# A CFD Based Approach for Better Understanding, Prediction, and Application of Inflow Control Technologies

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# FLOWPRO Insight

Welcome to FlowPro Insights

Advanced completion performance analysis

Single-zone Application

Multi-zone Application

# Segregation in Annulus of ICD/AICD Completed Wells

- Background
  - Investigations were carried out in Flowpro/Lundin to illustrate the impact of annulus segregation in AICD/DAR completed wells.
  - A Lundin/Flowpro FoU project was started in 2019 to develop methodology for more physically correct modelling in reservoir simulations.

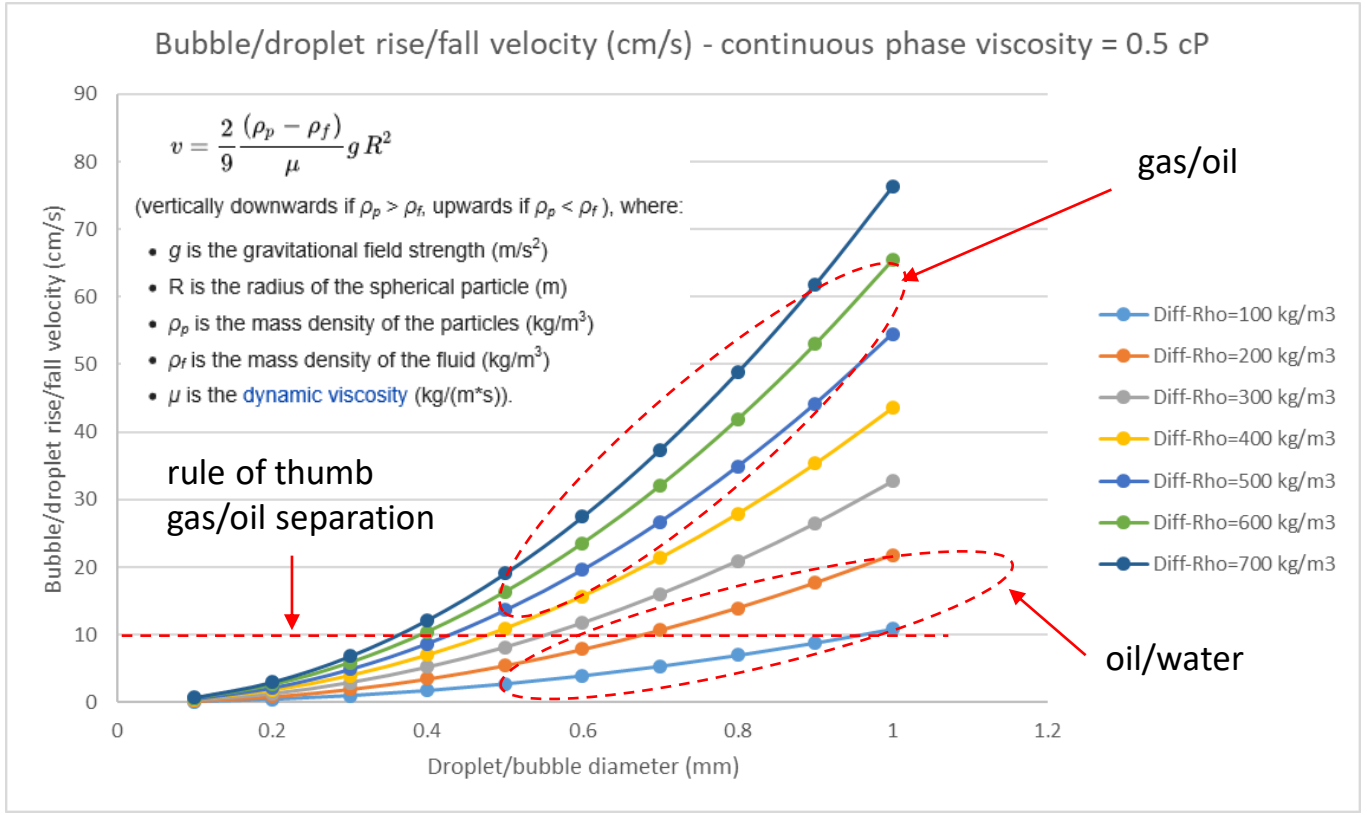
- K Langaas, AkerBP, 2017

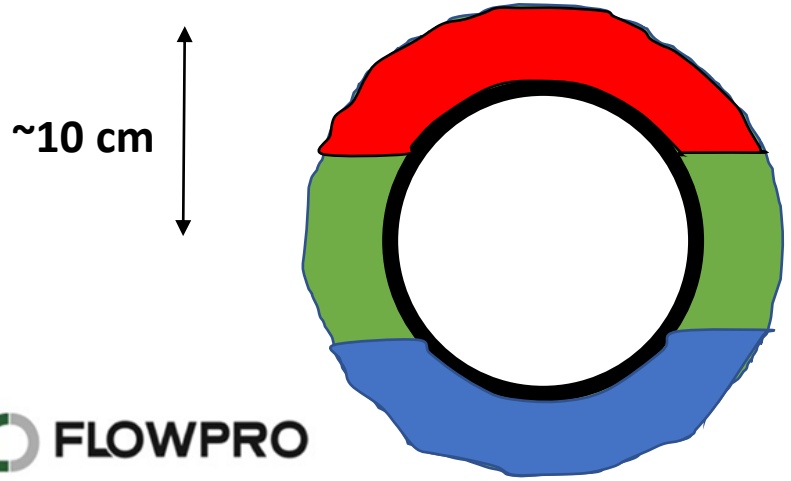
…..We are unsure if we can evaluate the equipment correctly in our standard tool. It could be that the effective behaviour of say a set of 8 AICVs in a packer element of 100m is different than one AICV with scaled interval inflow (scale of 8)….

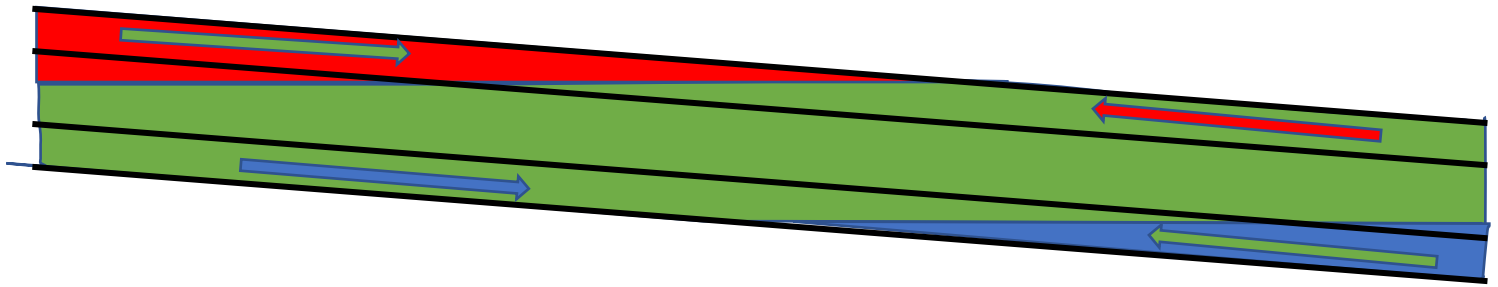
- Several companies have pointed out the likelihood of annulus segregation having an effect on AICD system performance, Ranold, Tendeka, Equinor etc…

# Introduction - Phase segregation in annulus

- Oil/water/gas may already enter the wellbore segregated from the reservoir.
- Rule of thumb gas bubble rise velocity in light oil at reservoir condition ~10 cm/sec
- Retention times > 30 minutes
- Axial annulus velocities < 0.5 m/s
- Radial sand face velocities ~ mm/s



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# Motivation

- Available tools assume **steady state fully mixed (oil, gas, water) flow through all AICDs**
  - In reality, fluids segregate in annulus which may result in significant error in pressure loss.
  - May result in incorrect AICD system design/selection
- Available tools do not model **interaction between valves**
  - Interaction between valves will take place, especially in autonomous valve systems
- Currently not possible to **upscale the completion to reduce simulation time**.
  - High number of valves need to be defined, resulting in unmanageable high CPU time.
  - Use of “device multiplier” will still neglect segregation and valve interaction.
- More optimal ICD/AICD/AICV designs by understanding how these physically work as a system.

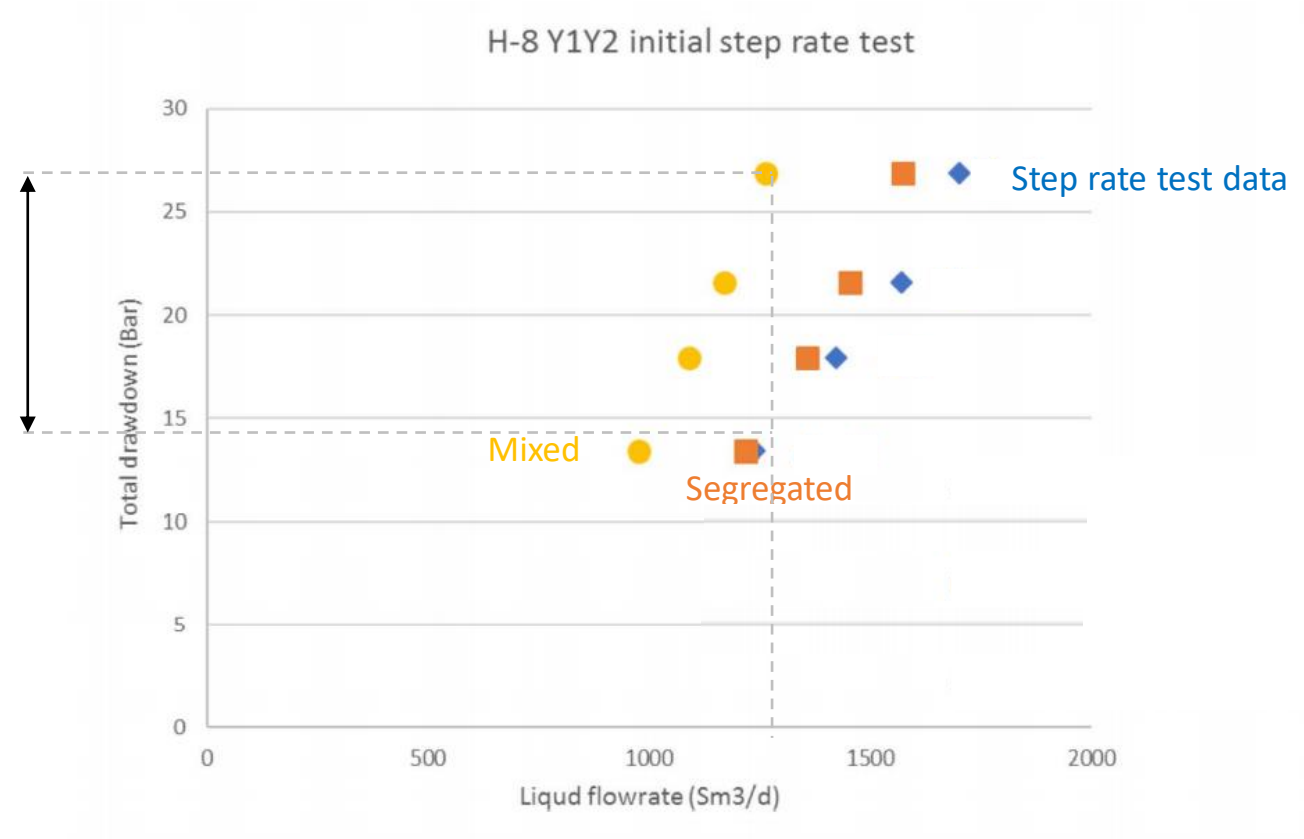
# Single zone Insight - Features

- Custom CFD, time dependent simulations capture annulus phase segregation
- Oil, water and gas are treated as separate phases
- Even or irregular phase inflow distributions along a zone
- Any number of ICD, AICD, AICV or DAR within zone
- Specified or random valve orientations with coning of phases to valve inlets

# AICD (RCP) Segregated vs. Mixed Flow - SPE195617-MS

Step rate tests on Oseberg showed that pressure loss indicates segregation of liquid and gas in annulus

Significant error made in AICD pressure loss by omitting segregation of phases in annulus




SPE-195617-MS, AICD Implementation on Oseberg H Vestflanken 2

Andreas Lien, Øyvind Midttveit, Atle Johnsen Gyllensten, and Martin Halvorsen, Equinor ASA

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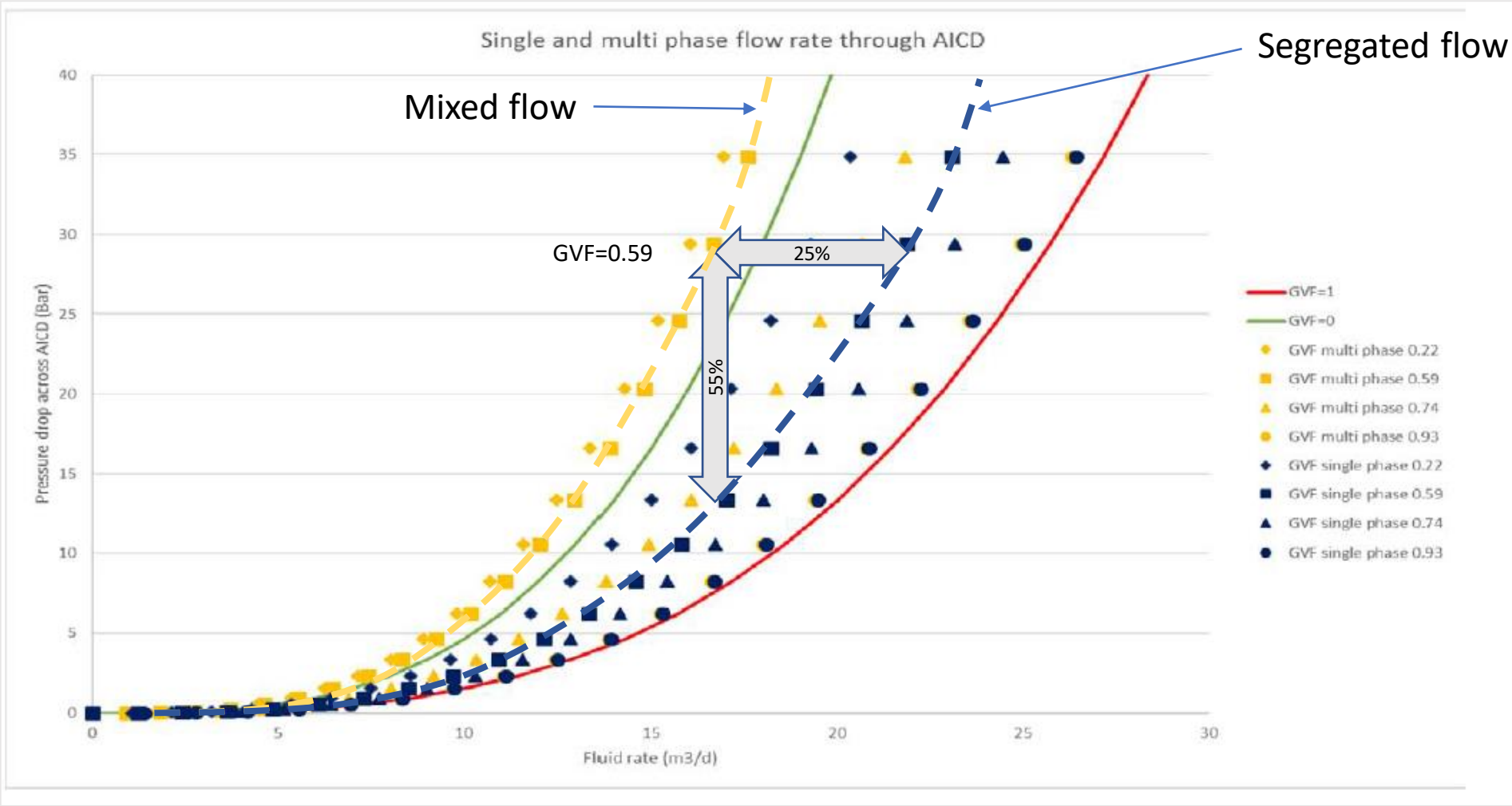
# AICD (RCP) segregated vs. mixed flow- SPE195617-MS

More pressure loss (less rate) for mixed flow than for segregated flow

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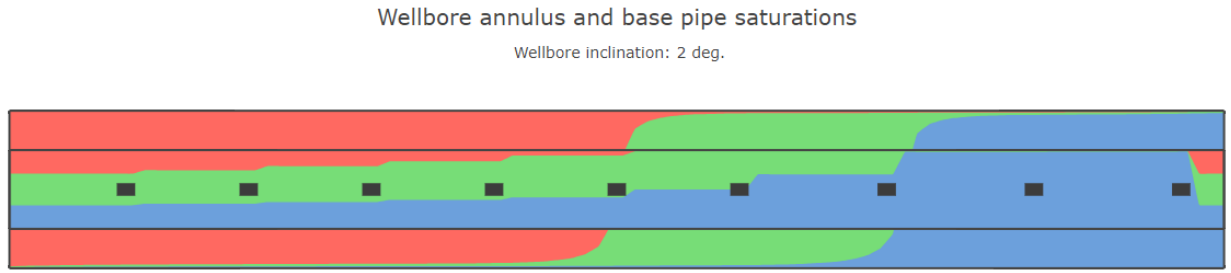
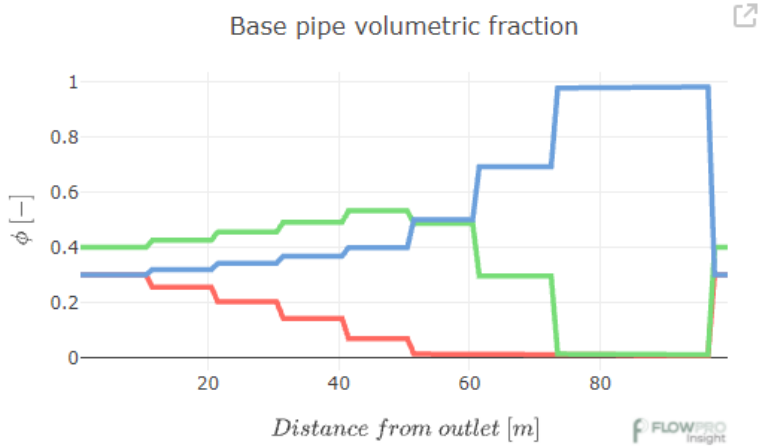
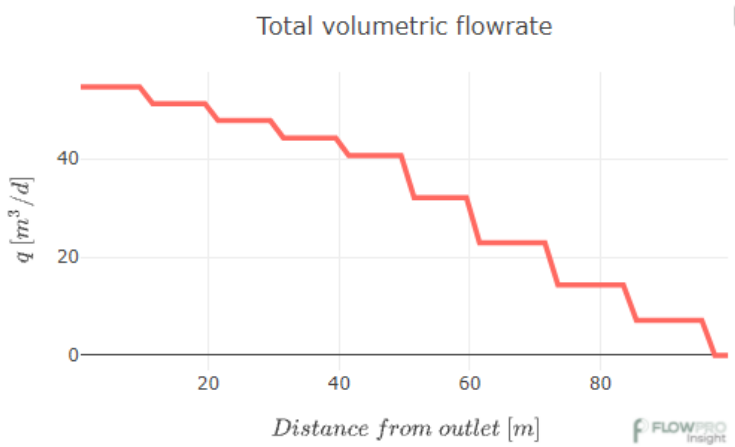
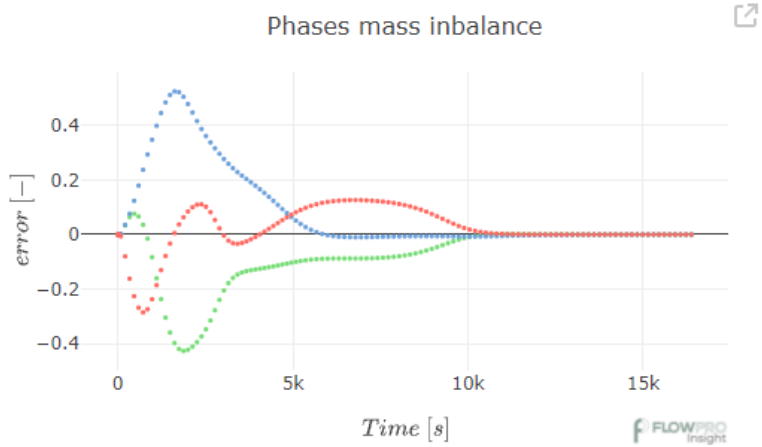
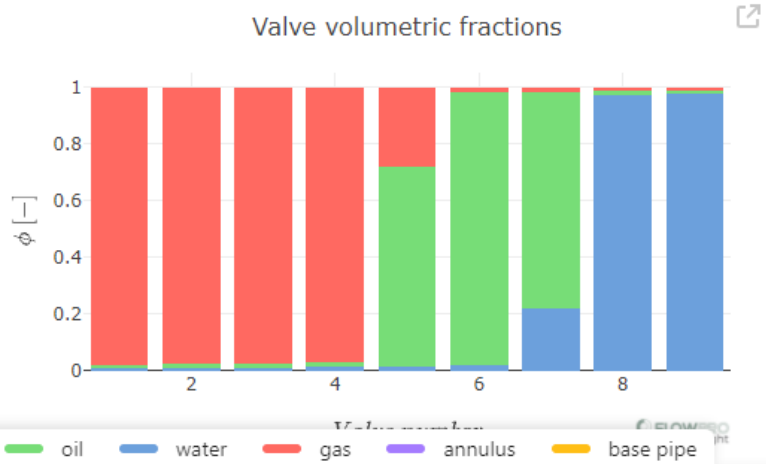
# Inflow Control Analysis – Example AICV completion

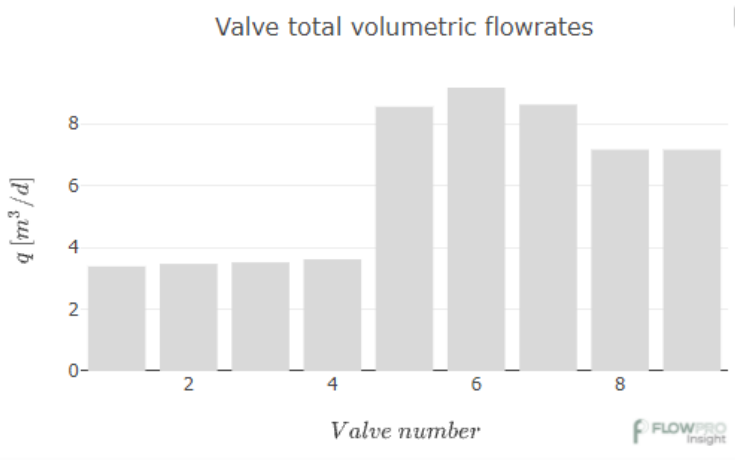


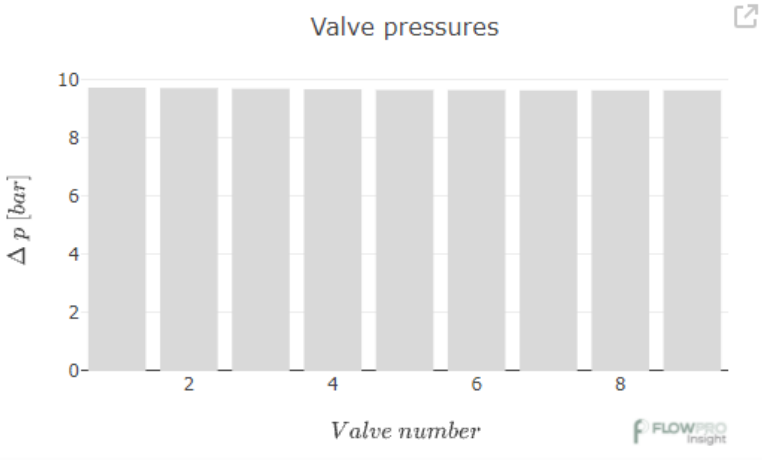



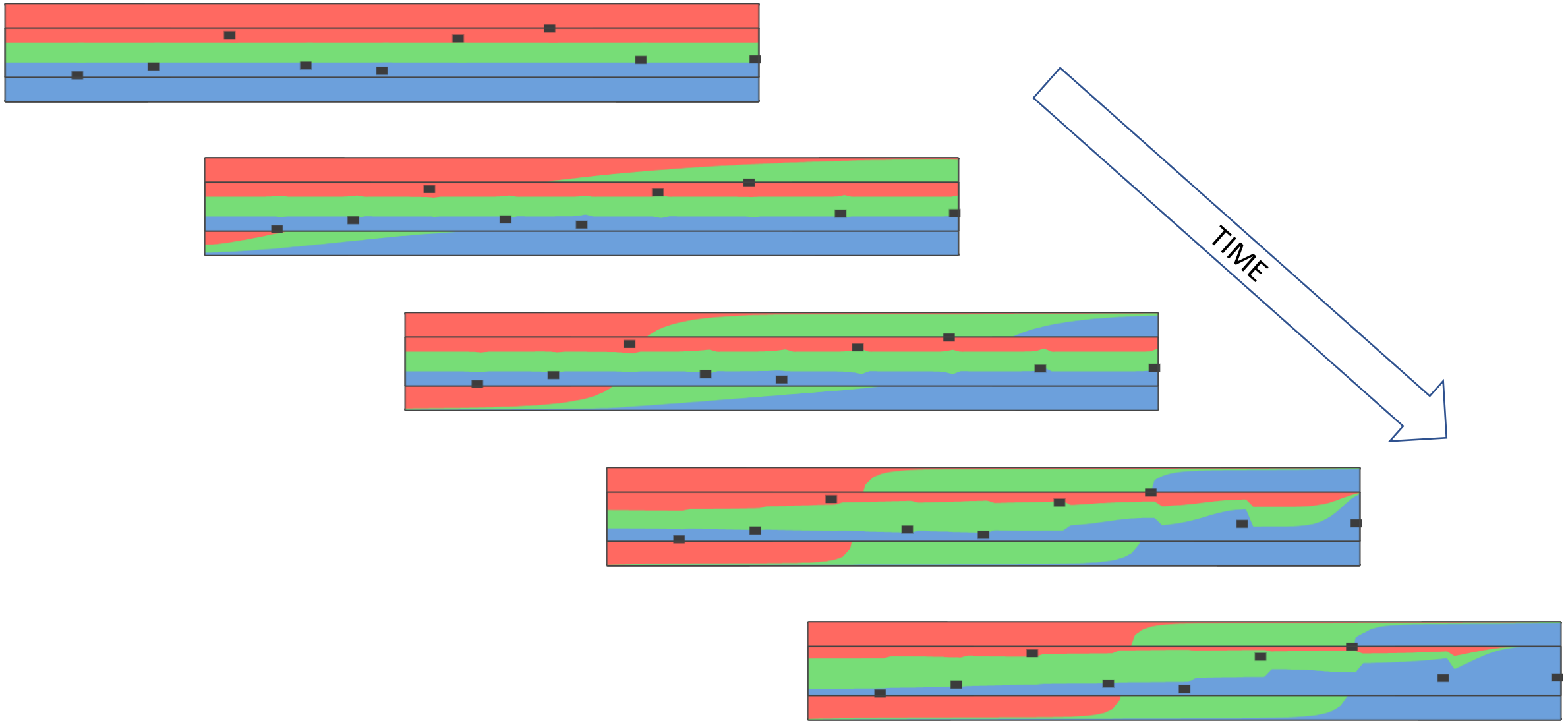



# Single Zone Transient Analysis



# Insight Used to Simplify and Improve Simulation of Inflow Control

Individual inflow control devices flow capacities defined from vendor test results

aAICD, z, x, y, a, b, c, d, e, f

or

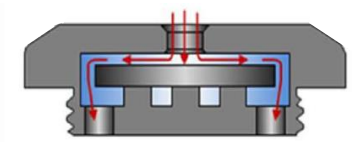
design/functional description

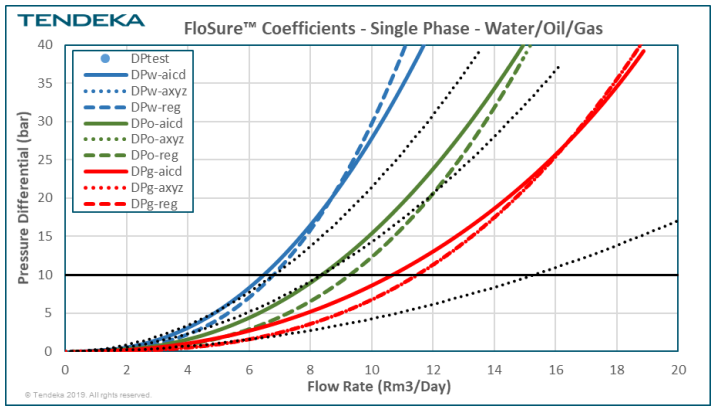
Calculate stabilized pressure loss across ICDs/AICDs in packer interval.

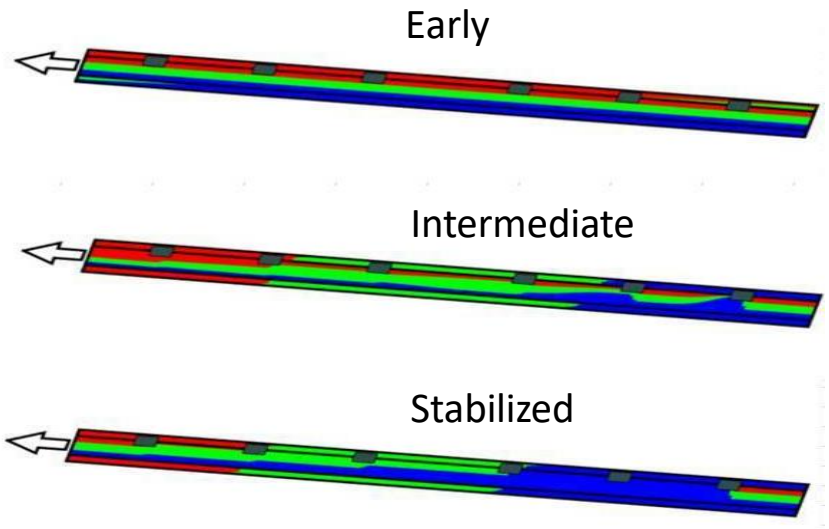
(# of valves per zone, qo, qw, qg)

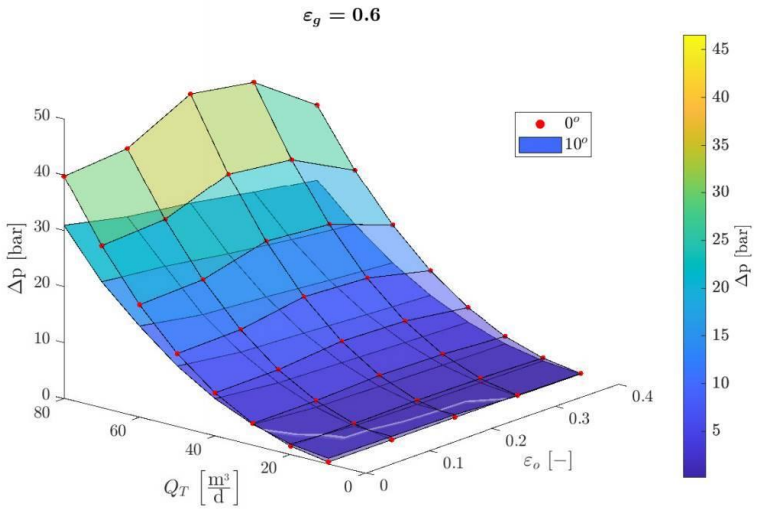
Use multivariate regression to match ICD/AICD pseudo factors/coefficients to include effects from segregation and valve interaction.

aAICD*, z*, x*, y*, a*, b*, c*, d*, e*,f*



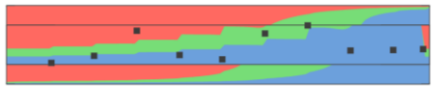


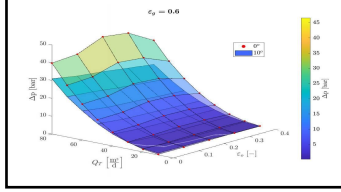



# Inflow Control Analysis, Design and Upscaling

## Single Zone Insight



Single run - digital lab Inflow Control Analysis

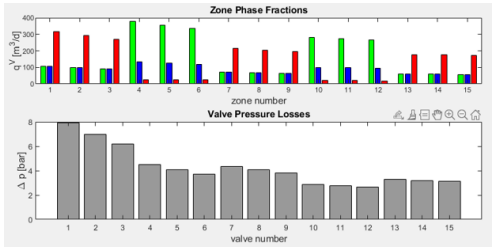


Multi Run Regression Inflow Control Upscaling

REPORT

## Zone - Inflow Performance Database

## Multi Zone Insight




- Quick look / automatic inflow control optimization
- Export preoptimized completions to reservoir simulator

Reservoir Simulator

- Reveal
- tNavigator
- Eclipse
- Intersect

Physically correct simulation of inflow control technology

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# Insight Results are Used by Reveal Through the Generalized ICD Database

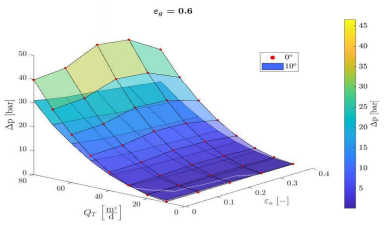
Reveal Reservoir and well simulation

phase flowrates
fluid properties

Pressure drop

regression factors
and exponents

**Insight**
Multi run regression
inflow control upscaling



| | Label | Interval Length | Effective Flow Area | Power | Reference Density | Reference Viscosity | Density Exponent | Viscosity Exponent | Rate Exponent | Density Water Exponent | Density Oil Exponent | Density Gas Exponent | Viscosity Water Exponent | Viscosity Oil Exponent | Viscosity Gas Exponent |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | m | cm2 | | Kg/m3 | mPa.s | | | | | | | | | |
| 1 | RPC9 | 5 | 1 | 7.893531 | 1000 | 1 | 0.2985 | 0.3652 | 2.3814 | 1.16 | 1.1054 | 0.566 | 1.2985 | 1.5 | 0.5657 |

Pressure drop = Power * Density * (Density/RefDensity)^DenExp * (RefViscosity/Viscosity)^ViscExp * (Rate)^RateExp

Density = DenW*(VolW^DenWExp) + DenO*(VolO^DenOExp) + DenG*(VolG^DenGExp)

Viscosity = ViscW*(VolW^ViscWExp) + ViscO*(VolO^ViscOExp) + ViscG*(VolG^ViscGExp)

FIELD UNITS Pressure drop (psi) : (Ref)Density (lb/ft3) : (Ref)Viscosity (cP) : Rate (ft3/d)

METRIC UNITS Pressure drop (Bar) : (Ref)Density (kg/m3) : (Ref)Viscosity (cP) : Rate (m3/d)

# AICD (viscosity dependent)

- RCP valve (Equinor, Tendeka)

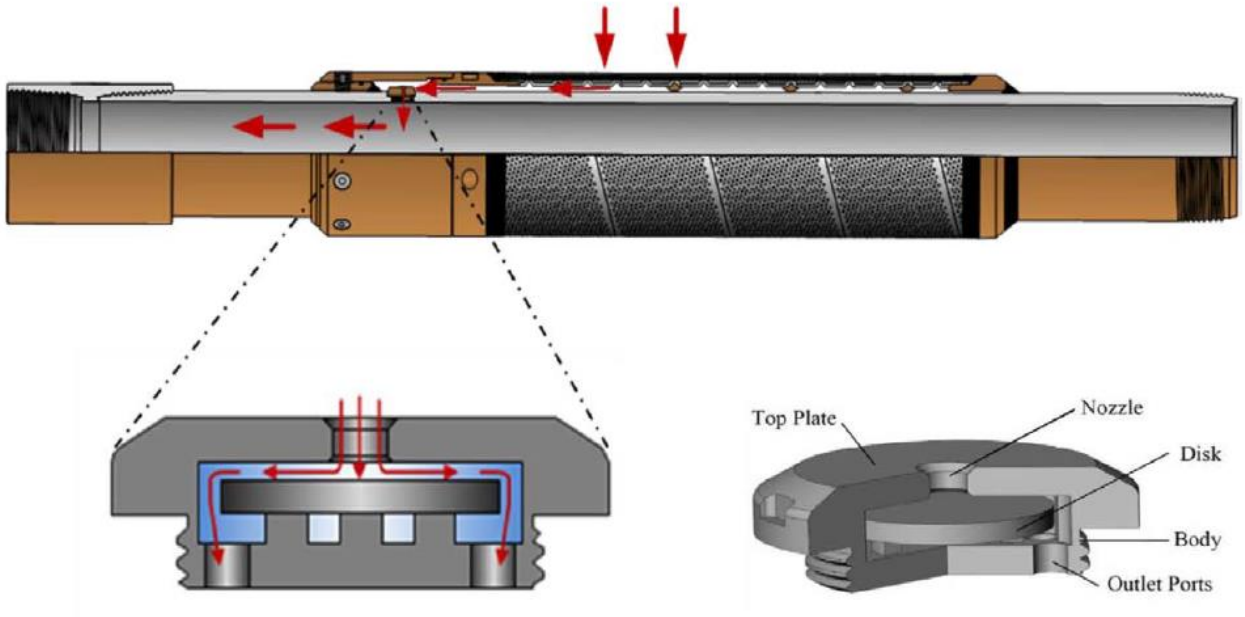
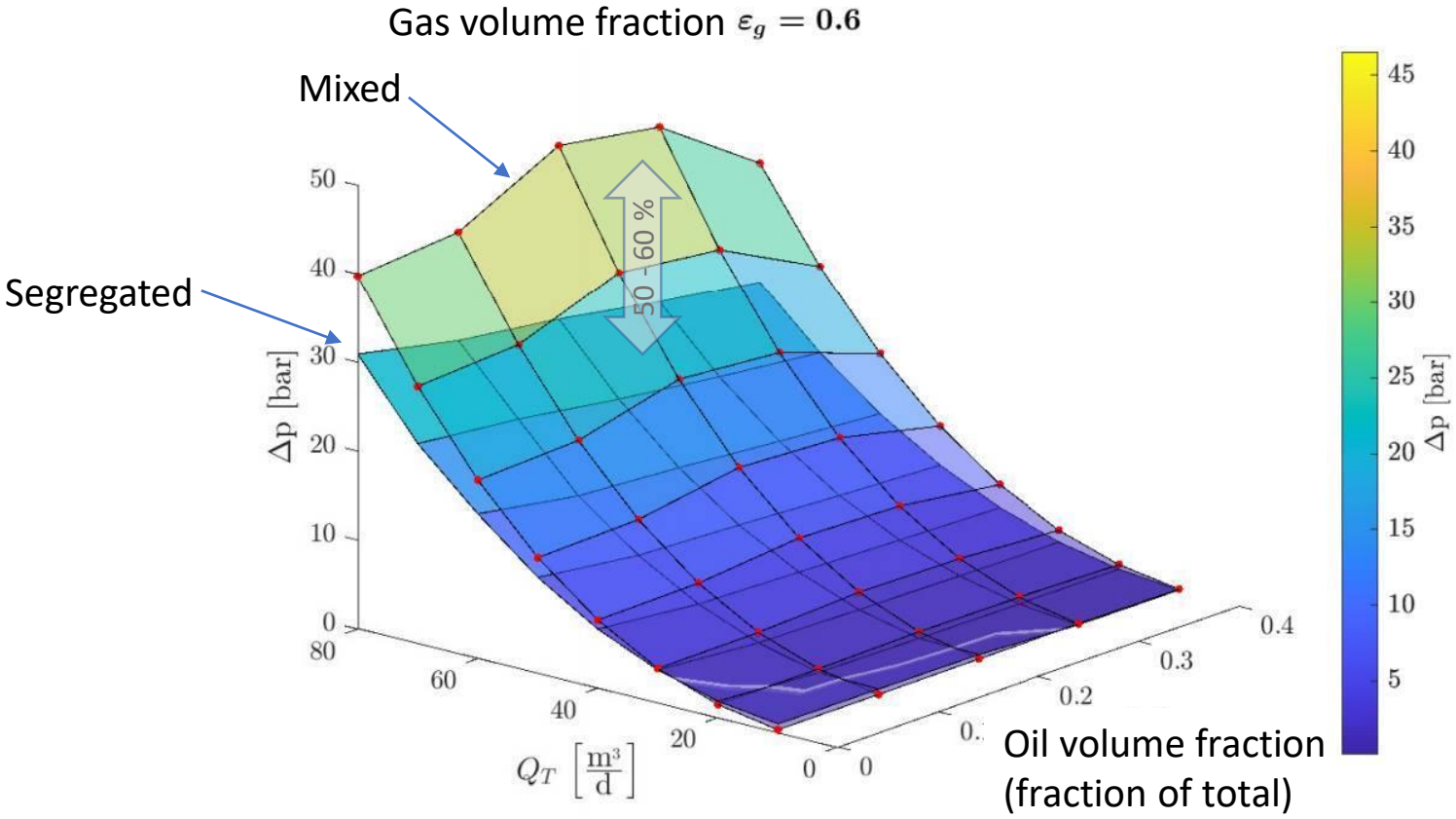



**Figure 3—RCP type AICD and flow paths (Moradi et al 2018).**

# *Insight corresponds well with observations in SPE195617*

REPORT

- RCP (Tendeka 5mm Flowsure)
  - Considerably greater pressure loss might be calculated for mixed compared to segregated flow through a valve system.

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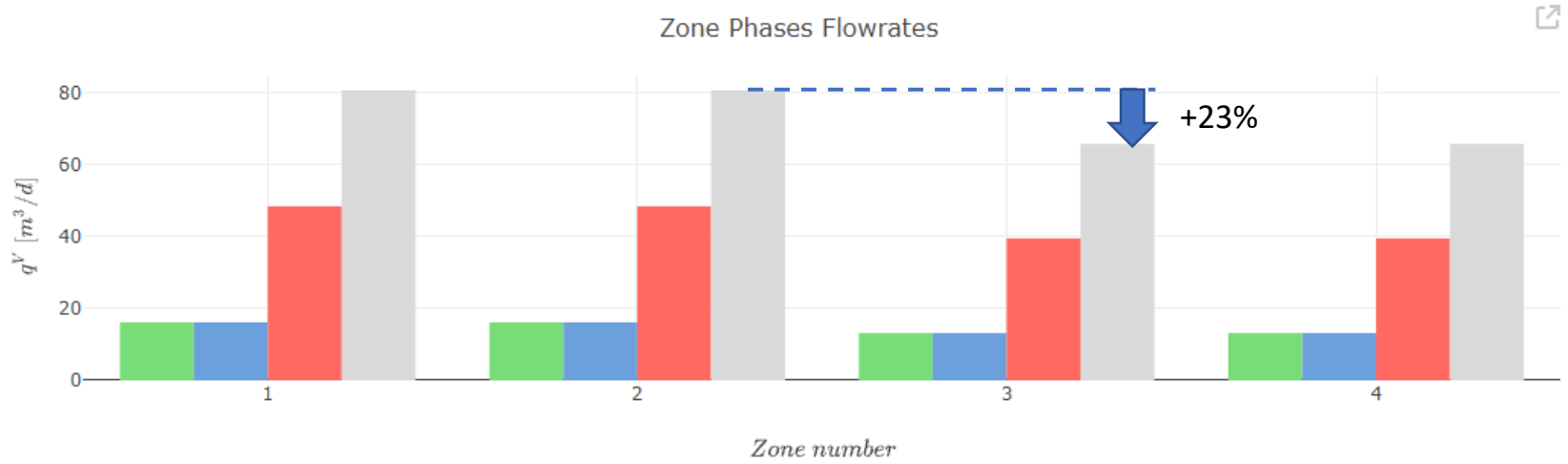
# RCP - Significant Prediction Errors Can Be Made if Ignoring Annulus Segregation

If simulating mixed rather than segregated

Up to 28% lower flowrate for same DP

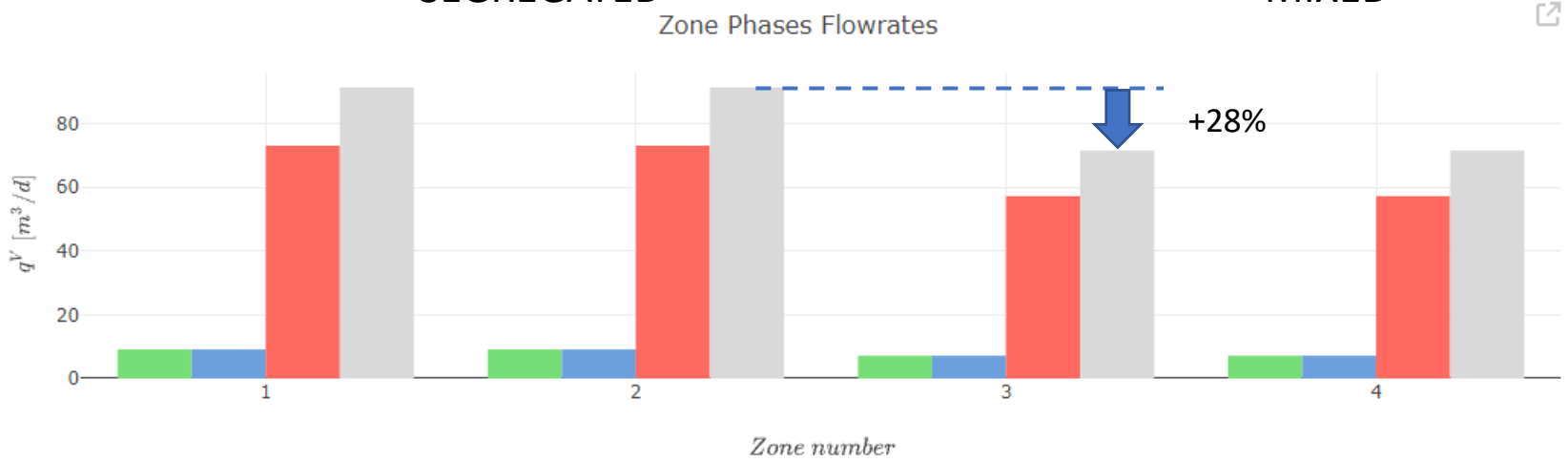
**60 vol % gas**

SEGREGATED MIXED




**80 vol % gas**

SEGREGATED MIXED

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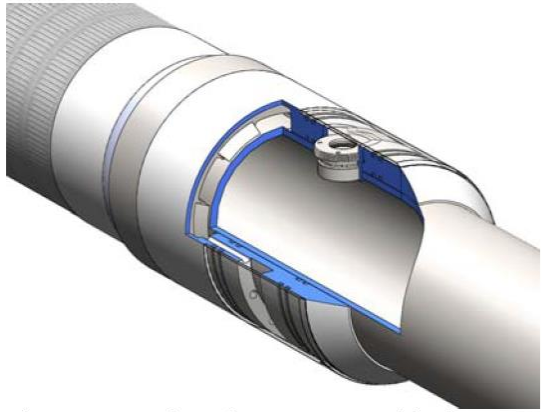
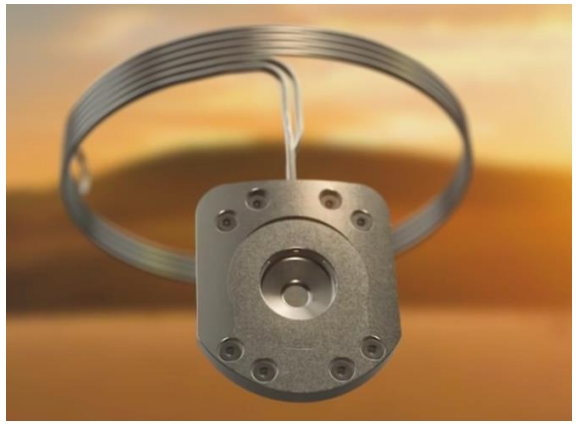
# AICV's (viscosity and density dependent)

- Inflow control valve (InflowControl Technology)





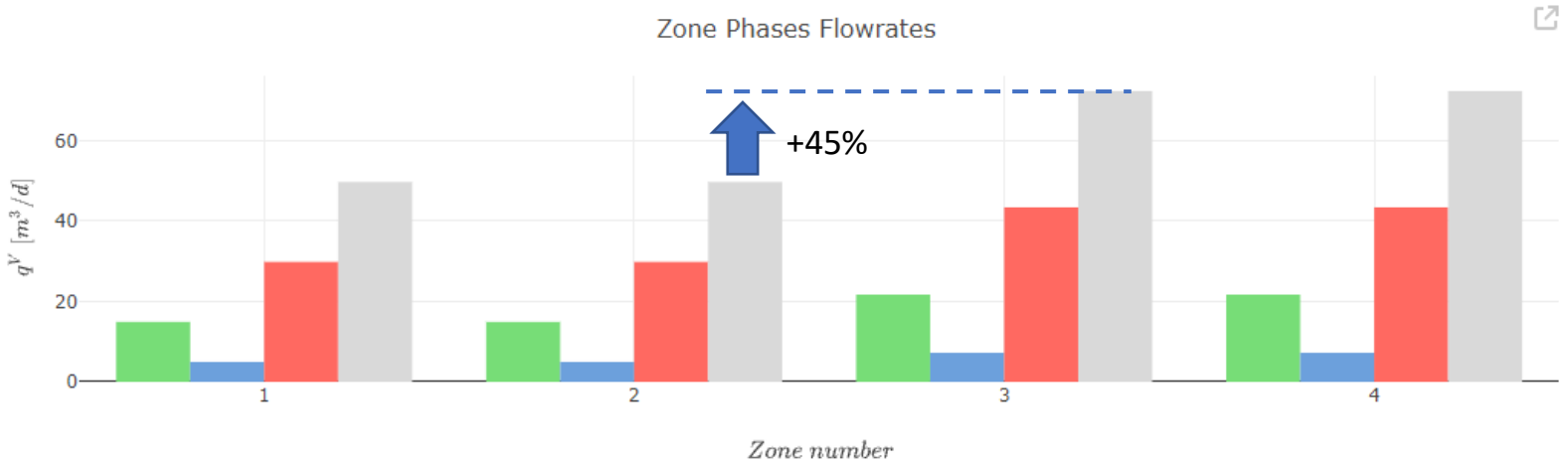
# AICV - Severe Prediction Errors can Be Made if Ignoring Annulus Segregation

If simulating mixed rather than segregated

- Up to 113% larger flowrate for same DP

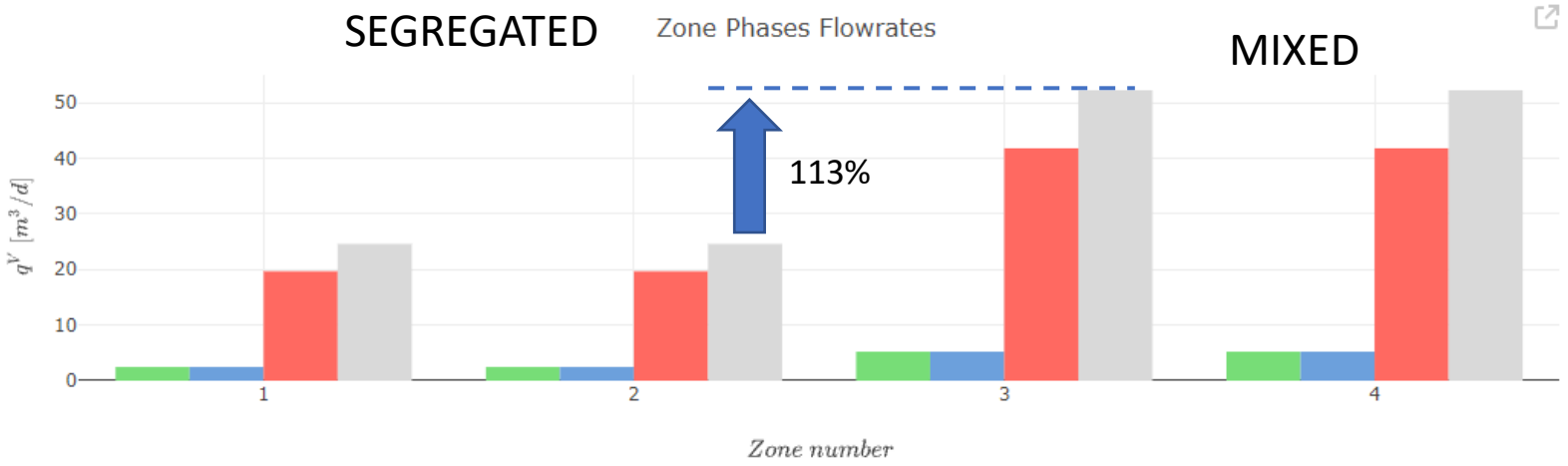
**60 vol % gas**

SEGREGATED MIXED




**80 vol % gas**

SEGREGATED MIXED

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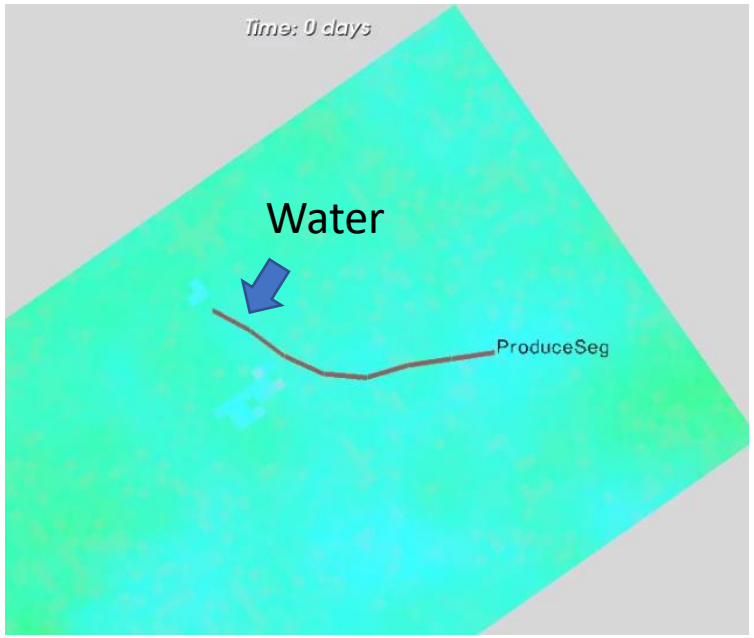
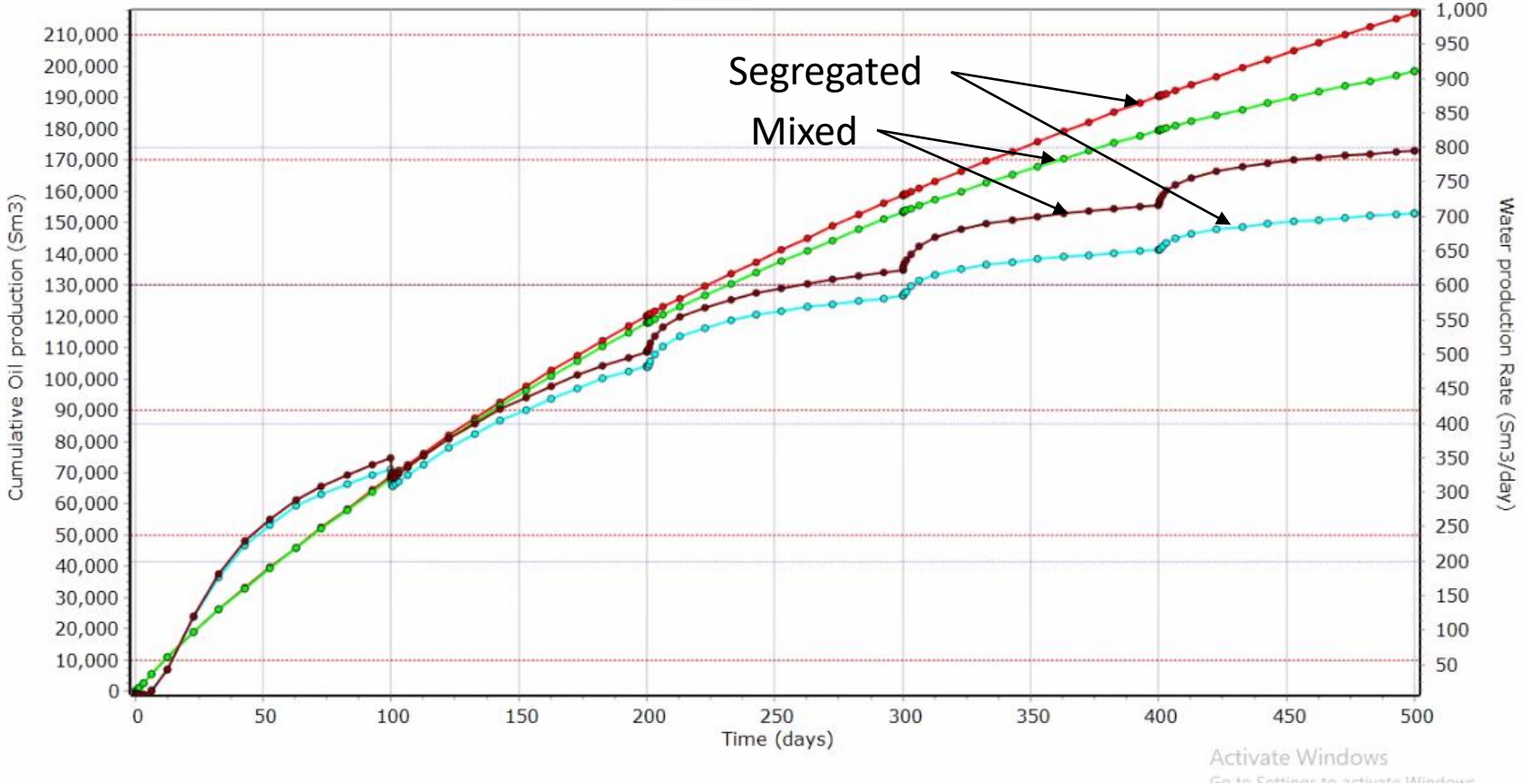
# Comparison of Cumulative Oil Production for segregated vs. mixed annulus flow

- **progressive water influx** to 400m toe zone
- 1400m horizontal well
- 2xAICV per 12m

If simulating mixed rather than segregated

- **10% lower cumulative oil**

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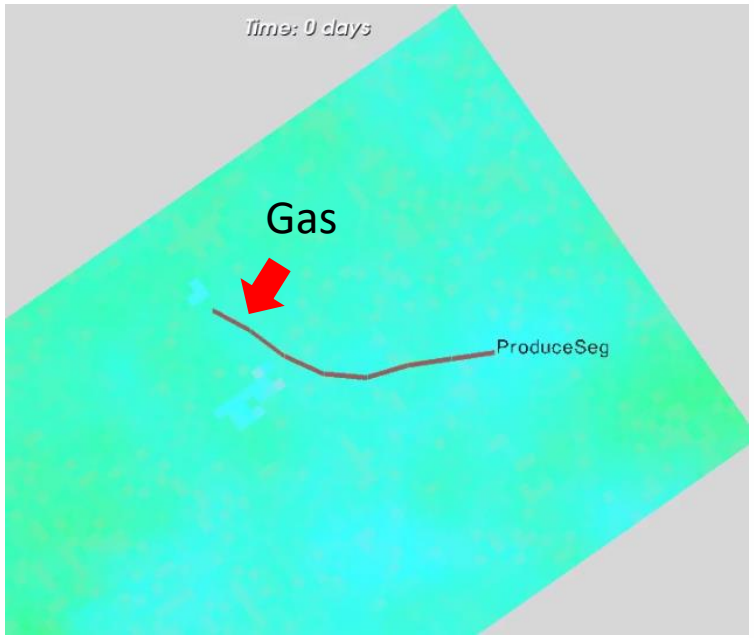
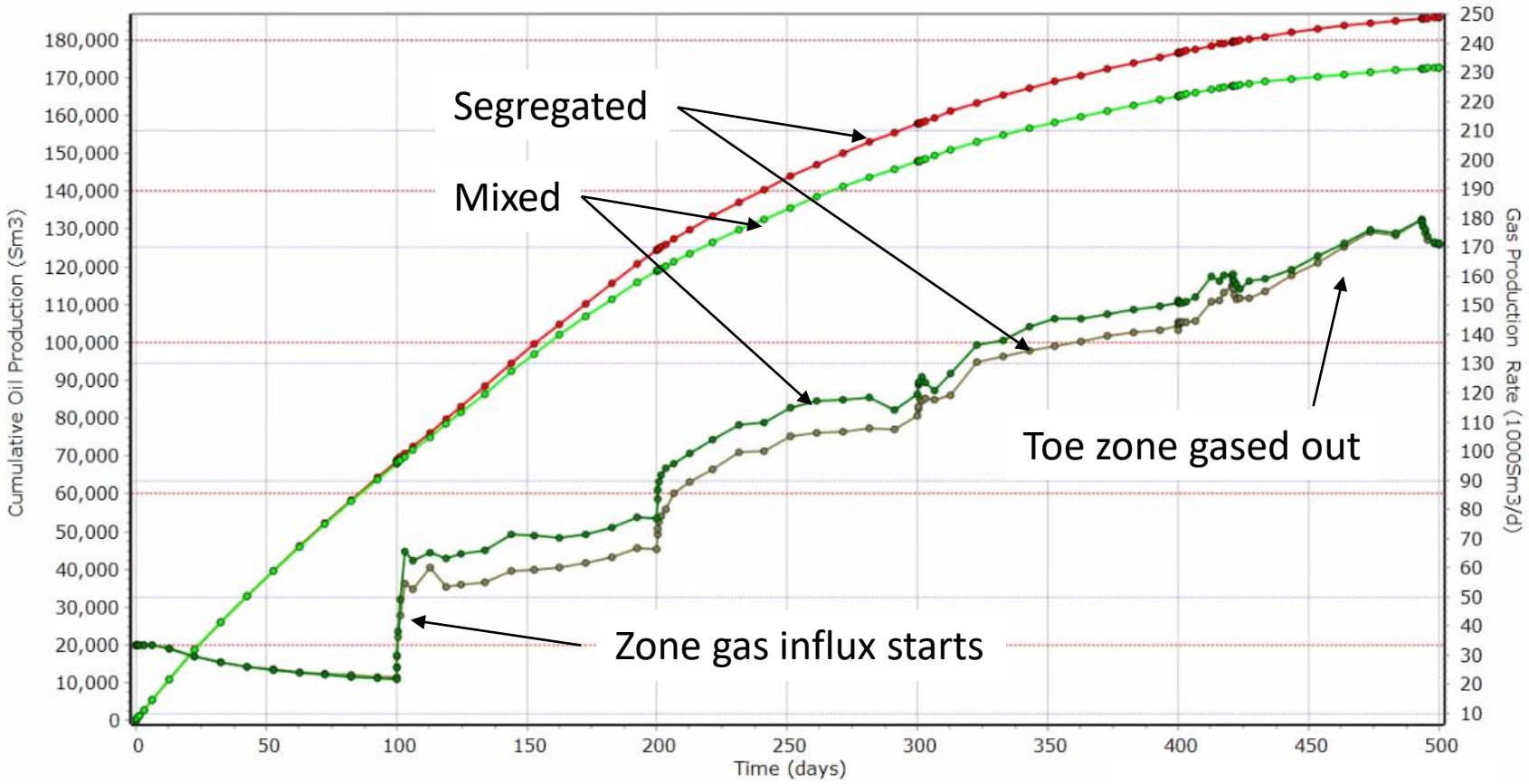
# Comparison of Cumulative Oil Production for segregated vs. mixed annulus flow

- **progressive gas influx** to 400m toe zone
- 1400m horizontal well
- 2xAICV per 12m

If simulating mixed rather than segregated

- **9% lower cumulative oil production**

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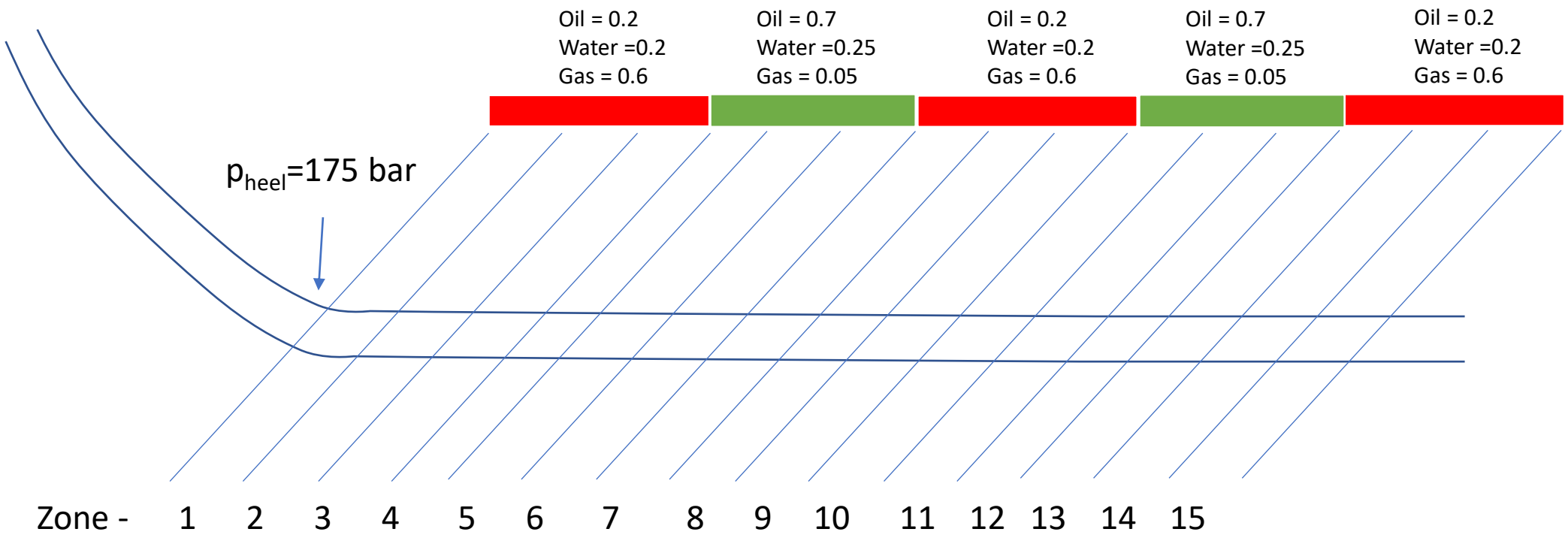
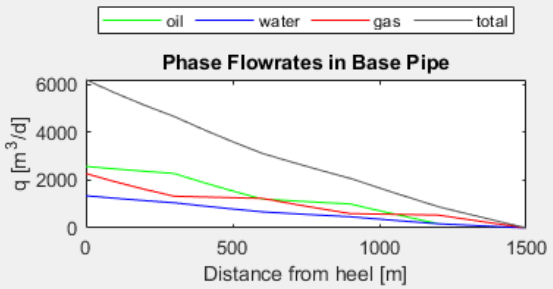
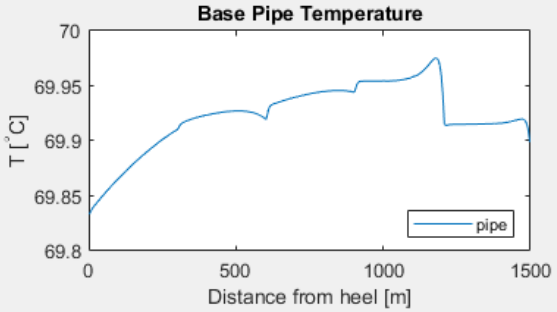
Multi Zone simulation – 15 zones alternating gas and liquid inflow – simple IPRs

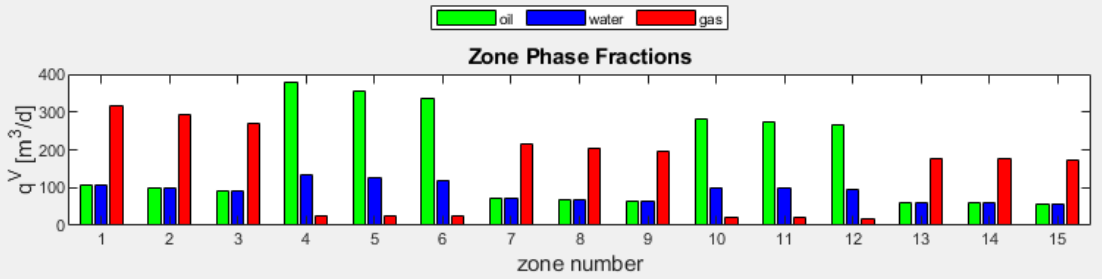
Example - K=200 mD, kv/kh=1, radial inflow, re=100 m $p_{res}$=185 bar
6 x 5mm RCP valves in each zone

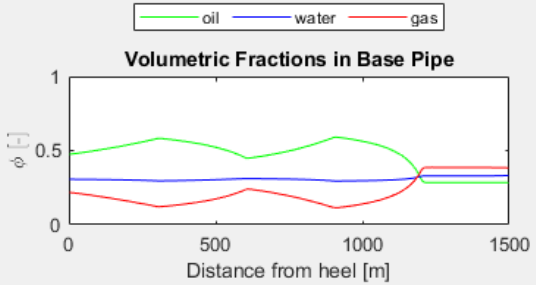


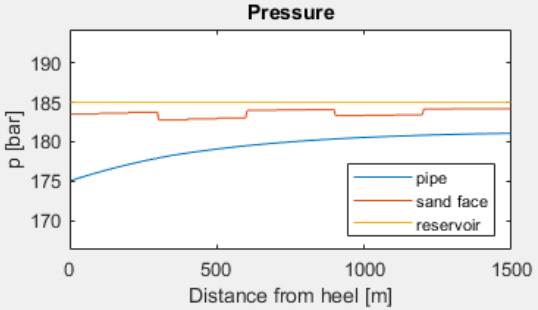
# Multi Zone simulation – 15 zones alternating gas and liquid inflow

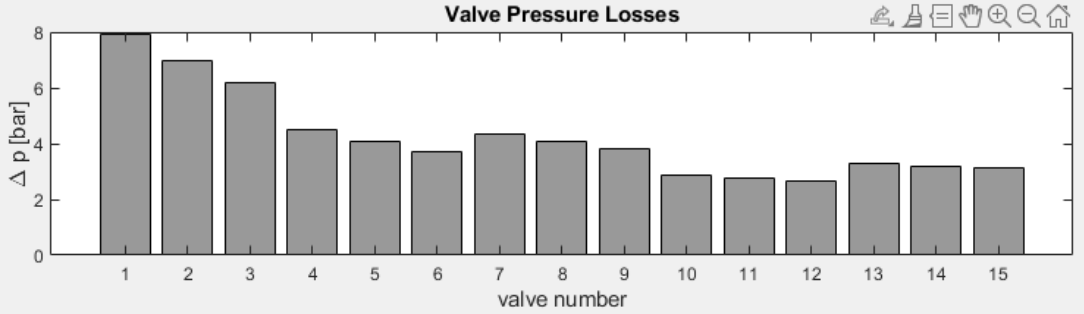


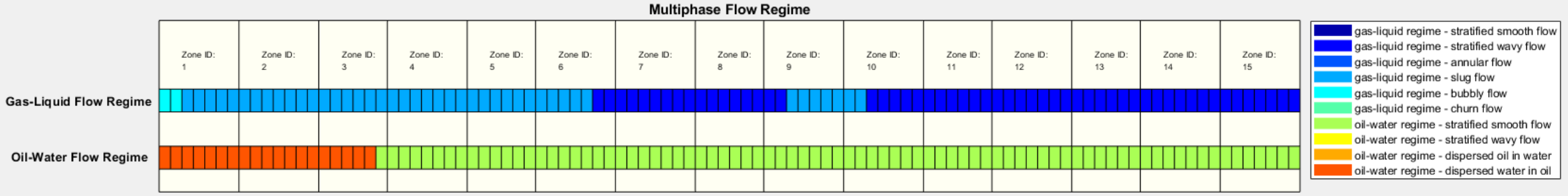




**time [s]: 1243.04**

# Thanks