WellDesk

# WELLSTIM - NEXT-GEN ACIDIZING SIMULATOR

# PRODUCT RELEVANCE

Although more affordable than fracking, acidizing is an underrated operation due to complexity of chemical processes involved. WellDesk makes the acid simulation seamless by bringing more value to operators of ca +15% NPV. The common reasons for acid treatment failure that can be resolved by WellStim are:

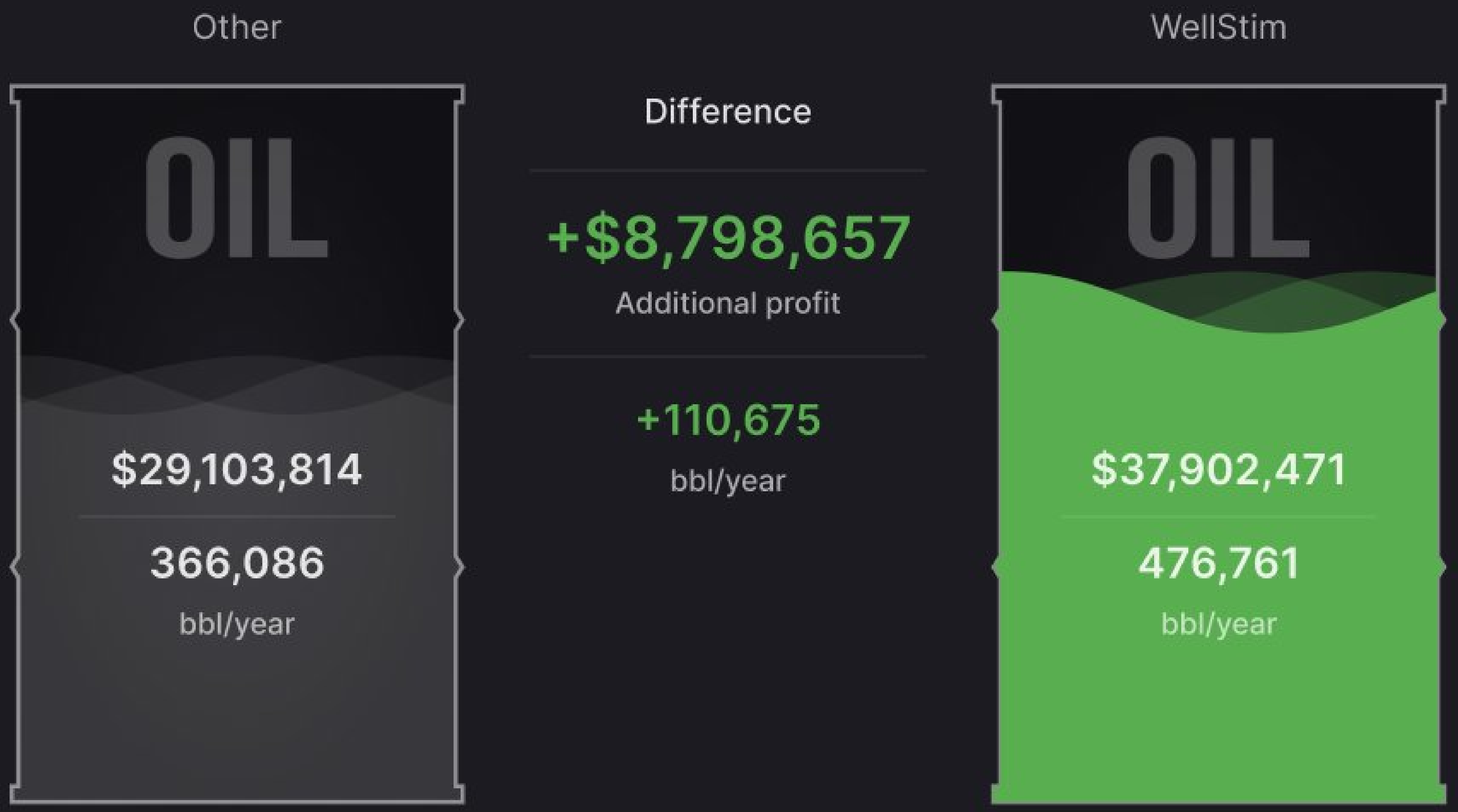
- Incorrect selection of reagents, their volumes, and injection rates
- Errors in determining forecast indicators of technological and economic effects
- Misinterpreted geophysical and hydrodynamic data
- Non-trivialness of flow diverters or deep-penetrating stimulation technologies
- Difficulty in predicting the risks of acid breakthrough into lower/ upper horizons
- Unintended hydraulic fracturing

# YOUR GAINS FROM USING OUR PRODUCT:

Increases the effect of acid stimulation by **23%** compared to competitor software.
Oil production rate soars due to more accurate modeling and optimization.

Example:

Number of wells - 100
Production before stimulation - 71 bbl/d
Stimulation effect duration - 180 days
Stimulation frequency - 2 per year
Production increase rate - 1.45
Oil price - $79.5



# COMPONENT MODULES

**01** Acid Stimulation Design

Calculates near-wellbore zone properties and the penetration depth of the injected fluids

**02** Advanced 2D Modeling

Creates a multiphase transient two-dimensional displacement flow model, recognizing heat and mass transfer

**03** Well Potential Evaluation and Planning

Performs retrospective analysis and determines the potential of the candidate well

**04** Acid Stimulation Optimization

Selects fluid types and volumes, optimal injection rates and pressure

**05** Test Injection Analysis

Analyzes test injections with a comprehensive set of tools (friction evaluation, Horner, SRT, etc.)

**06** Radial Drilling Modeling

Designs radial channels and their acidizing

**07** Formation Damage Modeling

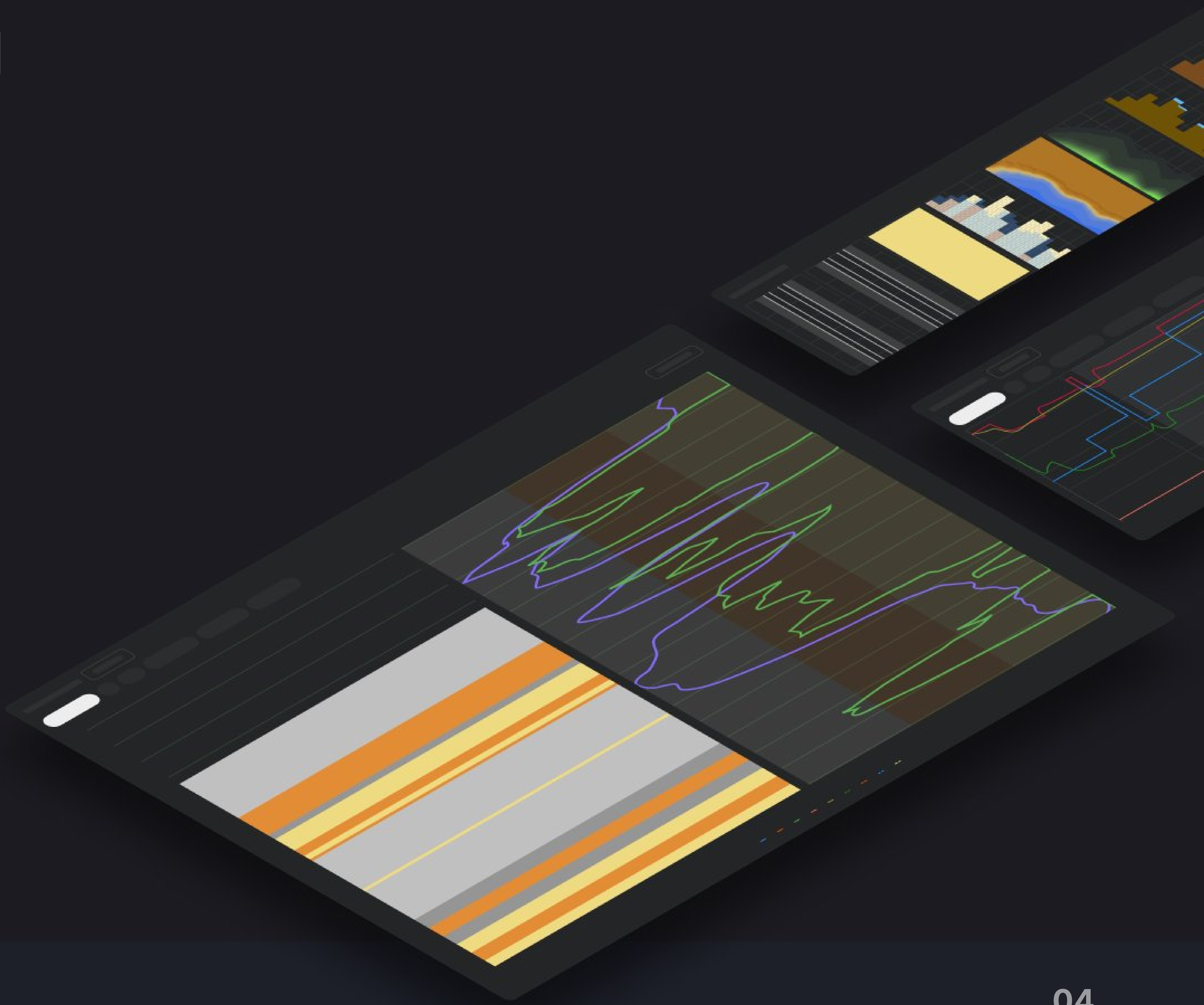
Predicts and calculates pore clogging in near-wellbore zones of injection and production wells

**08** Thermo-Gas-Chemical Stimulation & Foam Acid Modeling

Models the injection of foamed and binary compounds with exothermic reactions and thermobaric effects

# ACID STIMULATION DESIGN

- Constructs a geomechanical and petrophysical model of the reservoir
- Determines near-wellbore zone conditions using geophysical well logging, log interpretation and hydrodynamic well testing data
- Models multistage interval treatments, coiled tubing treatments, and run-in/run-out injections
- Selects optimal injection rates and volumes for matrix acidizing



# ADVANCED 2D MODELING

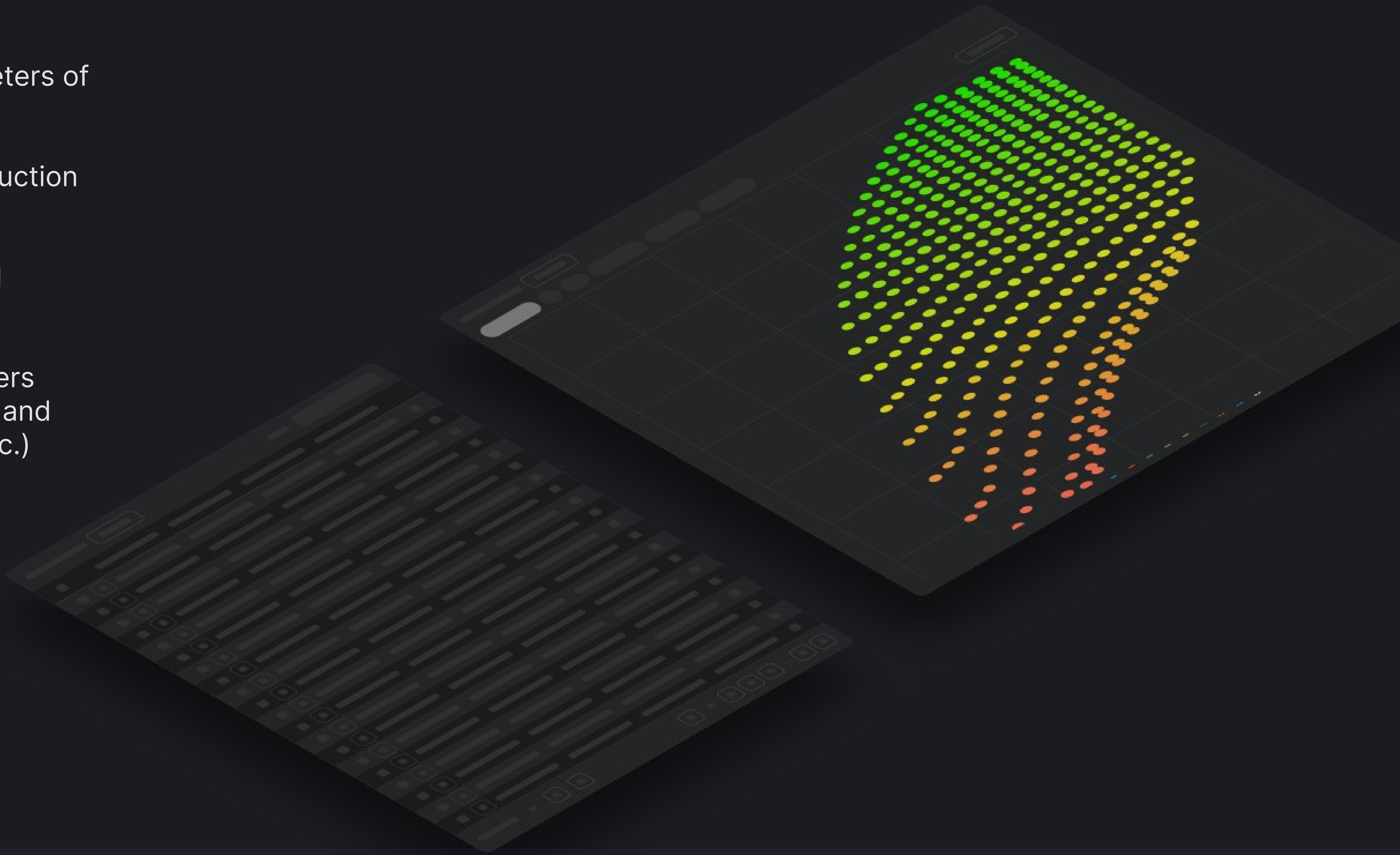
- Designs transient non-isothermal two-phase multi-component profile model of the reservoir
- 2D axisymmetric filtration of the injected fluids with varying rheological properties through the wellbore into a vertically and horizontally heterogeneous reservoir
- Includes gravitational effects
- Includes natural fracture opening by increasing effective permeability
- Includes dissolution of carbonate and terrigenous matrices

# WELL POTENTIAL PLANNING AND EVALUATION

- Determines technical potential of the well
- Selects candidate wells for stimulation treatments
- Assesses economic feasibility of treatments
- Analyzes retrospective data
- Considers effectiveness of previous treatments
- Determines treatment effectiveness
- Assesses near-wellbore zone conditions

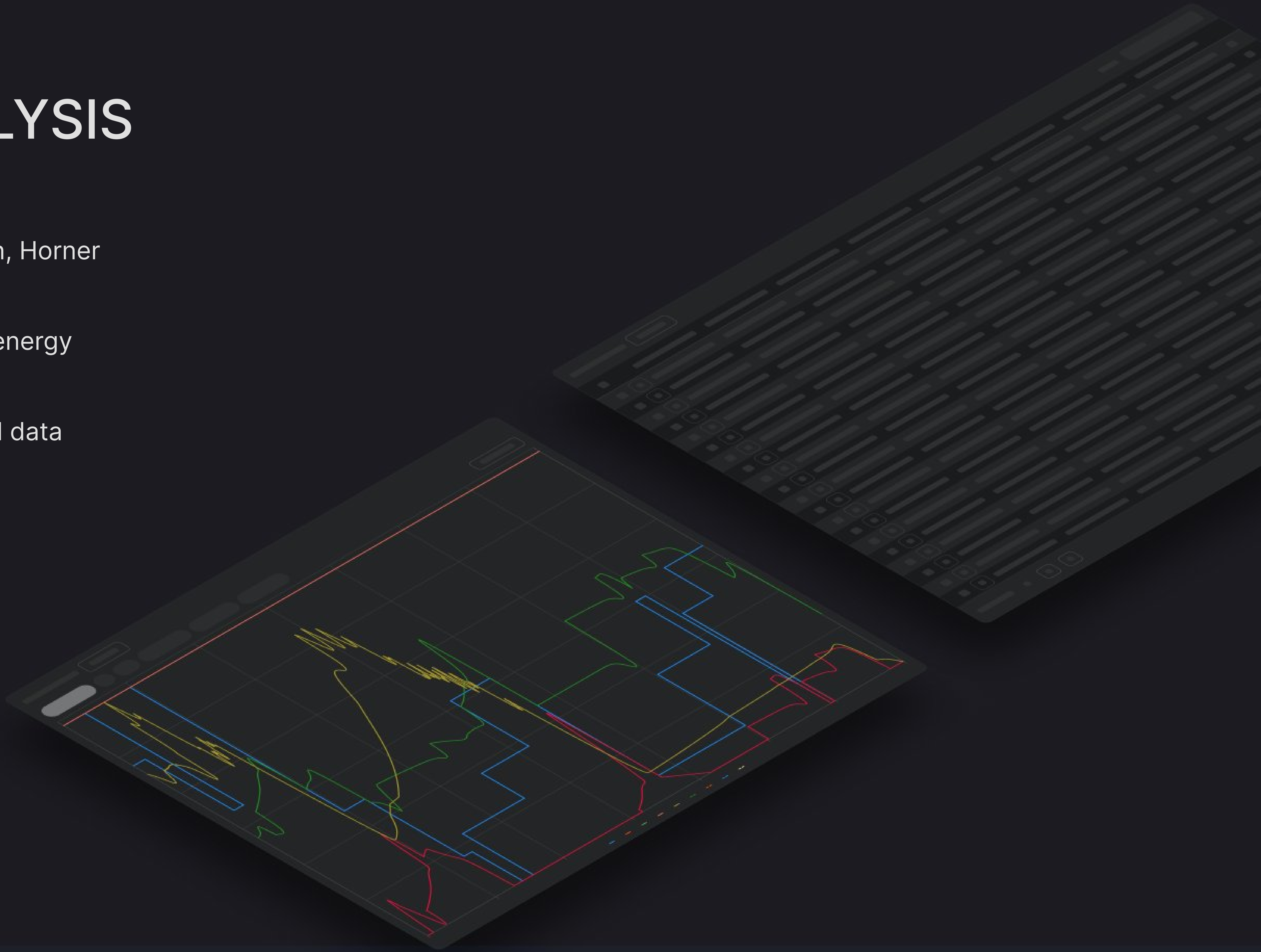
# ACID STIMULATION OPTIMIZATION

- Automatically searches for optimal parameters of the matrix acidizing design
- Lists target optimization parameters (production increase, skin factor, water cut, NPV, etc.)
- Uses advanced methods for solving global optimization problems
- Employs a wide range of variable parameters (injection scenario modes, acid properties and diverter types, model input parameters, etc.)



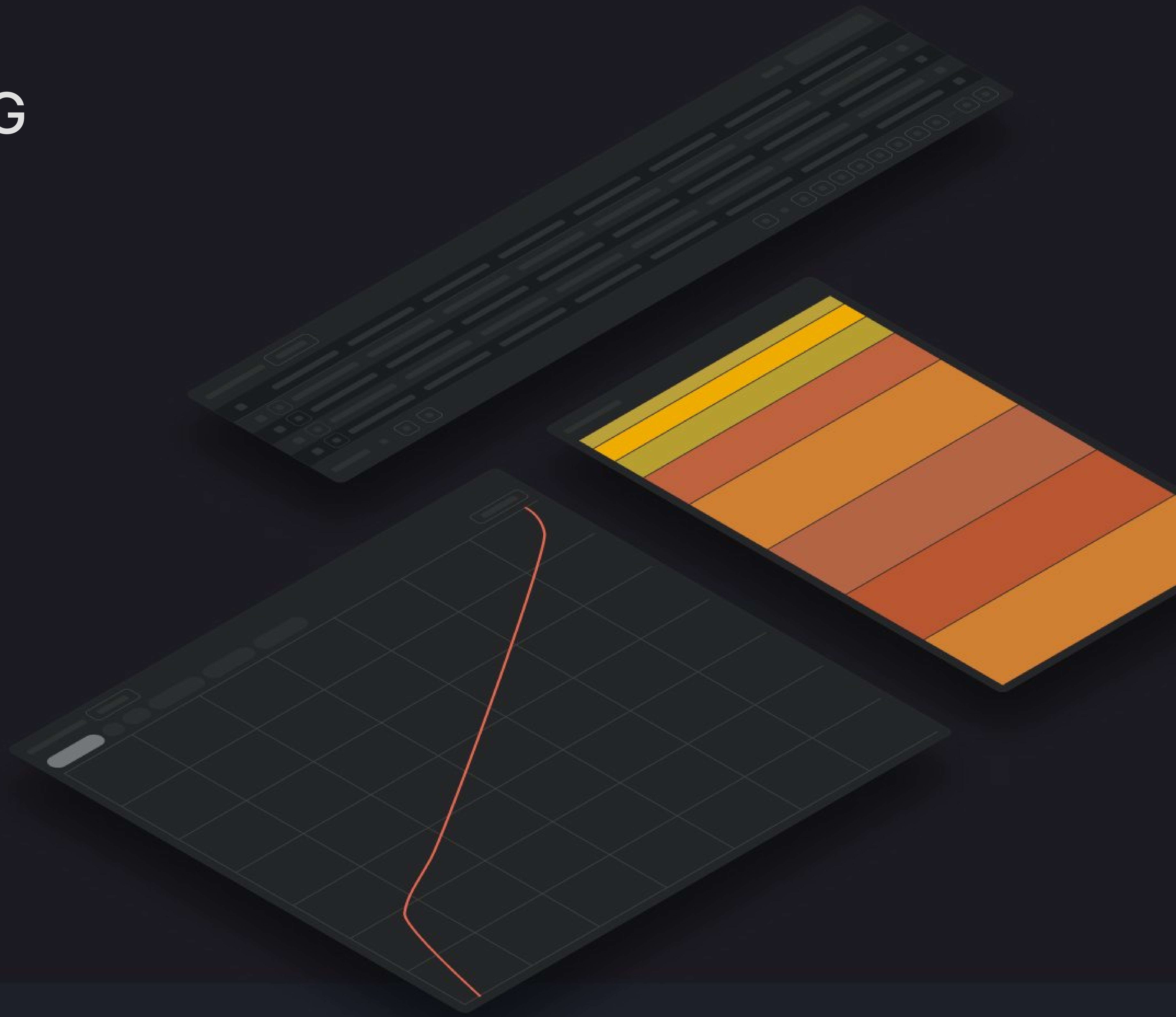
# TEST INJECTION ANALYSIS

- Analyzes test injections (friction evaluation, Horner plot, SRT, etc.)
- Refines filtration properties and reservoir energy status
- Matches completed operations with actual data
- Calibrates the design and the model



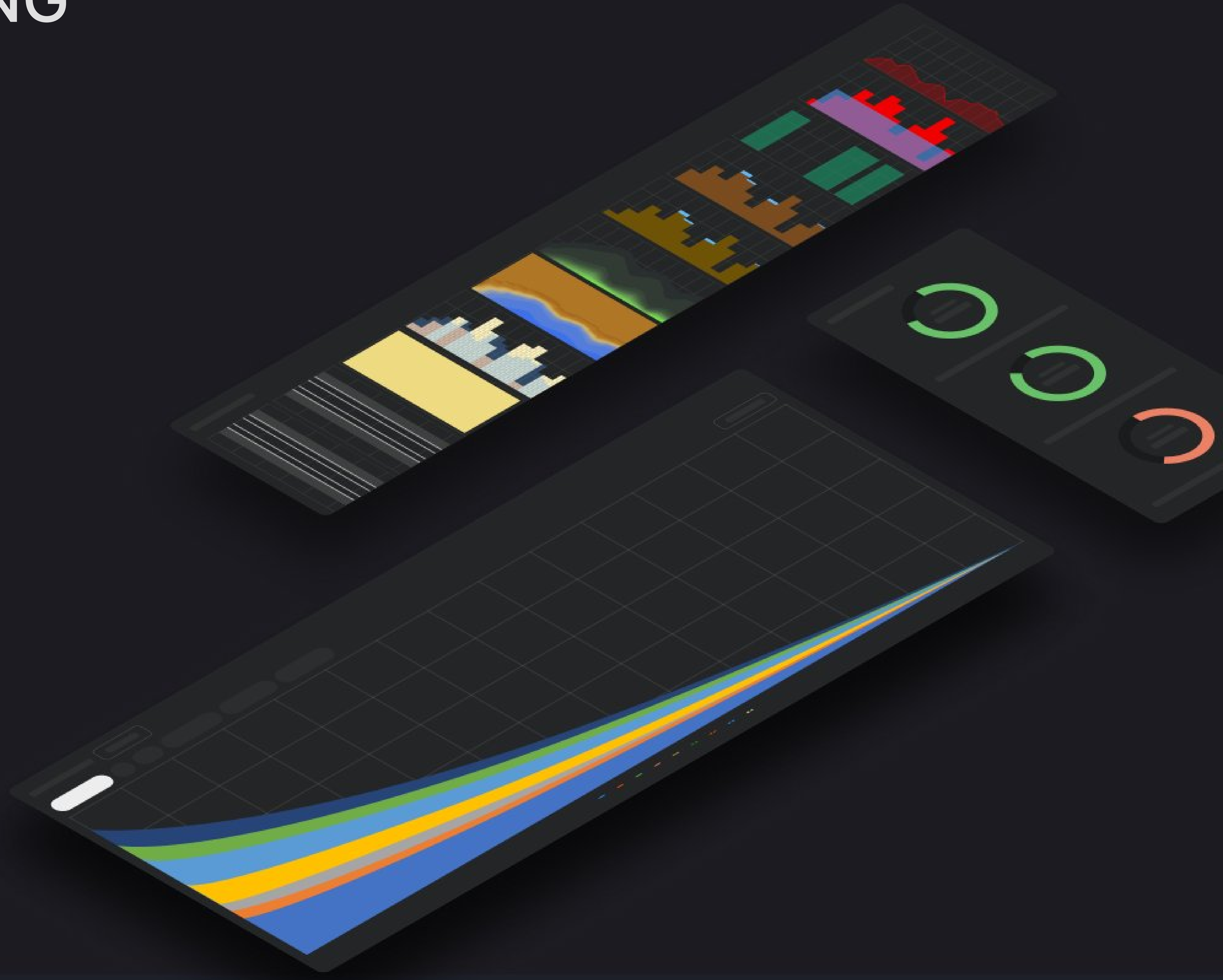
# RADIAL DRILLING MODELING

- Calculates optimal radial channel trajectory to achieve maximum productivity
- Calculates inflow profile along the radial channel
- Can load actual wellbore trajectory
- Models matrix acidizing for the radial channel, using actual or planned trajectory
- Can design multiple channels with(out) stimulation, and calculate total production rate



# FORMATION DAMAGE MODELING

- Forecasts formation of salt-based plugging agents and corrosion particles in the reservoir, based on the well operation data and information on the 6K composition of the injected water
- Calculates mass and distribution of various types of plugging agents in the reservoir
- Generates injection scenarios including the types and the volume of reagents  used for removing plugging agents



# THERMO-GAS-CHEMICAL STIMULATION & FOAM ACID MODELING

- Models the injection of foamed and binary systems with exothermic reactions and thermobaric effects
- Reflects the impact of temperature on viscosity change of formation fluids and injected compounds
- Models the increased acid reaction rate with carbonate rock
- Models thermal effects in the wellbore
- Forecasts temperature recovery at the well bottom during the reaction soak period
- Forecasts technical and economic efficiencies of the thermo-chemical stimulation

# CASES

CLIENT ONE

- Created detailed acid treatment designs: >1000
- Created template acid treatment designs: >500,000 (the whole well stock), 2500 best wells identified
- Average production rate increased by 12%
- The time spent on modeling decreased by 50%. Field and hydrodynamic research costs reduced by 30%
- High convergence of simulation results with actual data:
  >90% for oil production rate increase and >87% for skin

CLIENT TWO

- Validated new formation damage module in the acid treatment modeling of the injection well stock
- Created acid treatment designs for 15 wells
- High convergence of stimulation results with actual data:
  >90% for oil production rate increase

CLIENT THREE

- Validated simulator performance in low-temperature sites of complex wells (3 wells with dolomites)
- High convergence with actual data:
  >98% for oil production rate increase and >94% for skin

# COMPARISON WITH COMPETITORS

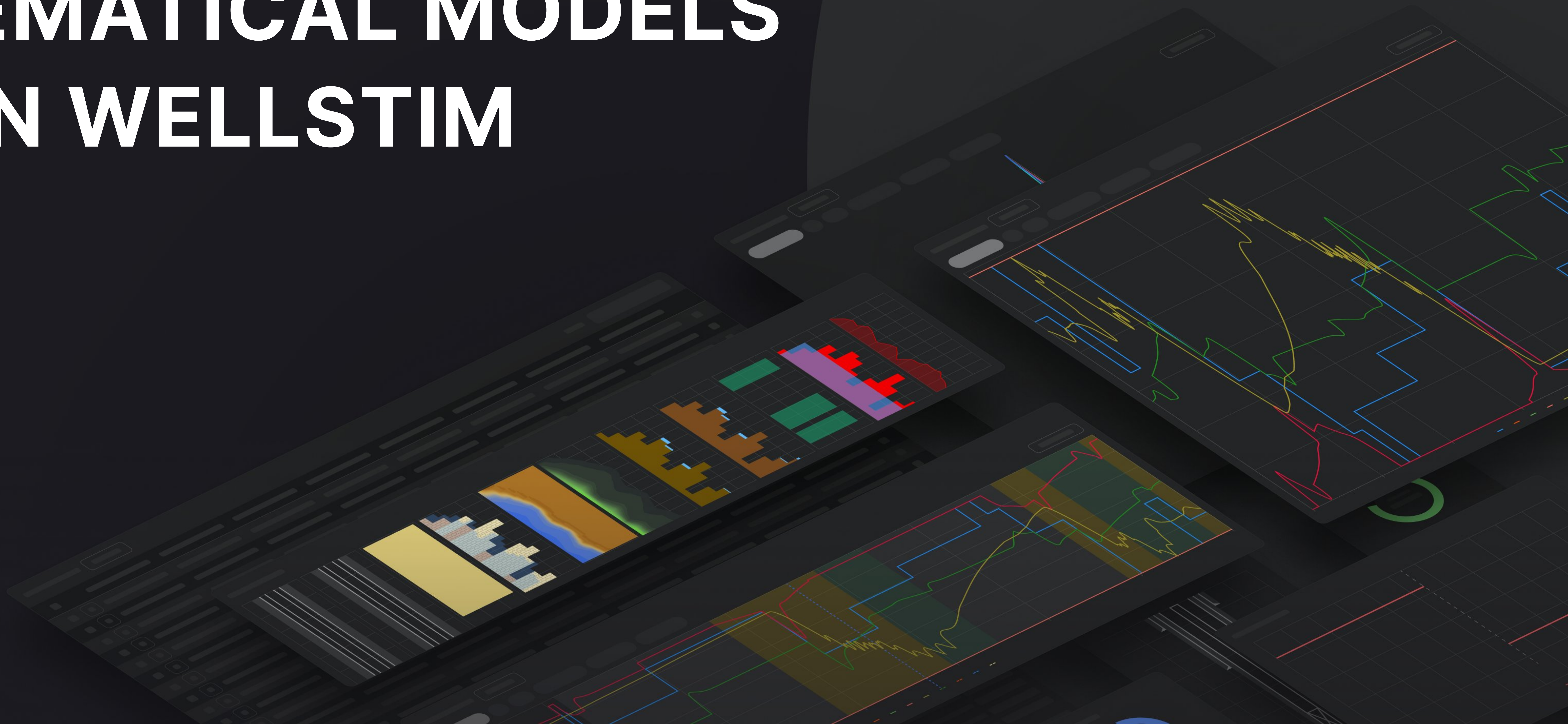
| Company | Schlumberger | CARBO | WellDesk |
|---|---|---|---|
| Product | Kinetix Matrix | StimPro | WellStim |
| Reservoir Filtration Model | | | |
| Piston-like pseudo-steady-state 1D displacement model | + | + | + |
| Multiphase transient 2D displacement model | - | - | + |
| Phase permeability in filtration processes | + | - | + |
| Non-Newtonian fluid rheology (power law) | + | + | + |
| Flow diversion in the reservoir (formation of “fingering”) | - | - | + |
| Vertical flows in the reservoir and cross-layer flows | - | - | + |
| Temperature effects in the reservoir | + | - | + |
| Natural fracture opening in the rock during injection | - | - | + |
| Gas well acidizing modeling | + | - | + |
| Injection well acidizing modeling | + | - | + |
| Adhesion/absorption of particulate and fiber-based diverters | + | - | In development |
| Rheology of self-diverting acid systems | + | - | + |
| Optimization | | | |
| Numerical optimization algorithm | - | - | + |
| Acidizing design based on expert systems | - | + | + |

| Company | Schlumberger | CARBO | WellDesk |
| --- | --- | --- | --- |
| Product | Kinetix Matrix | StimPro | WellStim |
| Well Model | | | |
| Horizontal well geometry | + | + | + |
| Multi-stage interval acidizing | + | - | + |
| Calculation of pressure losses in the wellbore and perforations due to friction | + | + | + |
| Injection modeling during coiled tubing deployment/retraction | + | + | + |
| Various injection modes (direct/reverse circulation, annular injection) | + | - | + |
| No-access treatment of the near-wellbore zone | + | - | + |
| Thermal effects in the wellbore | + | + | + |
| Rock Dissolution Model | | | |
| Numerical model for carbonate rock dissolution by HCl | + | - | + |
| Numerical model for terrigenous rock dissolution by HCl+HF | + | - | + |
| Wormhole formation in carbonate reservoirs | + | + | + |
| Particle suffusion and sedimentation during dissolution | + | - | + |
| Inorganic acids | + | - | + |
| Numerical model for dissolution of clogging agents (salts and mechanical impurities) | + | - | + |
| Numerical model for drilling mud crust dissolution in the wellbore | - | - | In development |
| Numerical modeling of asphaltene, resin, paraffin dissolution and removing oil from the surface | - | - | + |
| Well Productivity Analysis | | | |
| Analysis of productivity zones in layered heterogeneous reservoirs with(out) partial perforation | + | - | + |
| Integration of well test data | + | - | + |

| Company | Schlumberger | CARBO | WellDesk |
|---|---|---|---|
| Product | Kinetix Matrix | StimPro | WellStim |
| Retrospective Production Analysis | | | |
| Post-stimulation production dynamics, with decline rates | - | + | + |
| Skin factor dynamics | - | - | + |
| Economic analysis of well intervention outcomes | - | + | + |
| Forecasting pore clogging in near-wellbore zones | - | - | In development |
| Injection Test Analysis | | | |
| Reservoir pressure analysis | - | + | + |
| Natural fracture opening analysis | - | - | + |
| Prediction of absorption effects during stimulation | - | - | + |
| Data Management | | | |
| Automated data export from files of different formats | + | + | + |
| Lithotype identification based on logging data | + | + | + |
| 1D geomechanical model | - | + | + |
| Logging interpretation and calculation of petrophysical properties | + | - | In development |
| Stimulation matching based on actual wellhead/bottomhole sensor data | + | + | + |
| Real-time predictive modeling | - | + | + |
| Thermoacid foam stimulation and binary systems | + | - | + |
| Digital library of formulations and designs | + | + | + |
| Stimulation modeling with hydromonitor nozzles | - | - | In development |
| Horizontal wellbore tailpipe length calculation | - | - | In development |

WellDesk

# MATHEMATICAL MODELS USED IN WELLSTIM



# MODELS USED

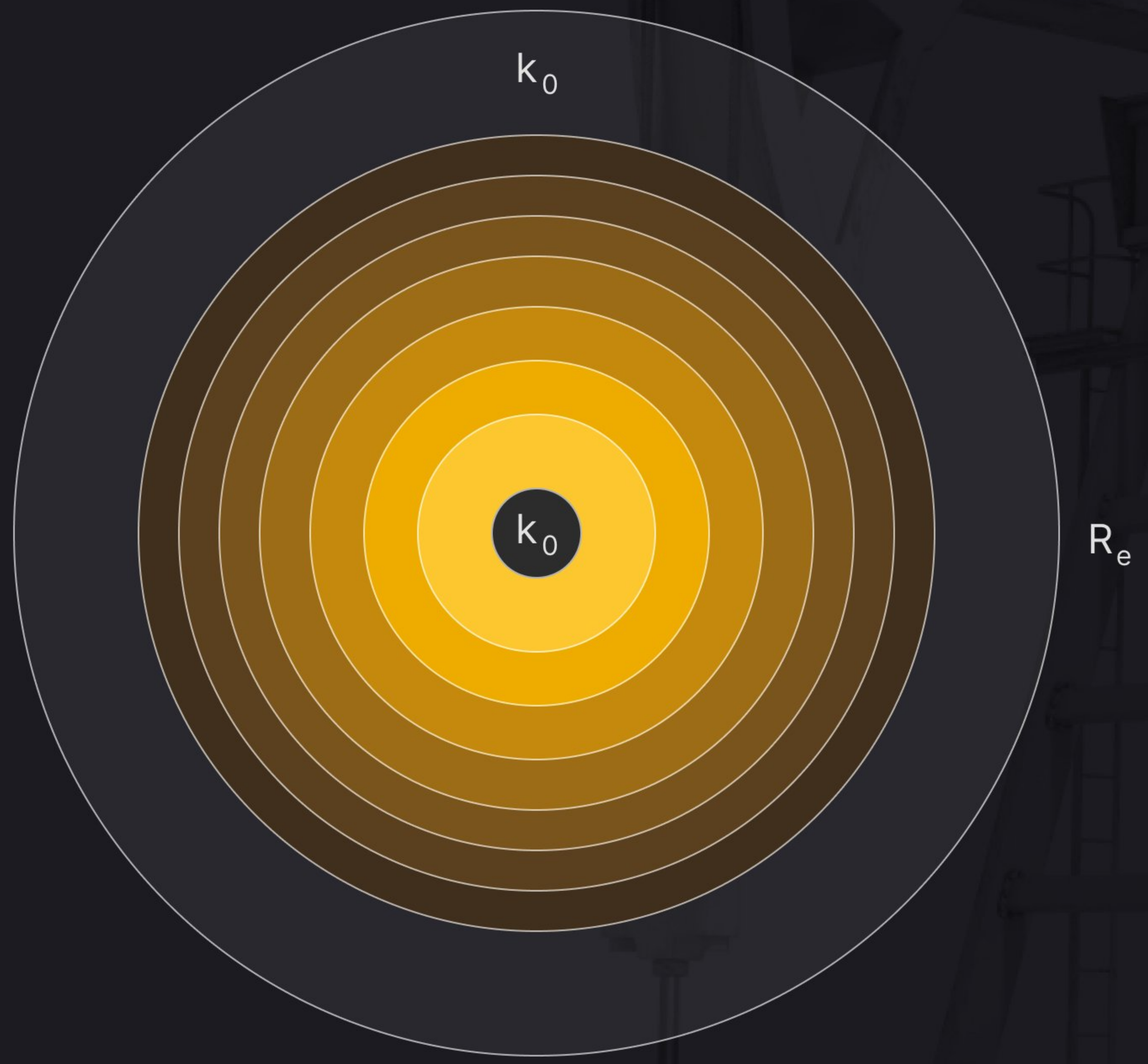
<table>
<tr><th>Model</th><th>Description</th></tr>
<tr><td>Well model</td><td><ul><li>Single-phase flow of power-law incompressible fluids in a wellbore column with various properties</li><li>Friction losses based on basic models or using specified friction loss tables</li><li>Various injection modes from the wellhead to the bottomhole: through tubing, through the annular space, direct and reverse circulation modes, injection via coiled tubing, injection with a linear increase/decrease in flow rate, movement of coiled tubing during injection</li><li>Influence of formation temperature changes and column construction (diameter, wall thickness) from the wellhead to the bottomhole</li><li>Various completion types: cased hole with perforations, open hole</li><li>Geometry and completion of the horizontal section: interval treatments with tubing movement</li></ul></td></tr>
<tr><td>Filtration model</td><td>Basic pseudostationary model:<ul><li>Pseudostationary isothermal one-phase one-dimensional filtration model for incompressible fluids in a non-deformable reservoir</li><li>Filtration of power-law fluids in a porous medium</li><li>Layered heterogeneous reservoir</li><li>Natural fracture opening by increasing effective permeability</li><li>Dissolution of carbonate and terrigenous matrices</li></ul>Profile Model:<ul><li>Nonstationary non-isothermal two-phase multicomponent reservoir profile model</li><li>2D axisymmetric filtration of injected fluids with various rheological properties through a wellbore into a vertically and horizontally heterogeneous reservoir</li><li>Gravity effects</li><li>Natural fracture opening by increasing effective permeability</li></ul></td></tr>
<tr><td>Acid dissolution model</td><td><ul><li>Acid wormhole formation using semi-empirical models with the possibility of adaptation to the operational object</li><li>Acid dissolution of the carbonate matrix and the release of thermal energy due to the reaction</li><li>Residual concentration during the reaction soaking process</li></ul></td></tr>
</table>

# SKIN AND ROCK DISSOLUTION

The skin is determined by calculating the integral over the radius from the wellbore, taking into account the irregular distribution of increased matrix permeability for each layer *j* of the reservoir:

$$S(j) = \int_{r_w}^{r_e} \frac{K_0(r)}{K_s(r)} \cdot \frac{dr}{r} + \ln\left(\frac{r_w}{r_e}\right)$$

- $r$ – integration variable over the radius
- where $r_w$ – wellbore radius at the outer diameter of the casing
- where $r_e$ – drainage radius of the well
- $K_o$ – initial permeability, mD
- $K_s$ – altered permeability, mD
- $j$ – reservoir layer index



# SKIN AND WORMHOLE FORMATION

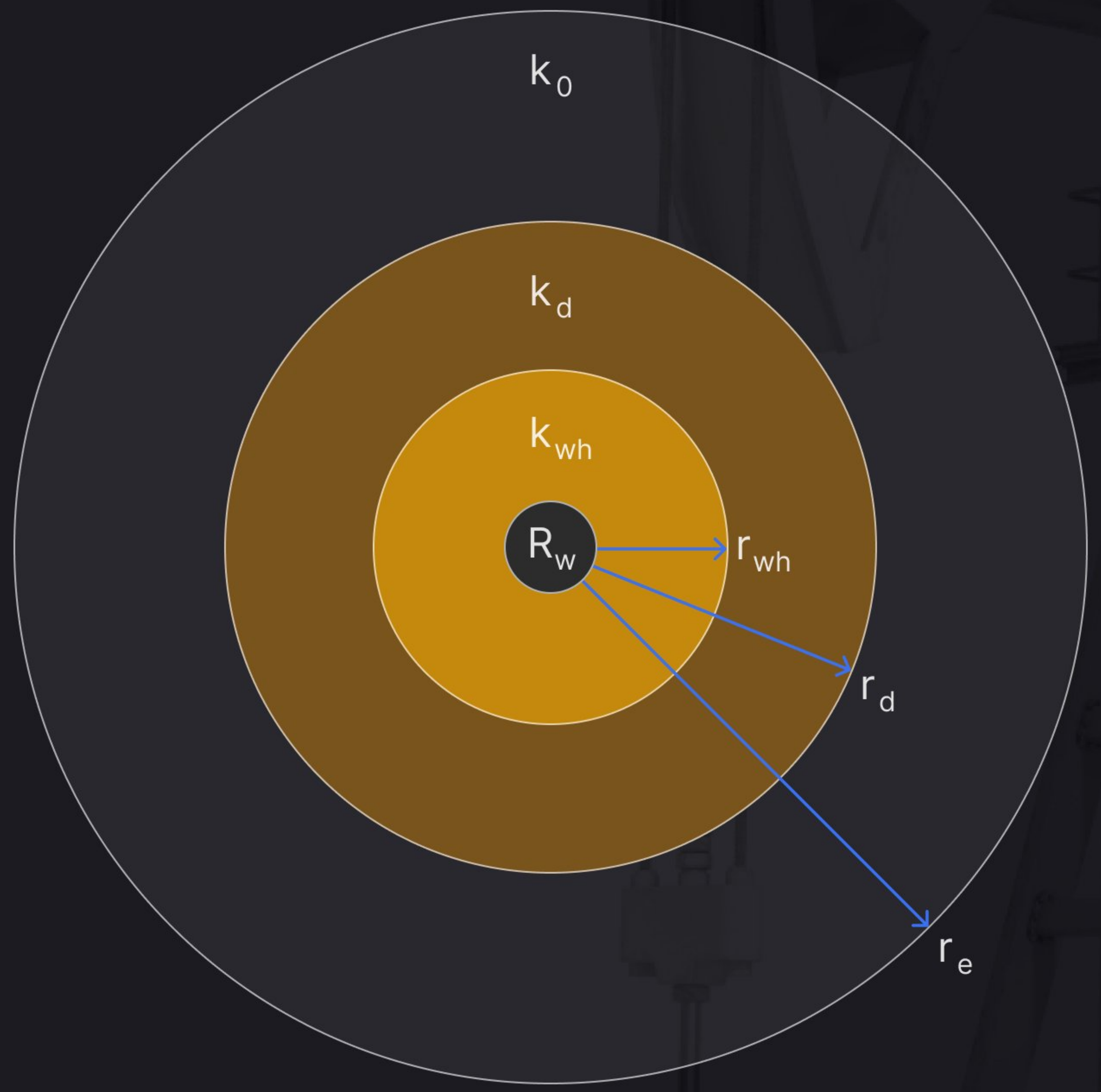
Taking into account the presence of a wormhole propagation zone with a radius $r_{wh}$ and increased permeability $K_{wh}$ in this zone, the wellbore skin factor is determined by the following expression for each reservoir layer $j$:

$$S(j) = ln\left(\frac{r_e}{r_d}\right) + \frac{k_0}{k_d} ln\left(\frac{r_d}{r_{wh}}\right) + \frac{k_0}{k_{wh}} ln\left(\frac{r_{wh}}{r_w}\right) - ln\left(\frac{r_e}{r_w}\right)$$

Taking into account the calculated penetration radius of dissolution channels and the known values of the skin factor and formation damage radius before treatment:

$$S(j) = \ln\frac{r_{wh}}{r_w}\left(\frac{k_0}{k_{wh}} - 1\right) + S_0 \frac{\ln\frac{r_d}{r_{wh}}}{\ln\frac{r_d}{r_w}}$$

- where $r_d$ – formation damage radius
- $r_{wh}$ – stimulation radius
- $K_{wh}$ – enhanced permeability of the stimulation zone, mD
- $j$ – reservoir layer index



# FILTRATION MODEL

**01** Filtration process involves:

- Water phase—acid, salt, and water components
- Oil and gas phases—gas is completely dissolved in water

**02** A separate phase:

- Rock containing the reagent and porous medium

**03** Objective of the acid stimulation:

- Two-phase, multicomponent, non-isothermal filtration of incompressible fluids, with heat release during chemical reactions

**04** Key equations:

- Reaction kinetics equation for dissolution
- Mass conservation equations for acid, oil, and the water phase (containing water and acid)
- Mass conservation equation for the rock skeleton to account for dissolution-caused changes in porosity

**05** Initial and boundary conditions are set to match reservoir conditions

**06** Partial differential equations

are solved numerically using the control volume method, upwind scheme is applied for discretizing the equations

**06** Bottomhole pressure calculation

is performed iteratively until total injection rate convergence is achieved

Continuity equations for the water and oil phases:

$$\frac{\partial}{\partial t}(m\rho_w S_w) = -\frac{1}{r}\frac{\partial}{\partial r}(ru_w\rho_w) - \frac{\partial}{\partial z}(v_w\rho_w) + \chi_r J_a$$

$$\frac{\partial}{\partial t}(m\rho_o S_o) = -\frac{1}{r}\frac{\partial}{\partial r}(ru_o\rho_o) - \frac{\partial}{\partial z}(v_o\rho_o)$$

For the acid component in the water phase:

$$\frac{\partial}{\partial t}(m\rho_w S_w C) = -\frac{1}{r}\frac{\partial}{\partial r}(ru_w\rho_w C) - \frac{\partial}{\partial z}(v_w\rho_w C) - J_a$$

For the salt-water component in the water phase:

$$\frac{\partial}{\partial t}(m\rho_w S_w[1-C]) = -\frac{1}{r}\frac{\partial}{\partial r}(ru_w\rho_w[1-C]) - \frac{\partial}{\partial z}(v_w\rho_w[1-C]) + \chi_s J_a$$

A source term characterizing the mass of acid consumed per unit of time per unit of volume:

$$J_a = (1-m)\rho_w\gamma C,$$ γ – chemical reaction constant [1/c]

# ACID DISSOLUTION MODEL

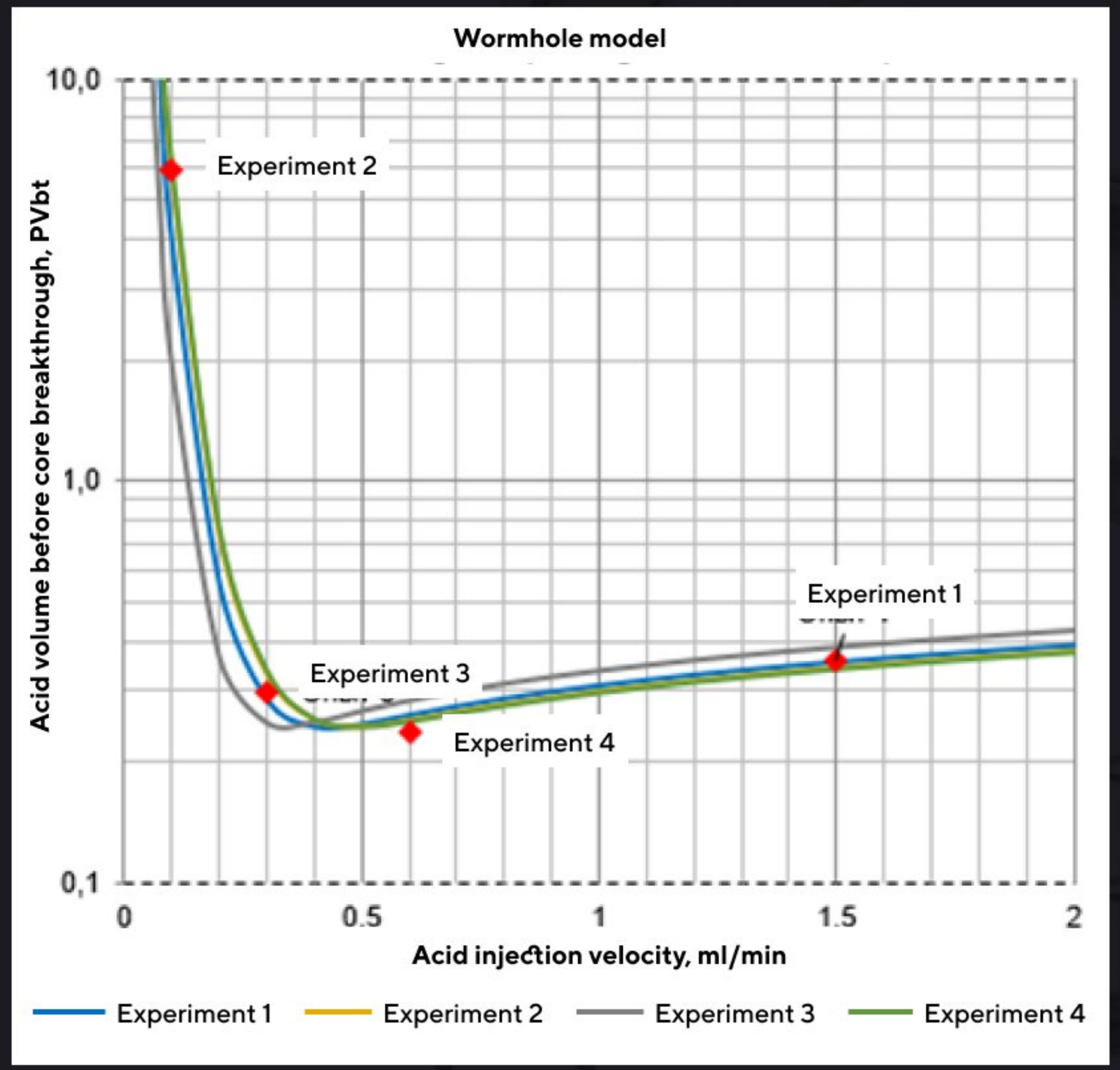
Gong, M: $$PV_{bt} = f_1 \frac{N_{da}}{N_{pe}}^2 + f_2 \frac{N_{pe}}{N_{ac}}^{1/3}$$

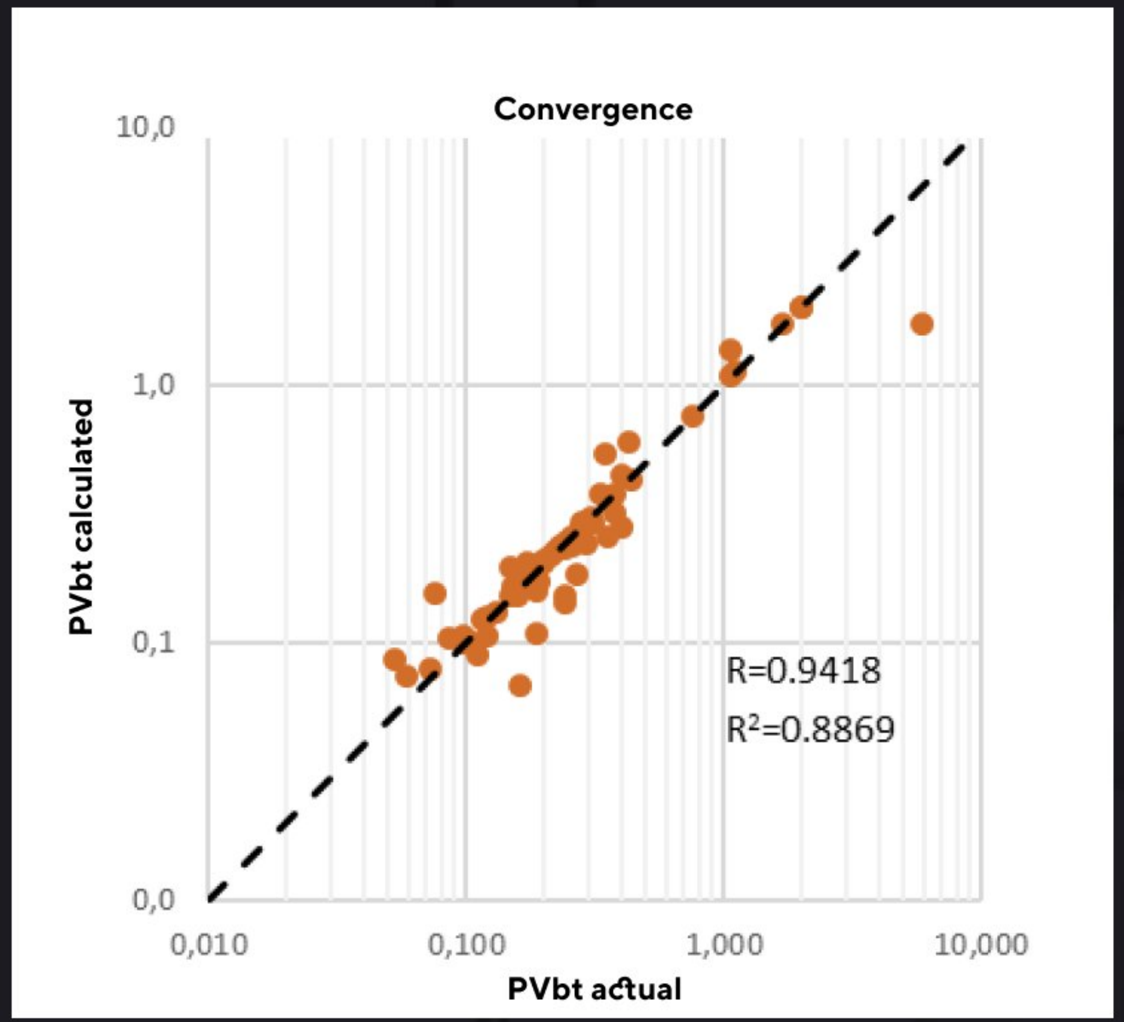
Schwalbert, M.P.: $$PV_{bt} = \frac{Q \cdot PV_{bt-opt}}{\pi r_к^2 \varphi \cdot V_{i-opt}^{1/3} \cdot \left(\frac{Q}{\pi r_к^2 \varphi}\right)^{2/3} \cdot (1 - \exp(-\frac{4}{V_{i-opt}^2} \cdot \left(\frac{Q}{\pi r_к^2 \varphi}\right)^2))^2}$$

Advantages:

- Flexibility in calibrating the model for different types of reservoirs based on laboratory core tests
- Ability to determine the optimal acid injection rate
- No need to estimate wormhole density or to provide a microscopic description of the rock structure

More than 70 filtration experiments have been conducted on standard core rock samples to adapt the models





1. Gong, M., El-Rabaa. A.M. Quantitative Model of Wormholing Process in Carbonate Acidizing // SPE 52165. 1999. DOI:10.2118/52165-MS
2. Schwalbert, M.P. et al. Anisotropic-Wormhole-Network Generation in Carbonate Acidizing and Wormhole-Model Analysis Through Averaged-Continuum Simulations // October 2018. SPE Production & Operations 34(01). DOI:10.2118/185788-PA.

# A REVIEW OF DIFFERENT ACID DISSOLUTION MODELS

| Model Category (Approach) | Authors | dL/dt | Calculation of optimal Q | Non-Newtonian fluids | Non-Newtonian fluids | | | Calculation speed | Limitations |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Diffusion | Convection | Dissolution velocity | | |
| Based on the Péclet number | Daccord, G. et al. (1989) | + | + | + | + | + | + | + | Describes only the convection-limited dissolution mode. |
| | Frick, T.P.(1994) | + | + | + | + | + | + | + | Wormholes are modeled as fractals. The injection rate does not affect the dissolution pattern |
| Based on the transition pore size | Wang, Y. et al. (1993) | + | + | + | + | + | + | + | A microscopic description of the pores is required and cannot be scaled up to the wellbore scale. Only the convection-limited dissolution regime applies. |
| Based on the capillary tube | Wang, Y. et al. (1993), Hung, K.M. et al. (1989) | + | + | + | + | + | + | + | A microscopic description of the pores is required and cannot be scaled up to the wellbore scale. Only the convection-limited dissolution regime applies. |
| | Buijse, M. (1997) | + | + | + | + | + | + | + | It is not possible to predict the treatment efficiency (skin factor). |
| | Gdanski, R.D. (1999) | + | + | + | + | + | + | + | Applicable only within the range of optimal flow rates for the convection-limited dissolution regime. |
| Based on the Damköhler number | Wang, Y. et al. (1993), Hung, K.M. et al. (1989) | + | + | + | + | + | + | + | It is not possible to predict the treatment efficiency (skin factor). |
| | Buijse, M. (1997) | + | + | + | + | + | + | + | It is not possible to predict the treatment efficiency (skin factor). Applicable only to the mass transfer-limited dissolution regime. |
| | Gdanski, R.D. (1999) | + | + | + | + | + | + | + | It is necessary to know the wormhole density. The model does not account for acid leakage, which leads to an overestimation of the treatment depth. |
| Grid-based (2D, 3D) | Hoefner, J., Fogler, H. (1988) | + | + | + | + | + | + | + | Challenges in scaling the model to the wellbore level include the need for a large volume of high-quality input data and enormous computational resources. |
| | Fredd, C.N. & Fogler, H.S. (1999) | + | + | + | + | + | + | + | |

# A REVIEW OF DIFFERENT ACID DISSOLUTION MODELS

| Model Category (Approach) | Authors | dL/dt | Calculation of optimal Q | Non-Newtonian fluids | Non-Newtonian fluids | | | Calculation speed | Limitations |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Diffusion | Convect ion | Dissolution velocity | | |
| Numerical two-scale stochastic | Various authors (1997-2020) | + | + | + | + | + | + | + | Primarily applicable for modeling dissolution in core samples. Require a very large amount of computational power and assume a uniform random distribution of porosity/permeability. |
| Numerical coarse-grained continuous | Various authors (1997-2020) | + | + | + | + | + | + | + | Require a moderate amount of input data and computational power. |
| Semi-empirical | Gong, M. & El-Raaba, A.M. (2005) | + | + | + | + | + | + | + | Challenges in scaling the model to the wellbore level include the need for a large number of filtration experiments. It is also necessary to know the wormhole density. |
| | Buijse, M. & Glasbergen,G. (2005) | + | + | + | + | + | + | + | |
| | Furui, K. et al. (2012) | + | + | + | + | + | + | + | An extended version of Buijse (2005), combined with Heng (1989) capillary tube model. The limitations are similar to those of the Buijse model. |
| | Dong, K. et al. (2017) | + | + | + | + | + | + | + | An improvement of the Faray model with a correction for changes in reservoir temperature. The limitations are similar to those of the Buijse model. |
| | Schwalbert M.P. et al. (2019) | + | + | + | + | + | + | + | An improvement of the Faray model with a correction for the effect of core diameter. The limitations are similar to those of the Buijse model. |

- For application in an industrial simulator, it is advisable to use numerically averaged-continuous models of the acid dissolution process that eliminate the need to input data on non-random or artificially distributed medium heterogeneity, while also enabling calculations at a moderate speed
- To account for effects related to the formation of acid wormholes, it is advisable to use existing semi-empirical models that can be adapted through a series of filtration studies


1D filtration model used by all our competitors, run in WellStim
Download report
Charts
Results table
Economics
0 s
1 h 1 m 12 s
2 h 2 m 24 s
3 h 3 m 36 s
5 h 6 m
Measures by time dynamics
Save
Settings
1. Acid 1: TATOL
2. Diverter (invert emulsion 2)
3. Acid 1: TATOL
4. Diverter (invert emulsion 2)
5. Acid 1: TATOL
6. Diverter (invert emulsion 2)
7. Acid 1: TATOL
8. Diverter (invert emulsion 2)
9. Acid 1: TATOL
10. Water
Rate, m³/min
Pressure, atm
Skin
Time, min
Trajectory
Tablet
Add column
Templates
Save
TVD
MD
Gis permeability
Porosity
Rw mm
Lateral Extend m
Increased porosity [of unit]
Sediment concentration [%]
Oil rate before
Oil rate after
Skin factor after
Rwh
Dolomite
Limestone


2D filtration model applied to the same acidizing design
Download report
Charts
Results table
Economics
0 s
1 h 1 m 12 s
2 h 2 m 24 s
3 h 3 m 36 s
5 h 6 m
Measures by time dynamics
Save
Settings
1. Acid 1: TATOL
2. Diverter (invert emulsion 2)
3. Acid 1: TATOL
4. Diverter (invert emulsion 2)
5. Acid 1: TATOL
6. Diverter (invert emulsion 2)
7. Acid 1: TATOL
8. Diverter (invert emulsion 2)
9. Acid 1: TATOL
10. Water
Rate, m³/min
Pressure, atm
Skin
Time, min
Trajectory
Tablet
Add column
Templates
Save
TVD
MD
Gis permeability
Porosity
Rw mm
Lateral Extend m
Increased porosity [of unit]
Sediment concentration [%]
Oil rate before
Oil rate after
Skin factor after
Rwh
Dolomite
Limestone

WellDesk

# Share your thoughts with us!

info@welldesk.io