of each tracer



Langaas et al. (2018) SPE-187288-PA

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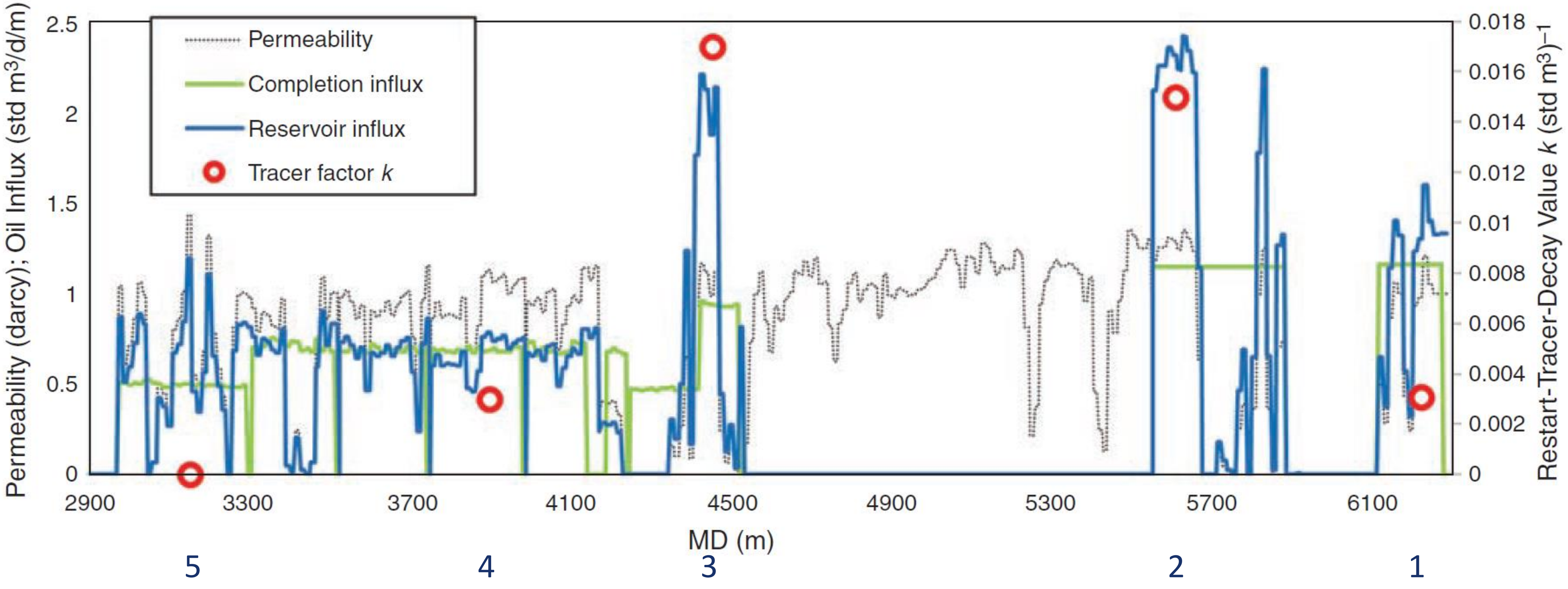
History match of well performance

- Both steady state inflow model and full dynamic model can be used
  - Steady state model is practical as easy to test scenarios
- Use lower completion model and try match all data
  - Liquid rate
  - Water-cut
  - Gas oil ratio
  - Flowing bottomhole pressure
  - Compare model with PLT or in our case tracer-based inflow estimates

Langaas et al. (2018) SPE-187288-PA

History match - steady state inflow



- Mainly oil flow – ideal for history-match uniqueness. Model had good match on lower completion dp
- Some mismatch vs. tracer-based influx estimates

Langaas et al. (2018) SPE-187288-PA

Summary and way forward

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1. Understand reservoir and well objectives
2. Understand ICT and chase improvements
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8. Learn and improve

- Recipe used for 40+ horizontal well branches
- Highly valuable – AICT have enabled many new wells
- Still improving
  - New AICT tested 2023
  - Better zonal AICT performance prediction with new software
  - Need shorter swell packer intervals

Acknowledgement

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- Presented material is result of good integrated team work. Thanks to all Aker BP colleagues involved (especially co-authors on papers mentioned)
- Equinor P-lab for great service and support, and for allowing us to test equipment
- All technology vendors of ICT and tracers that we have co-operated openly with to chase improvements together
- Aker BP for permission to publish and share openly within the industry
  - and for supporting the SPE DL program