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Method for Modelling and Upscaling Inflow Performance of Advanced Well Completions While Incorporating Effects from Annulus Phase Segregation

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Abstract

Inflow control technology (ICT) is used in downhole completions to accelerate and increase oil production as well as delaying and reducing water and gas production. While great improvements have been made in inflow control hardware technology, simulation capabilities have not advanced at the same pace, limiting the benefit of applying new hardware technology. Mixed flow, steady state network modeling of the lower completion was introduced in the late 1990s to facilitate simulation of more complex completions including long horizontal wellbores and passive inflow control devices. However, these methods lack the physics required to model modern autonomous valve systems where analytical predictions and field experience show that annulus phase segregation has significant impact on inflow control performance. This work presents a new modelling workflow where fluid segregation effects in the annulus of an ICT completion are solved by a novel computational fluid dynamics (CFD)-based modeling method. The workflow generates physically correct and efficient input to standard reservoir simulators by numerical upscaling of inflow control devices to a zone level. The study shows that segregation and valve interaction have large impacts on the completion performance, and if not accounted for can lead to significant simulation errors which can influence the selection of inflow control equipment. The presented method can provide more optimal completion designs resulting in accelerated production, increased oil recovery and less water and gas production. The implemented upscaling procedure facilitates accurate and fast reservoir simulations. The new CFD-based numerical method is checked and proved for consistency. Examples demonstrate how the model can be used to optimize inflow control application design.

Introduction

Static inflow control devices (ICD) were originally developed by Norsk Hydro in the early 1990s (Brekke et al., 1992) for use in long horizontal wells. ICDs facilitate longer effective completions with up to 25% improved oil recovery. If used together with annulus packers, well production can be controlled on a zone level. ICDs delay water and gas break through by evening out the inflow profile along the wellbore. Most completion vendors offer ICDs in the form of nozzles, orifices, pipes or labyrinths.

Autonomous inflow control devices (AICD), also developed by Norsk Hydro (Mathiesen et al., 2011 and 2014) improved oil rates and recovery further by selective choking of water and gas. AICDs reduce flow capacity automatically if water or gas enters the valve. A growing number of completion vendors offer autonomous inflow control devices that either respond to phase densities, viscosities, or both.

Significant advancements have been made in inflow control hardware, enabling devices to recognize what fluid is entering the device and autonomously choke oil, water, and gas differently. Although modern reservoir simulators can model wells with annulus flow, they ignore the effects of phase segregation in the annular space between the reservoir and the base pipe. This is primarily due to the high computational processing requirement of such simulations and lack of benefit prior to the development and deployment of autonomous inflow control devices.

The development of mixed-flow, steady-state wellbore modeling (Brekke et al., 1996) and iterative coupling schemes between network models and reservoir simulators (Brekke et al., 1993) helped incorporate lower completion pressure losses and complex flow paths into production and reservoir simulation tools. These advancements reduce the uncertainty associated with ICDs, ultimately contributing to their acceptance as standard completion tools. However, to make full use of AICDs, a new method has been developed to preprocess the computationally intensive task of simulating annular phase segregation effects and seamlessly integrating it into existing reservoir simulators and steady-state production modeling software.

It is well established (Langaas et al., 2024; Malbrel et al. 2024) that segregated flow is the dominant multi-phase flow regime in the annulus of long horizontal wells equipped with ICT. In multi-phase flow, a fluid velocity of more than 0.3 m/s is required to transition from segregated to mixed flow regime (Brauner and Ullmann, 2004; Nossen et al.,2017). ICTs significantly limit annulus flow velocity which will favor segregated annulus flow.

Also reported field observations support annulus phase segregation. Lien et al. (2019) matched step rate tests for two laterals with AICDs in the Oseberg field. Manually arranging for annulus phase segregation with flow of individual phases through separate AICDs matched the well performance substantially better than allowing mixed flow through the AICDs. Further evidence of segregated annulus flow can be derived using industry standard CFD software as discussed in the below example used for model verification.

If more than one inflow control device is installed within a zone, oil, water and gas will be unevenly distributed to each device due to phase segregation in the annulus. The mixed flow assumption currently used in wellbore flow simulations is a simplification and is not valid for these type of wells. For autonomous devices, the prediction error can be substantial. A case study using the new workflow (Langaas et al., 2024) shows that phase segregation and valve interaction have significant impacts on completion performance, and if not accounted for can lead to large simulation errors and to selection of sub optimal inflow control equipment. Several authors have seen the need to include annulus phase segregation in the reservoir simulation of these type of wells (Muradov et al., 2018; Bertram et al., 2021; Konopczynski et al., 2021) with different proposed semi-analytical solutions.

Our proposed solution is a numerical, CFD based dynamic simulation method for more physically correct modelling of how several ICT devices work together in a zone (Brekke et al., 2022 and 2024). By using analytical or experimental models for single inflow control devices, inflow performance of zones with multiple, interacting inflow control devices can be predicted with the developed methodology. Results for a wide range of boundary conditions are generated to produce upscaled zonal inflow control performances for reservoir simulation. Different well inflow control designs can be upscaled and passed on to the reservoir simulator to deliver fast and more correct dynamic modeling of well and reservoir. Thus, the presented method can provide more optimal completion designs resulting in accelerated production, increased oil recovery and less water and gas production. The implemented upscaling procedure facilitates accurate and fast reservoir simulations. This article provides further description and verification of the new CFD-based method and workflow.

Method and Procedure

A new numerical method has been developed for analysis and upscaling of zones equipped with ICT. The new method accounts for annulus phase segregation and interaction between valves. The method follows a work process leading from lab data to production profiles through the following key steps also illustrated in Fig. 1:

1. Define lower completion design and operating conditions.
2. Establish flow performance for individual valves.
3. Define zone geometry and ICT setup.
4. Perform multi-run CFD simulations to cover relevant solution space.
5. Upscale by matching a function or a pressure drop table (VFP type) to the CFD simulation results.
6. (Optional) Screen and optimize lower completions with a multi zone well model.
7. Perform dynamic reservoir and well simulations using upscaled zonal inflow performance.

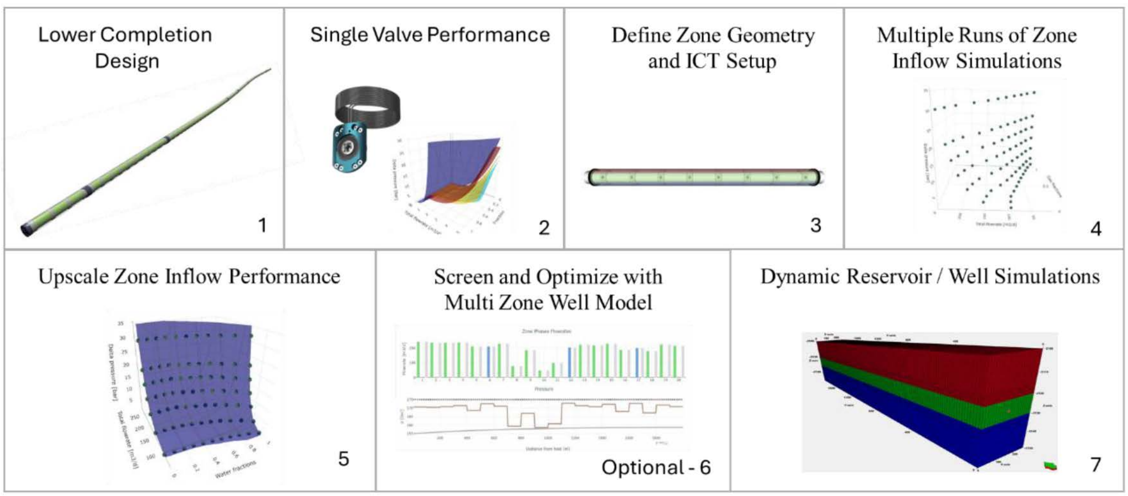

Figure 1—Illustration of ICT work process leading from Lab data to production profiles.

Define lower completion design and operating conditions

Before simulation and upscaling of zone inflow performance can take place, we specify key elements of the lower completion. Fig. 2 shows a typical horizontal wellbore with annulus packers dividing the well into isolate zones. Each zone has a specific number of inflow control devices. Wellbore trajectories for horizontal wells are often simplified as being perfectly horizontal. However, a "horizontal" well is not perfectly horizontal, and even a small deviation from horizontal will impact how the segregated phases distribute between valves inside the zone. Thus, importing or manually defining a realistic wellbore trajectory is an important first step.

Most ICT applications are in wells where the local inflow of oil, water and gas are affected by variations in reservoir quality along the wellbore. ICT can in these cases be used to choke back or promote production between isolated zones. Annulus packers are required to prevent annulus flow between zones. The importance of number and placement of packers in a well with autonomous inflow control devices is discussed by Langaas (2025). Finally, suggested size, number and type of inflow control devices can be defined. Often, many alternatives are evaluated to determine the optimal solution for a specific well.

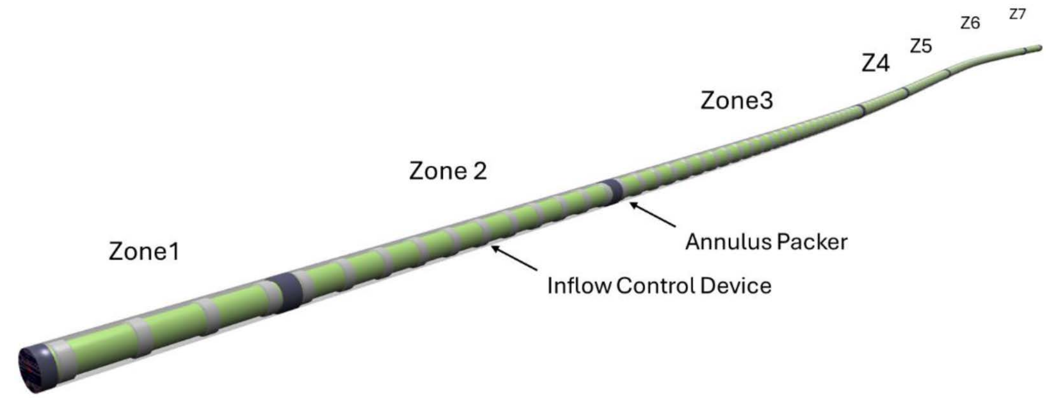

Figure 2—Illustration of lower completion design.

Establish flow performance for individual valves

To model the performance of all types of inflow control devices, several valve models are implemented in the new work process. This part of the process often requires vendor cooperation regarding valve geometry, operational requirements, performance data or lab test results.

Valve model 1 - The orifice equation used for static inflow control devices - ICD. ICDs in the form of nozzles and orifices are being modelled using the standard equation for pressure loss through an orifice as shown in Eq. (1).

$$\Delta p = \frac{1}{2}\rho\left(\frac{q}{A * C_d}\right)^2 \tag{1}$$

Valve model 2 – The RCP function. For autonomous inflow control devices, the phase dependent performance is often provided as a regression to lab test data of the rate-controlled production (RCP) function (Mathiesen et al., 2011 and 2014). It is important that the autonomous valves have been tested with fluids of the same densities and viscosities as are expected downhole during production.

The RCP equation is given by Eq. (2) through Eq. (4):

$$\Delta p = \left(\frac{\rho_{mix}}{\rho_{cal}}\right)^z \left(\frac{\mu_{cal}}{\mu_{mix}}\right)^y \rho_{mix}\ \mathrm{a}AICD \left(\frac{q}{q_{cal}}\right)^x \tag{2}$$

$$\rho_{\text{mix}} = \alpha_{\text{oil}}^a \rho_{\text{oil}} + \alpha_{\text{water}}^b \rho_{\text{water}} + \alpha_{\text{gas}}^c \rho_{\text{gas}} \tag{3}$$

$$\mu_{\text{mix}} = \alpha_{\text{oil}}^d \mu_{\text{oil}} + \alpha_{\text{water}}^e \mu_{\text{water}} + \alpha_{\text{gas}}^f \mu_{\text{gas}} \tag{4}$$

Where x, y, z, a, b, c, d, e, f are regression parameters used to match the function to laboratory test data. The users either receive these regression parameters from the vendor or use regression models to generate these from test data.

The ICT device used here to illustrate the new work process is an autonomous inflow control valve (AICV) described in Langaas et al. (2024). The matched RCP function regression coefficients and operating fluid properties are provided in Table 1 and Table 2.

Table 1—RCP function parameters used to match experimental data.

P_cal kg/m3	µ_cal cP	q_cal m3/d	x	y	a bar*m3/kg	z	a	b	c	d	e	f
1000	1	1	6	5	2.5e-11	1	1.5	5	1	1	1	1

Table 2—Properties of test fluids at test conditions (70°C and 200 bar).

Test Fluid	Density [kg/m3]	Viscosity [cP]
Oil	756.6	0.82
Gas	139	0.02
Water	1006.7	0.46

The matched RCP function, representing one valve, is shown in Fig. 3. The blue surface describes the two-phase oil-water performance, and the oil-gas performance is given by the red surface. The single-phase oil, water and gas performances are illustrated by green, blue and red dotted lines. Just by comparing the single-phase performances we see that this specific valve has a significantly higher flow capacity for oil than for water and especially gas.

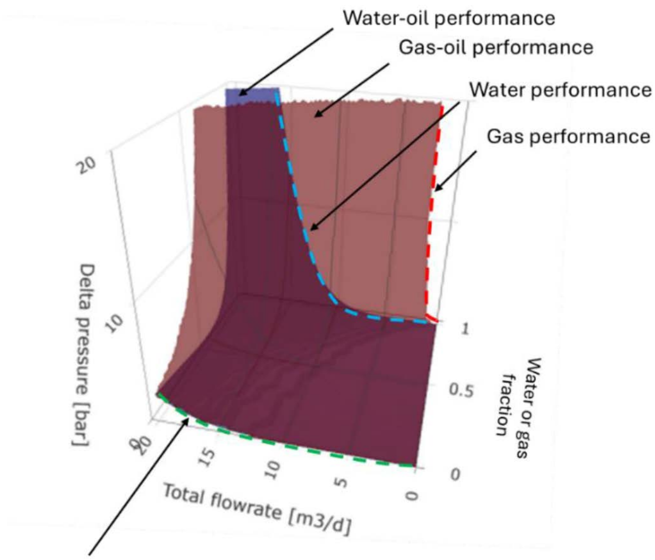

Figure 3—Flow performance plot – single autonomous valve. (Blue surface behind red surface.)

Since the valve performance is very phase sensitive, we need to simulate every valve in the wellbore with as correct oil-water-gas composition as possible. As stated earlier, commonly used steady-state mixed flow wellbore models do not have the capacity to correctly estimate which phase that will enter a specific valve. Thus, the proposed work process is critical to ensure results with acceptable quality.

Valve model 3 – The trinary valve model used for density activated AICDs and ICVs. The RCP function was developed for RCP valves (floating disk AICD) which are primarily viscosity sensitive with a smooth transition of choke level between phases. For some autonomous valves, the performance cannot be captured with the RCP function. This is the case for density sensitive autonomous valves and surface controlled downhole valves. Thus, an explicit (trinary) model with different pressure loss formulations for oil, water and gas was developed and used for these types of valves. Various characteristics for switching between pressure loss formulations are implemented. Sufficient flexibility is built into the trinary valve model to facilitate matching of experimental data. In the trinary valve model, the pressure loss vs. flow rate is calculated from Eq. (5).

$$p_a - p_p = \frac{1}{2}\xi\rho_{mix}\left(\frac{q^V}{A^V}\right)^{\alpha} \tag{5}$$

Define zone geometry and ICT setup

The CFD simulations are performed for each packer zone of the well. The zones must be defined as correct as possible, and it is good practice to do quality assurance of consistency before entering large scale simulations work (multi-run, explained below). Important input to the simulations includes wellbore diameter and trajectory, zone length, type and number of inflow control devices, densities and viscosities, initial and boundary conditions for pressure, saturation reservoir productivity and flowrates. Fluid properties should match expected downhole operating conditions and be consistent with fluid data used for single valve performance matching.

Due to the dynamic nature of the process where fluids segregate, and valves interact, the model needs to be transient. However, as will be explained below, our key interest in this workflow are the steady state solutions. Fig. 4 shows the stabilized results at the end of simulation for a 100m zone with 8 evenly distributed AICVs. The upper graphics illustrates the stabilized phase saturations in the annulus. The graphics are not to scale, which distorts the actual horizontal interfaces between oil, water and gas. However, the relative locations of the phases compared to the completion geometry such as valve inlets are correct.

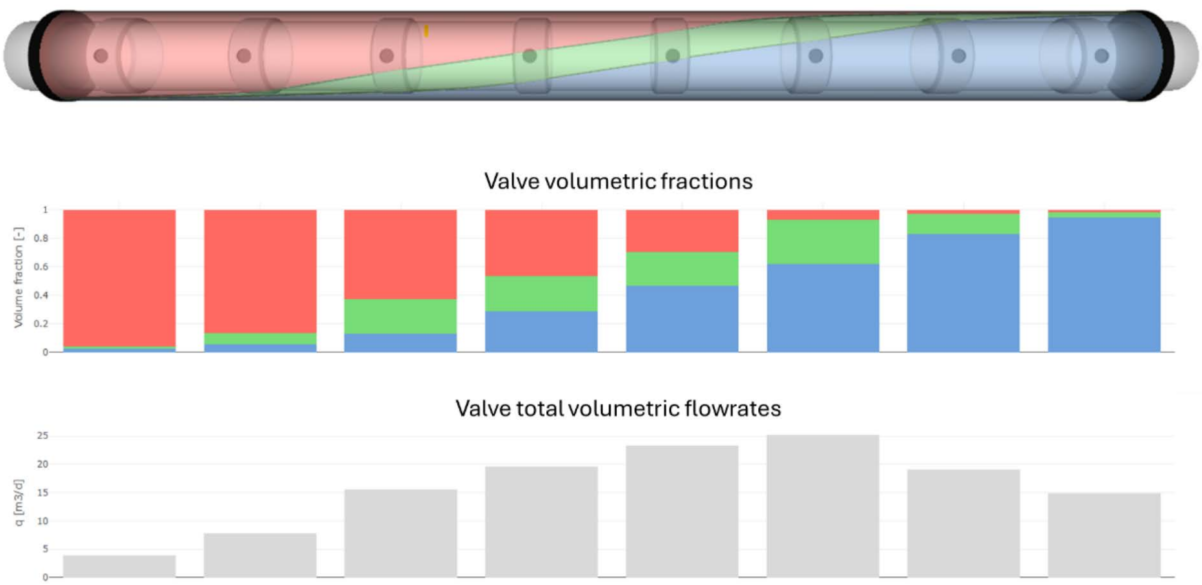

Figure 4—Output from single zone detailed analysis. 100m zone with 8 AICVs. (Well zone inclination is 89° while shown as perfect horizontal in this figure and not a true scale.)

Valves have the following options of production from the annulus:

- **Unoriented valve inlet position:** This flow model assumes that the valve withdraws all phases at a rate proportional to their fraction at the location of the valve.
- **Oriented valve inlet position:** We can specify or randomize the valve's inlet around the circumference of the base pipe. For the oriented valve inlet position, we have two approaches for phase withdrawal.
    - **Binary phase withdrawal:** The binary phase withdrawal model considers phase segregation in the annulus. The phase flowing into the valve is evaluated based on the vertical location of the valve's inlet relative to the location of the oil, water and gas phases.
    - **Coning model:** In addition to the withdrawal of the phase at the valve's inlet. This model extends the binary phase withdrawal model by also allowing the phase immediately above the valve inlet to be withdrawn if conditions are satisfied.

It is seen from the of volumetric fractions and flowrate plots in Fig. 4 that valves producing more water or gas operate with reduced flowrate compared to the ones producing more oil. Thus, we can see that the autonomous inflow control valves work as intended. If higher levels of water and/or gas enter a zone, an increasing number of valves will operate with reduced capacity. Thus, zones with high inflow of water and/ or gas will be choked back while production from zones with higher inflow of oil will be promoted.

Initial conditions for the transient simulation are guessed locations of fluid interfaces within the completion. To detect when the zone operates in steady state, we inspect the phase mass imbalances illustrated in Fig. 5 where phase specific accumulations of mass between sand face and the zone's outlet are given vs. time (oil-green, water-blue, gas-red). At time zero, before segregation and valve interaction has started the mass imbalances are naturally zero. The duration of the transient period depends on fluid properties, valve type, zone length and production level. For this specific case we experience 2 to 3 hours of transient behaviour before the mass imbalances approach zero, which means that steady state condition is reached.

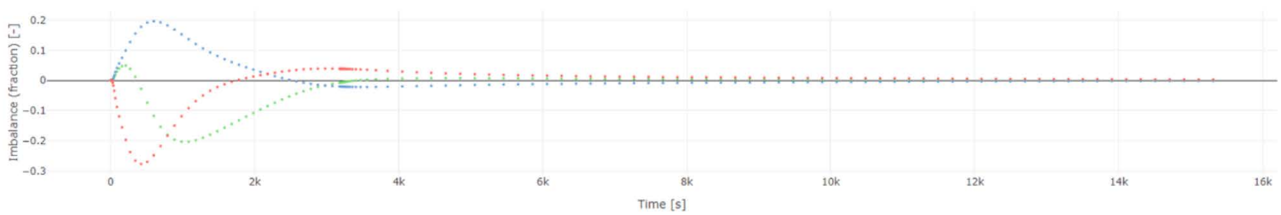

Figure 5—Phase mass imbalance vs. time.

Perform multi-run CFD simulations to cover relevant solution space

Multi-run simulations are essential to prepare input for the upscaling procedure. Transient simulations are executed for a wide range of completion pressure drops and phase fractions. Parallel computing solves this CPU demanding problem effectively. Fig. 6 shows results from sensitivity simulation of the 100m zone with 8 AICVs as described above. The green dots represent stabilized pressure loss vs. phase fractions and total flowrate. From left to right we see two phase gas-oil performance with no water, 3 phase performance where free gas fraction is fixed to 0.5 and oil-water is varied, and two-phase oil-water performance with no gas. The objective of the multi-run simulations is to preprocess all flow conditions a specific zone can be exposed to in the dynamic reservoir simulator. When solved once, the results can be re-used many times to simplify and speed up the wellbore models in the reservoir simulator.

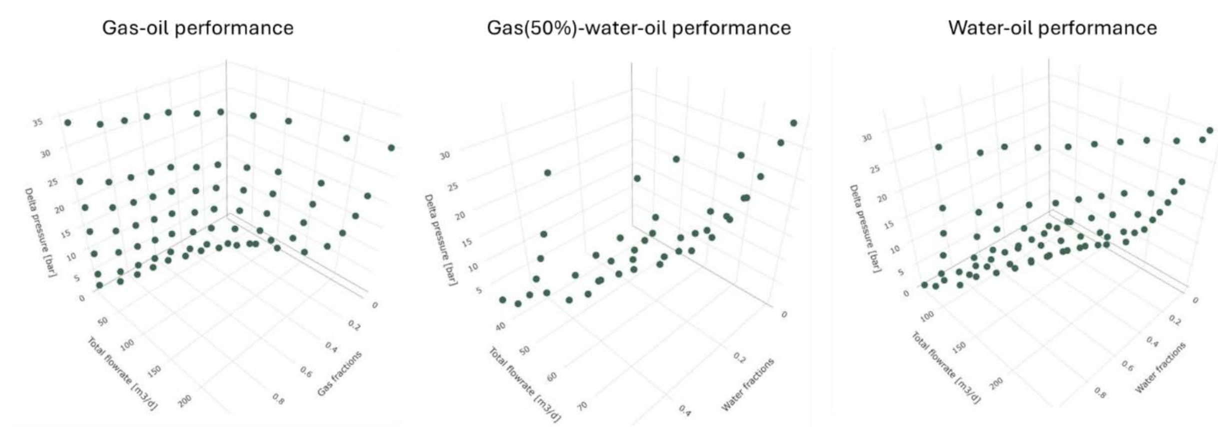

Figure 6—Example multi-run result of 100 m completion zone with 8 AICVs. Pressure loss vs. phase fractions and total volumetric flowrate.

Upscale by matching a function or a pressure drop table (VFP type) to the CFD simulation results

To use the pre-processed zonal ICT result in the reservoir simulator we make use of already existing and proven functionality in standard reservoir simulators. Two such functionalities are the RCP function and VFP tables. The RCP function given by Eq. (2) through Eq. (4) is matched to the zone inflow performance through regression. This is the same equation used to represent single valves within a zone but is here used to represent the effective zonal inflow control performance of a multi valve system.

The VFP format is a standard pressure loss table regularly used to model multi-phase flow in the vertical part of the completion. However, we can also use VFP tables to model pressure loss through ICTs downhole. The tables are based on standard condition volumes and require the same PVT flash calculations as used in the reservoir simulator. Fig. 7 shows the surface for a matched VFP table together with the points representing the simulated multi run results for the above described 100 m zone with 8 AICVs.

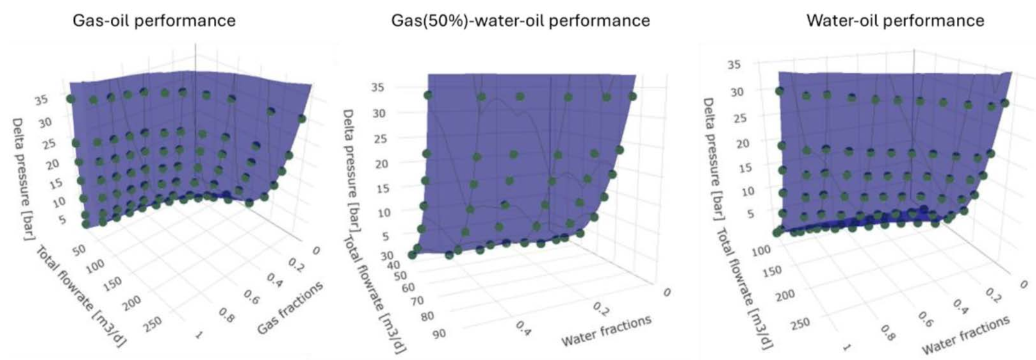

Figure 7—Upscaled zonal ICT model. Surface representing VFP table is shown together with multi run results (green dots).

In Fig. 8 the upscaled water/oil and gas/oil performances with and without phase segregation in annulus are illustrated for the 100 m zone with 89° deviation and 8 AICVs. For the mid ranges of water or gas fractions, the mixed flow assumption predicts the zone to have nearly twice the flow capacity than if annulus phase segregation is considered. Since phase segregation is the dominant annulus flow regime in horizontal wells with ICT and open annulus, we can conclude that a significant error is made if we ignore it. The upscaled effective performance of a zone with 8×2.75mm ICDs is plotted for reference. We see that the passive ICD completion does not choke gas and water nearly as much as the reactive AICV completion.

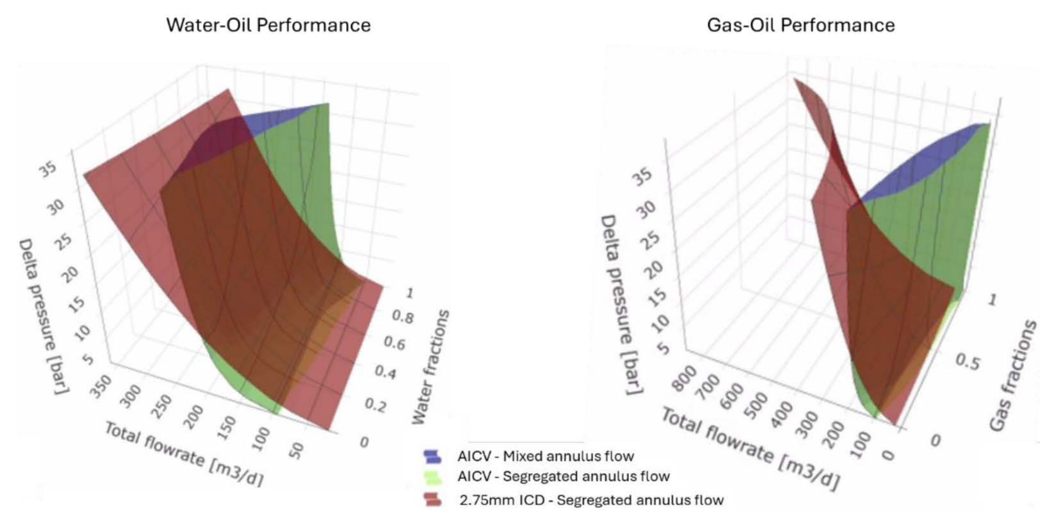

Figure 8—Comparison of upscaled zone inflow control performances with and without segregated flow in the annulus.

(Optional) Screen and optimize lower completions with a multi zone well model

The upscaled inflow control performances can be used in steady state well modelling to start evaluating ICT solutions. This can be helpful in the lower completion design process before use in more time demanding dynamic reservoir simulations. In the below example, a 2000 m long well with an inclination of 89° was used with 20 equal length zones having random zone productivities between 0 and 100 m3/d/bar. Distribution of productivities is illustrated in Fig. 9. Upscaled inflow performances for two different completions were used for comparison: 1) 8 × AICVs per zone, 2) 8 × 2.75 mm ICDs per zone. The two alternatives have approximately the same production capacity for oil.

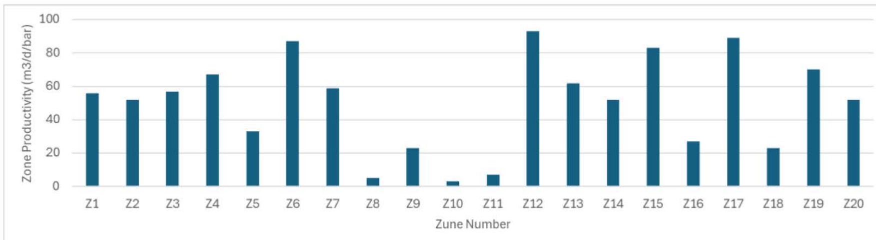

Figure 9—Zone productivities for example multi zone well.

Reservoir pressure was set to 175 bar and completion outlet pressure to 155 bar for all cases. The fluid properties used are described in Table 2.

Steady-state well simulations were performed to illustrate the effect of using the two different valve systems: 1) 8 × AICVs per zone, 2) 8 × 2.75mm ICDs per zone. Water influx to the wellbore is in this example gradually increased by sequentially watering out the zones starting with the highest productivity zone and continuing with zones of lower productivity until the well is producing 100% water. Fig. 12 shows that water cuts out from the well are reduced significantly more for the AICV completion (left figure) than for the ICD completion (right figure). Dashed lines in both plots represent the performance of a screen completion without inflow control.

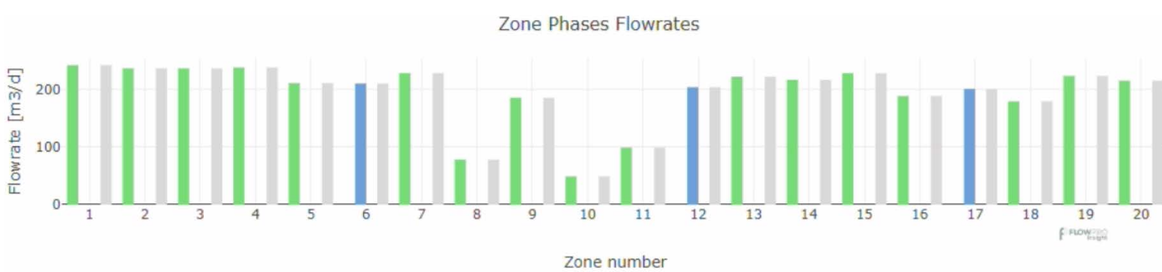

Figure 10—Zone phase flowrates for example multi zone AICV well. (grey=liquid, blue=water, green = oil)

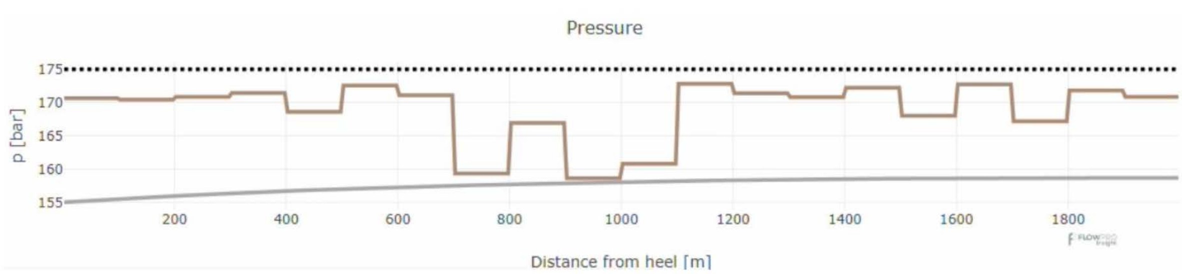

Figure 11—Reservoir, annulus and base pipe pressures along example multi zone well. (black=reservoir, brown=annulus, grey=base pipe)

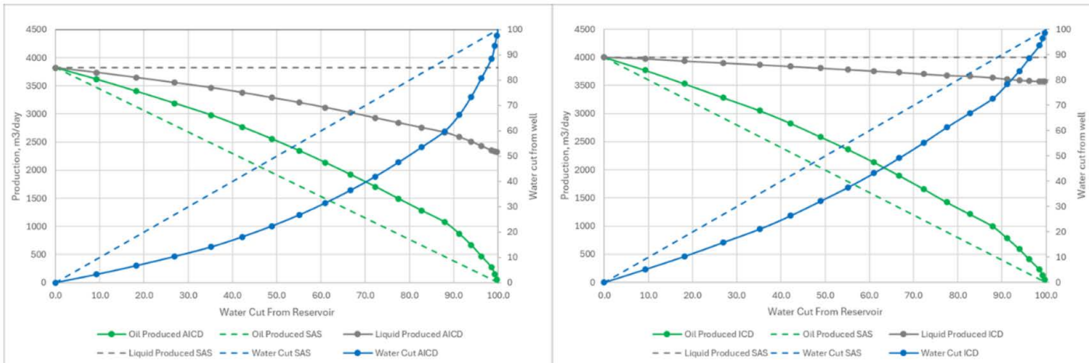

Figure 12—Example multi zone well performance. Left - AICV completion, right – 2.75 mm ICD completion.

We also observe that the AICV completion will produce more oil than the ICD throughout the whole range of water cuts. This sensitivity is performed with fixed heel pressure, does not consider vertical lift capacity or time dependent reservoir response and is therefore only qualitative. To conclude which ICT method to use for a specific well, dynamic reservoir modelling as described in the next section must be performed together with economic evaluations.

Perform dynamic reservoir and well simulations using upscaled zonal inflow performance

To quantify the potential benefit of using different inflow control technology, a dynamic reservoir simulation needs to be performed. The upscaled zonal ICT models from step 5 above is here used in dynamic reservoir simulations to include the impact of annulus phase segregation and to speed up the coupled wellbore-reservoir simulations. How to use the upscaled zone inflow performances in a reservoir simulator to study and compare different completion alternatives was discussed by Langaas et. al (2024). The performance of AICVs and ICDs were compared in a 2000m long wellbore in a high permeability reservoir with water and gas influx and various levels of reservoir heterogeneity. Fig. 13 (right) shows a homogeneous case with bottom water drive with 100m packer intervals from that study. Each 100m zone has one upscaled zonal ICT performance that accounts for phase segregation. The saturation shown is after 1 year production. Fig. 13 (left) shows the comparison between AICV and ICD based on simulation using the new workflow. During the first 7 years of production the AICV case recovers 11.5% more oil and 8.7% less water.

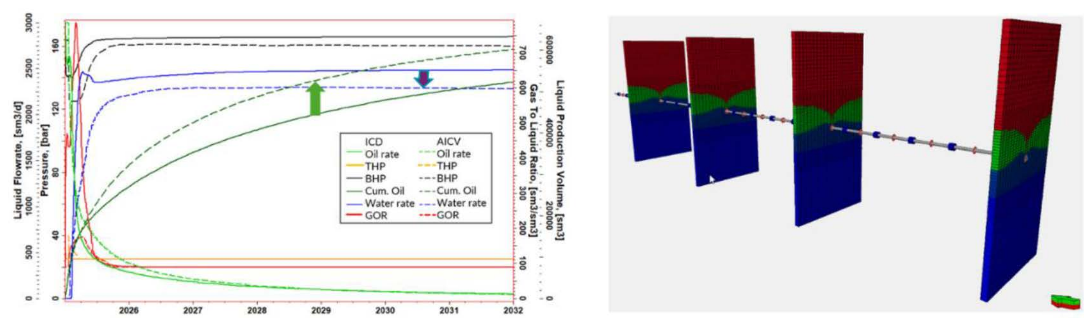

Figure 13—Homogenous case with bottom water drive. Left: Comparison of AICV vs. ICD with new workflow accounting for phase segregation. Right: Saturations after 1 year production. gas=red, oil=green, water=blue. (From Langaas et al. 2024)

A comparison of cumulative oil production between AICV and ICD using the new and old work processes is illustrated in Fig. 14 While simulations with the new work flow shows most cumulative oil produced with the AICVs, simulations with the old workflow with no phase segregation in annulus shows more cumulative oil being produced with the ICD completion. Thus, if we ignore phase segregation in the annulus, we may install a sub-optimal ICT completion. The new workflow also gives a more correct projection of lower completion pressure loss which is key to a good lower completion design. Using the old workflow (assuming mix flow) we will typically underestimate completion pressure losses for wells with AICVs and could risk installing less than optimum number of devices. Since the segregation effect can work in the opposite direction for some autonomous valves, it must be simulated for each specific valve type.

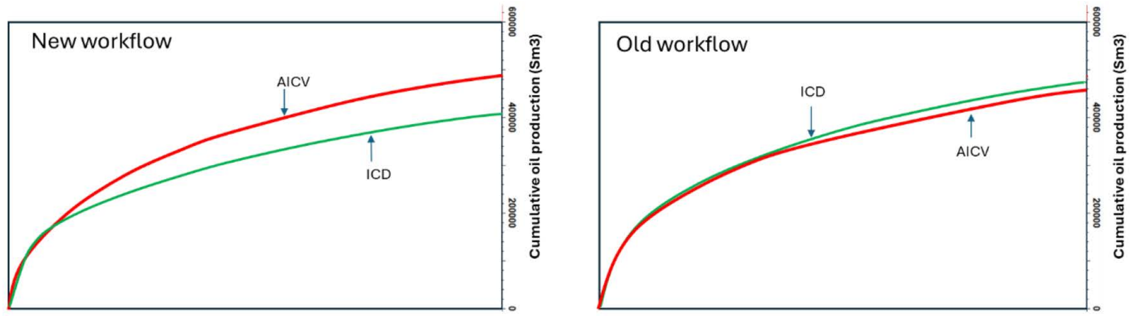

Figure 14—AICV and ICD performance comparison – (left) segregated annulus flow vs. (right) mixed annulus flow

Model Verification - Comparison with Industry Standard CFD

The developed CFD-based method for transient modelling of annulus phase segregation is optimized specifically for advanced lower completion geometries to perform fast and physically correct calculations. To illustrate achieved accuracy and simulation efficiency, comparison with an industry standard CFD method (ANSYS Inc., 2021) was performed. Table 3 shows fluid properties used in the test.

Table 3—Fluid properties used in verification test (down hole conditions).

Fluid	Density [kg/m3]	Viscosity [cP]
Oil	700	0.5
Water	1000	0.4

Fig. 15 (left) shows a 24 m long well zone with 4 evenly distributed 60 mm diameter orifice type ICDs located along the top of the base pipe. The large ICD diameter and short zone length are selected to reduce grid size in the industry standard CFD model to prevent unfeasible run times. A wellbore diameter of 8.5 inches and a base pipe/screen with an inner diameter of 4.9 inches and outer diameter of 6.0 inches are used. The zone slants downwards 0.2° from the zone outlet (deviation of 89.8°). The well zone produces 50% oil and 50% water at a downhole total flowrate of 48 m3/d. The fluids are entering from the surrounding reservoir through the annulus outer boundary. Initially, the well is filled with 50/50 oil and water with an oil water interface parallel with the wellbore.

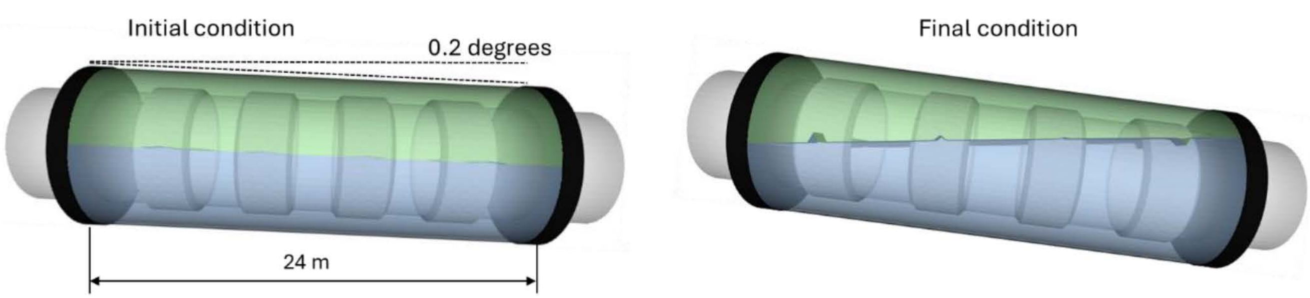

Figure 15—Numerical test model initial and final conditions. Blue = water, green = oil.

Fig. 16 (left) shows the model grid with 33.1 million cells. Fig. 16 (right) shows the high-resolution grid close to the ICDs.

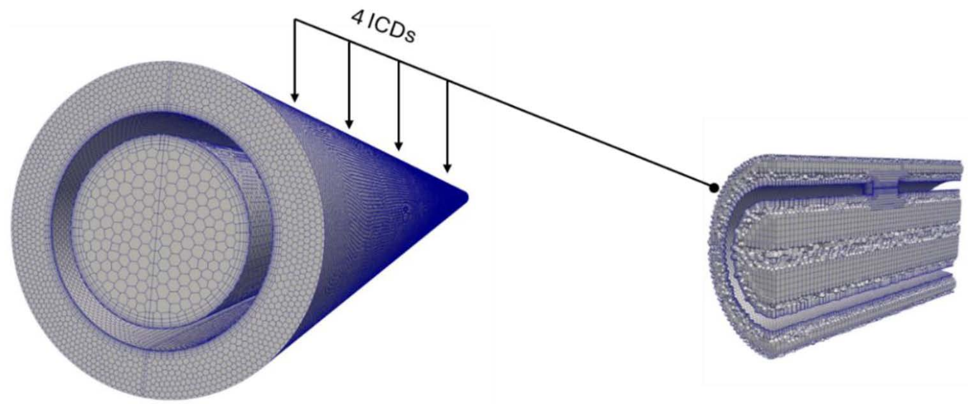

Figure 16—Grid used in industry standard verification model.

Fig. 17 illustrates the oil saturation along the wellbore annulus at different times into the simulation. For this case with a short wellbore, static ICDs and low viscosities, a steady state oil water interface is reached after a real time of approximately 2 minutes in both tools. For longer zones with dynamically operating autonomous inflow control devices, it will typically take several hours before steady state is reached. However, as the reservoir simulations normally operate with time steps on the order of weeks or months, the stabilized wellbore condition solution is valid for use. For autonomous valve systems with annulus phase segregation, we must go through the dynamic part of the CFD simulation to be sure we arrive at the correct stabilized condition.

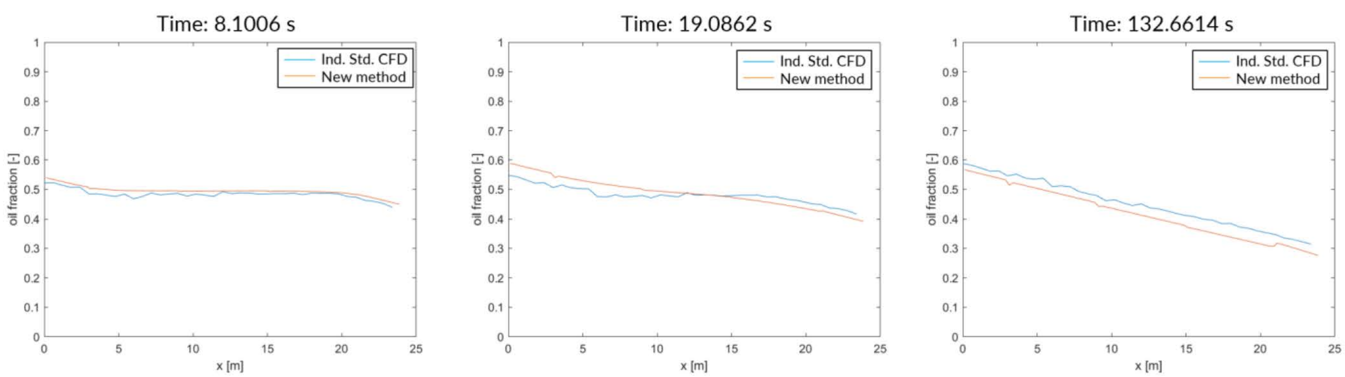

Figure 17—Numerical test result. Oil fraction in annulus as function of length along well. Left to right shows three time-steps where the last step is at steady state conditions.

The presented method was found to perform more than 3 million times faster than the industry standard CFD method. The oil saturation showed a maximum relative error of 4.93% and an average error of 3.49%.

Fig. 18 shows the oil saturation and velocity fields in the annulus of the industry standard simulation. We see that the flow is segregated with a very short oil/water transition zone showing no signs of mixed flow. From the velocity field we see that the maximum annulus velocity close to the orifice is 0.07 m/s. A velocity above 0.3 m/s is typically required to trigger a transition from stratified to mixed flow. This case demonstrates that industry standard CFD supports the need to include phase segregation effects in the type of wells discussed in this article.

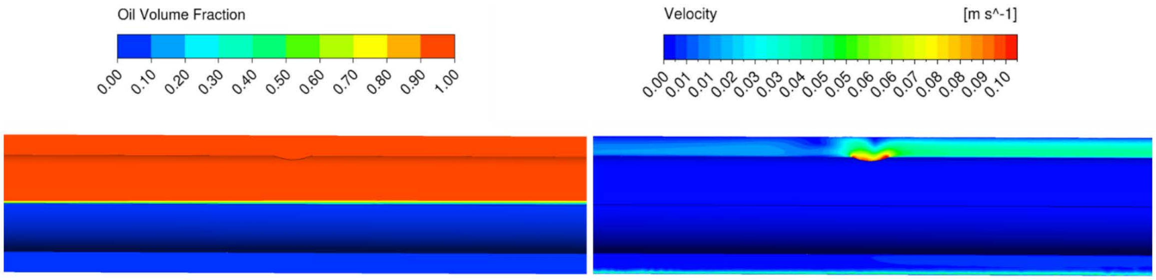

Figure 18—Industry standard CFD model - annulus oil saturation and velocity field.

Conclusions

- A CPU time efficient, CFD-based simulation method is successfully developed to incorporate annular phase segregation and valve interaction for wells completed with ICT. The approach improves the accuracy of inflow performance predictions significantly, particularly for autonomous valves.
- A numerical upscaling procedure is developed to translate detailed flow physics into practical zonal ICT models for standard reservoir simulators through RCP functions or VFP tables. This approach facilitates the integration of the results into current industry workflows to achieve accurate and computationally fast reservoir simulations.
- This study concludes that sustained mixed flow in the annulus of long horizontal wells with ICT is not possible under typical operating conditions. Low annular velocities due to flow constraints through ICTs favor phase segregation, which significantly influences inflow control performance.
- The proposed workflow enables more correct optimization of inflow control device configurations, facilitating increased oil recovery, reduced water and gas production, and ultimately, improved economic performance.
- Verification of the model against industry-standard CFD tools confirms that the new method maintains high accuracy while it drastically reduces computational time by several orders of magnitude making it suitable for field-scale implementation.
- Simulation results show that including annulus phase segregation in modeling workflows can lead to materially different conclusions regarding the best ICT type to use, directly impacting production efficiency and project economics.
- The implementation of multiple valve models, including the RCP and trinary models, allows accurate simulation of a wide range of inflow control technologies, accommodating both viscosity- and density-sensitive devices.
- The modeling assumptions and methodology are supported by field observations and experimental data, reinforcing the reliability of the proposed approach.

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Nomenclature

SAS	Stand Alone Screen
ICD	Inflow Control Device
ICT	Inflow Control Technology
AICD	Autonomous Inflow Control Device
AICV	Autonomous Inflow Control Valve
p_{BH}	Bottomhole Pressure (bar)

GOC	Gas Oil Contact (m)
GOR	Gas Oil Ratio (fraction)
GVF	Gas Volume Fraction (of total fluid volume)
Kh	Permeability (horizontal direction) (darcy)
Kv	Permeability (vertical direction) (darcy)
PVT	Pressure Volume Temperature
p	Pressure (bar)
q	Flow rate (m3/d)
RCP	Rate Controlled Production (valve)
P_{WH}	Well Head Pressure (bar)
VFP	Vertical Flow Performance (pressure drop standardized table format)
WC	Water Cut
α(oil, water, gas)	Volume fraction of the free oil, water and gas phases at local conditions
a_{AICD}	ICT strength factor
x	Volumetric rate exponent
y	Mix viscosity exponent
z	Mix density exponent
a,b,c	Mix density tuning exponents
d,e,f	Mix viscosity tuning exponents
p_a	Pressure in annulus upstream valve
p_p	Pressure in base pipe downstream valve
α	Phase specific flowrate exponent
$\xi = \frac{1}{C_D 2}$	Phase specific pressure loss coefficient calculated from phase specific discharge coefficient
Cd	Discharge coefficient (dimensionless)
q^v	Volumetric flowrate through valve
A^v	Phase specific valve flow area

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