RFD
Rock Flow Dynamics

tNavigator™

Parallel Reservoir Dynamics for Geological Scale

The industry first integrated modeling and data analysis framework centered on dynamic reservoir simulations combining interactive 3D graphics and supercomputer parallel performance with no extra per core charge.

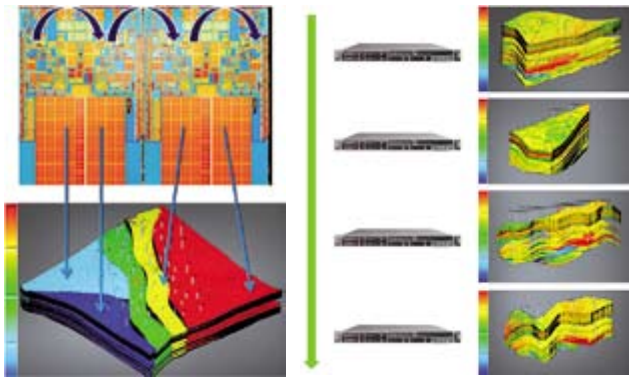
Parallel Reservoir Dynamics for Geological Scale

Maximize your reservoir simulation performance for free!

tNavigator is the industry leading parallel dynamic reservoir simulator that efficiently utilizes all available computational resources.

Based on the recent hardware developments, tNavigator provides tenfold boost to reservoir simulation performance. Smart balancing of the computational resources of multi-CPU multicore systems allowed breaking through the existing industry standard acceleration limits, and reaching almost an order of the magnitude improvement in cluster performance.

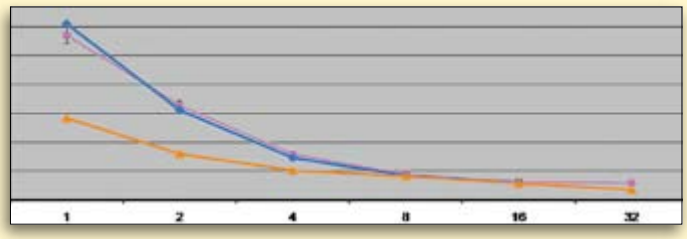
- MPI algorithms for clusters,
- System thread parallelization for multicore workstations,
- Hybrid technology for multicore CPU clusters,
- Efficient memory utilization,
- Uniform load distribution between the cores,
- Non-uniform memory access,
- All elements of the simulator are parallel



No additional fee for multicore computations. tNavigator software uses power of all the available CPU cores of the workstation. We do not tax your hardware!

Conventional MPI Solutions (Boost Up to 10–12)

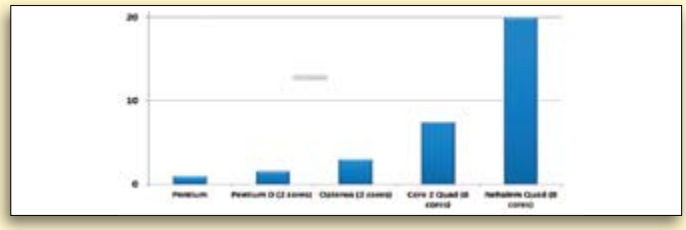
The performance of the industry standard cluster solutions cannot scale beyond 20 CPUs. The performance is affected by the limited cluster network I/O throughput.



Current industry best MPI parallel scalability

Shared Memory Thread Based Parallelization (Boost Up to 20)

Direct thread based parallel algorithms is most efficient approach for workstations with multicore CPUs. With minimal computation costs for data exchange between the cores, this technology takes full advantage of CPU evolution.

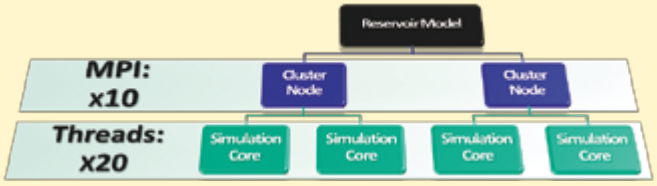


The performance evolution for Intel CPU based desktops

Hybrid Technologies for Multicore CPU Clusters

The main idea of the hybrid algorithm is to adopt two-stage parallel algorithm. The MPI algorithm handles parallel synchronization between the cluster nodes, while the threading technology is applied within each node to coordinate parallel calculations for CPUs and the cores.

If the dynamic reservoir model is large enough, and the load distribution is handled properly, the acceleration factor for a multicore CPU cluster can reach 300.

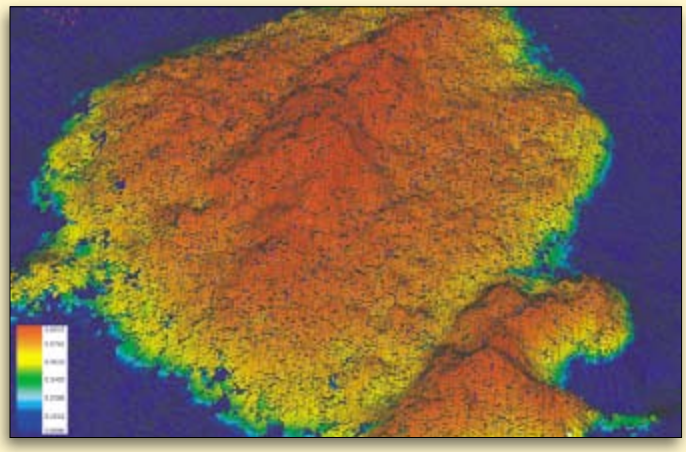


= x300!

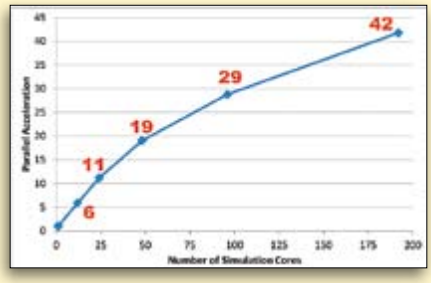
This kind of approach provides the best performance for distributed memory computational HPC systems based on modern multicore CPUs.

Results

The algorithm performance was studied on the RFD cluster with 20 nodes, 40 CPUs Xeon 5650, 240 cores, 480 Gb DDR3 1333MHz RAM, QDR 4x Infiniband (40 Gb/s). This is a portable cluster which can be placed in a small server room.



The three phase black-oil model for one of the world's largest oil fields is used for **tNavigator Hybrid** performance tests. It contains about 5 million active blocks, nearly 13 000 wells, and covers 40 years of production history.



The huge number of well perforations used in this reservoir model presents a very big challenge for parallel simulations. But even in this extreme environment, the hybrid algorithm shows excellent scaling results, and exhibits continuous growth of efficiency with additional computational cores. From the figure above, there is no evidence that the scalability limit is reached, and thus more computational resources can be easily added to the cluster. The total simulation time for this model was **1 hour and 22 minutes** compared to **57 hours** with one CPU core demonstrating **parallel acceleration factor of 42!** The acceleration factors for the less complex dynamic reservoir models are found in the range of **50–55**.

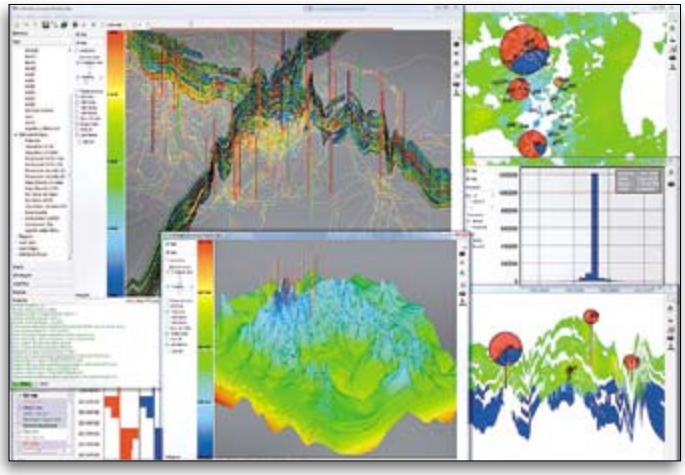
- **The current levels of scalability in the industry are mostly limited by the software, not hardware.**
- **The hybrid algorithm with SMP+MPI yields up to 10 times boost to HPC cluster performance.**
- **The best performance is achieved when the cluster nodes have multiple multicore CPUs.**

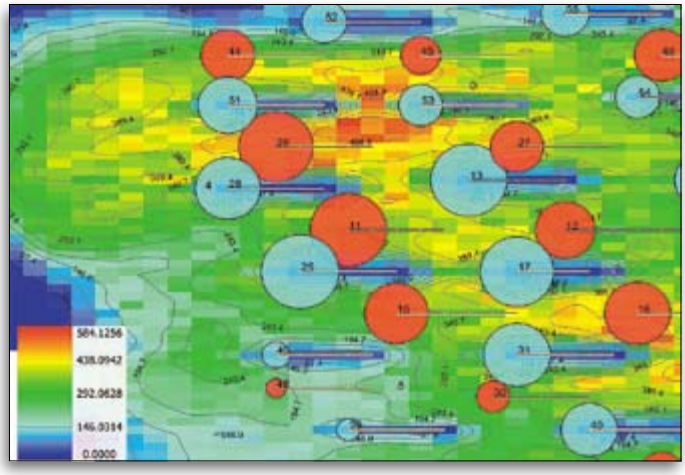
INTERACTIVE RESERVOIR SIMULATION TOOLS

tNavigator offers reservoir monitoring engineers and geologists unique runtime monitoring of the simulation runs, advanced field development planning and waterflood optimization functionality interactively with a 3D graphical user interface:

- **Run dynamic reservoir simulations 3–10 times faster with modern multicore computers.**
- **No painful data migration, since tNavigator directly loads and exports industry standard ASCII and binary formats.**
- **Easily handles small sector and large (1–20 million active grid blocks) full-field models with minimum or no upscaling.**
- **Run full finite difference simulations, perform 3D streamline-based waterflood analysis in the same interface for free, and no additional software to buy.**
- **Create and run forecast models instantly from any time step, right after the history matching is completed.**
- **Novel hydraulic fracture simulations for full-field models applied for generic, shale gas, and oil reservoirs.**
- **Efficient sidetrack optimization modeling.**
- **Split and merge dynamic reservoir model grids with no additional geological packages needed.**
- **Visualize dynamic well production and injection profiles perforation by perforation, at the runtime.**
- **Switch wells from production to injection, add new wells and well patterns, plan new horizontal well trajectories interactively with few mouse clicks.**
- **Include simulations of near well bore treatments into full-field modeling.**
- **Comprehensively benchmarked against industry standard packages, corporately used by international oil and gas majors.**

Multiple field development scenarios can be configured interactively with User Interface and run in series.





Runtime 3D Visualization Package

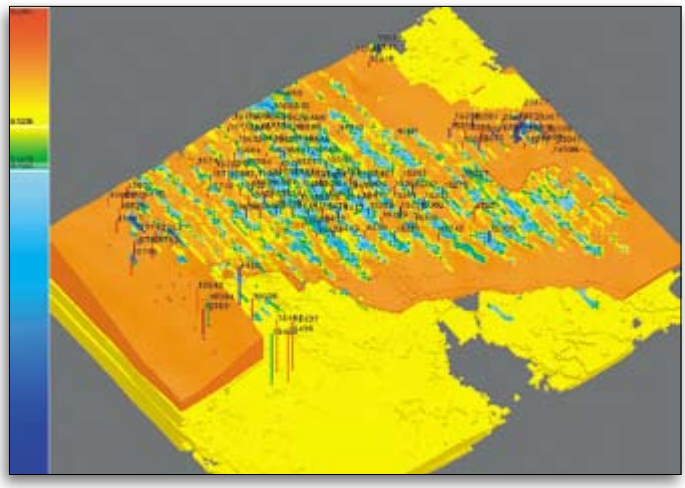
- Preprocessing, run monitoring, and the simulation result post processing is done using a single multi-window graphical interface working under Windows and Linux.
- Start, pause, re-start simulation runs and configure multiple forecast models with few mouse clicks.
- Every static and dynamic reservoir property in the model can be viewed as 2D, 3D maps, histograms, and user defined vertical profiles.
- Multifunctional 2D bubble maps to display well production and injection instant and accumulated rates.
- Runtime graphs of rates and property changes with time for each model grid block, for each well perforation.
- Dynamic contour lines of any 2D property map.
- Dynamic well production and injection profiles can be visualized at the perforation level at runtime.
- Waterflood optimization tools: 3D and 2D streamlines are calculated on each time step from the current pressure distribution, drainage matrix and injection efficiency graphs, user arithmetic, etc.
- Advanced comparison tables and graphs for efficient history matching.
- Advanced user map calculator.
- Click of the button comparison of multiple simulations results.

The package allows interactive adjusting of the dynamic model in the GUI with immediate visualization on maps and plots. All visualization features are available during the run for results monitoring. **tNavigator** offers various options for results interpretation, e.g. tables, graphs, bubble maps, contours, 1D and 2D histograms, well profiles, and various reports. The GUI provides an unlimited number of windows with different types of data synchronized for detailed results monitoring.

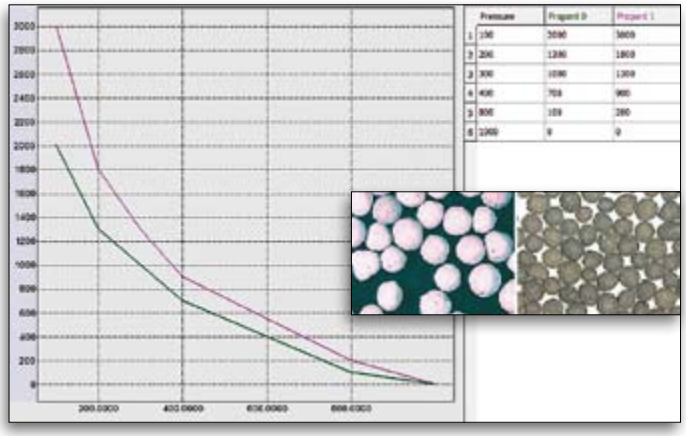
Hydraulic Fracture Modeling

tNavigator introduces a new approach to hydraulic fracture simulation. The fracture is considered as part of the well. To simulate fractures, a network of new "virtual" perforations is generated in the grid blocks intersected by the assumed fracture surfaces. The fracture efficiency is modeled through the individual virtual perforation efficiencies and proppant properties.

This approach provides the most realistic calculation of fluid inflow to the well. This new technology was successfully tested on large full-field models of giant Western Siberia reservoirs with a large number of hydraulic fractures.

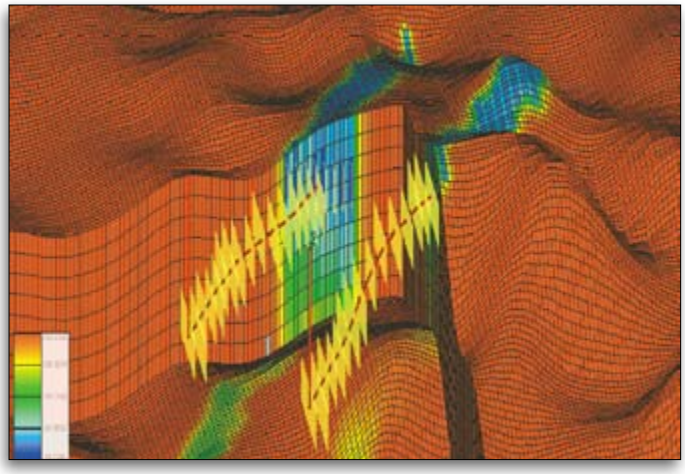


Hydraulic fracturing in **tNavigator** can be defined quickly via the graphical interface with two simple steps:



1. User defines a table of proppant properties (the dependence between pressure and permeability) and the function of proppant washout with the flow from the fracture or time dependence

2. User defines fracture parameters in the dialogue (azimuth angle, length, width, proppant type etc.). The fracture is immediately visualized in the 3D map as a plane.



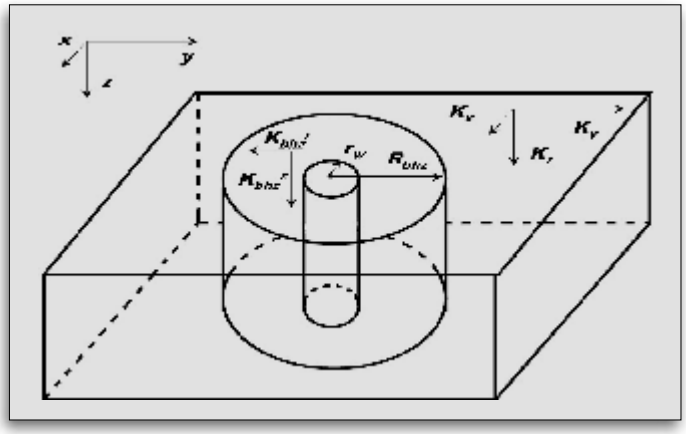
Multiple hydraulic fractures changing pressure distribution

A simple automatic method of converting models with negative skins to models with virtual perforations is implemented in the form of the new **tNavigator** keywords.

The new technology of fracture modeling can be easily extended from single to multiple fractures per well and effectively used for shale oil and gas production simulations.

Modeling of Near Well Bore Treatments in Full-field Models

The well bottom zone is considered in **tNavigator** as a new feature with its dynamic radius and dynamic permeability. A new module was developed which simulates

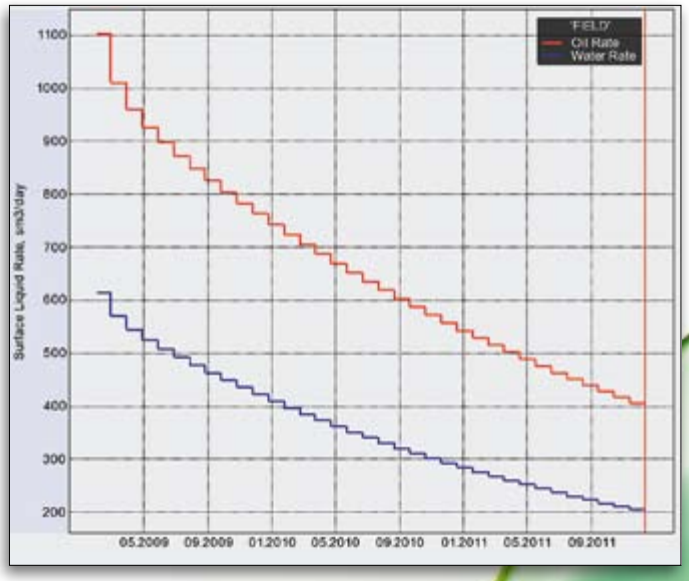


Bottom hole zone model

the well bottom zone obstruction and treatment with acids, solvents, and surfactants via a modified formula for influx — it takes into account static and dynamic effects of the near-well zone.

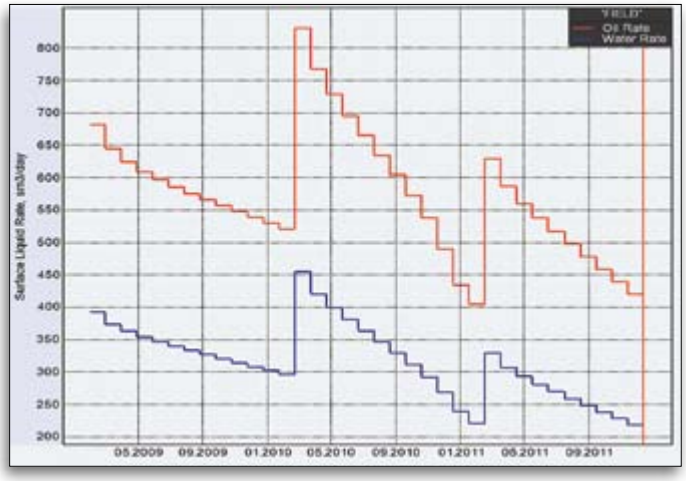
To set the well bottom zone at each perforation the user should specify the well bottom zone radius, radial and vertical permeability, and the dependence of bottom hole area radius on phase flow or time. For example, one can specify that the effect of well bottom zone cleaning with chemicals totally disappeared in half a year.

The users can run multiple treatment realizations and compare simulation results within the graphical interface of **tNavigator**. This is very convenient for the model history matching workflow. Also, this allows for optimal planning of the future treatments, when different realizations of the well bottom zone cleaning, affected zone radii, permeability and flow functions can be compared.



Rates without annual bottom hole treatments

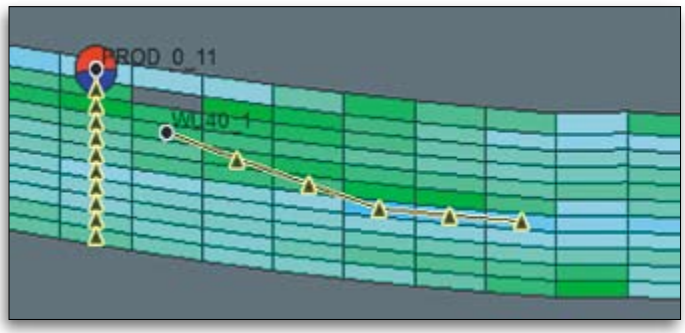
Parallel Reservoir Dynamics for Geological Scale



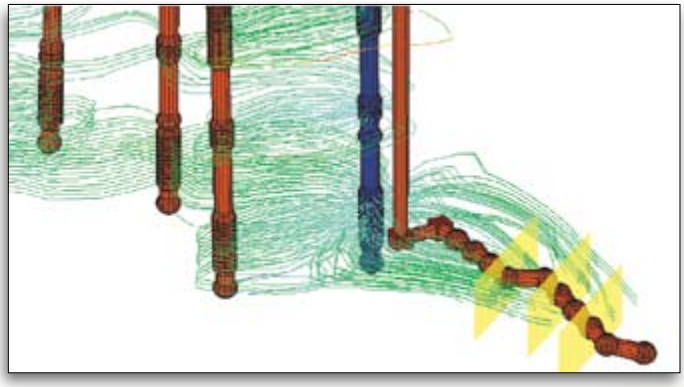
Rates with annual bottom hole treatments

Sidetrack Trajectory Optimization

- **Well path definition with a mouse.**
- **Run multiple simulations and compare results obtained with different sets of trajectories and input parameters.**
- **Instant visual evaluation of different production scenarios.**
- **Sidetracks can be modeled with fractures.**



The effectiveness of the flooding system can be easily evaluated based on the analytics, such as streamlines, injection effectiveness graphs, and liquid allocation tables.



tNavigator helps to find the optimal horizontal well paths in a short period of time:

1. A few alternatives for horizontal well trajectories can be defined with clicks of the mouse on 2D, 3D maps and user-defined vertical profiles.

2. The vertical profiles are most useful for defining the horizontal and deviated wells. It takes just a few minutes to define several alternatives.

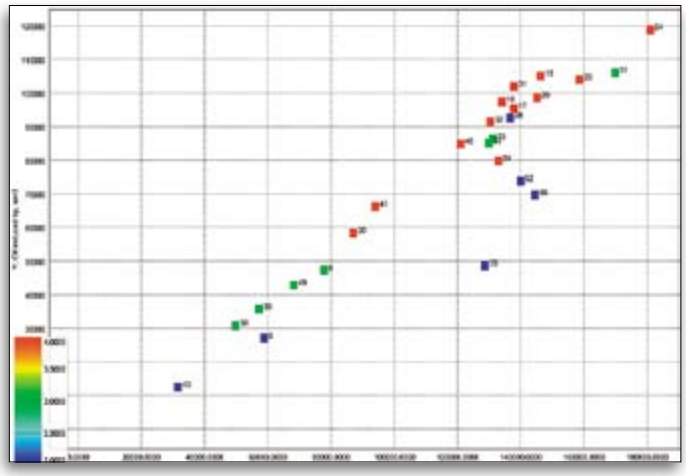
3. Different model versions are handled by **tNavigator** in batch mode. Simulation results for different models can be evaluated at one plot or diagram to pick the optimal development scheme.

Advanced Waterflood Optimization

- **Add 2D, 3D streamlines visualization and analytics, while running full finite difference dynamic reservoir simulations.**
- **Generate tables of injector-producer cross couplings and respective water, oil production allocation factors.**
- **Check for underperforming injectors in the injection efficiency graphs.**
- **Interactively adjust the production plan: shut wells, change the injection/production controls, switch wells from production to injections, add new wells, well patterns.**
- **Re-start the run with a new production plan interactively, see the changes in the production rates and their effective allocations, pressure distribution, and watercuts.**

Injectors			Responding Producers		
Well	Liquid, rm3	Oil, sm3	Well	Liquid, rm3	Oil, sm3
13	146285	105069	Reservoir	4049.03	
			11	32859.5	24539.4
			12	32320.5	24880.4
			26	24810.5	18911
			27	52245.1	36738.3
17	137920	95366.9	Reservoir	12919.1	
			11	19953.5	14906.9
			12	41711.1	32110.2
			15	33523.6	25297.3
			16	29813.1	23052.5
18	134046	97414	Reservoir	5181.11	
			10	30603.9	23049.7
			12	15991.5	12309.8
			16	36353.8	28110.2
			36	45915.4	33944.3
20	87034.4	58348.8	Reservoir	5932.94	

Runtime table of injectors-producers couplings calculated via 3D streamlines

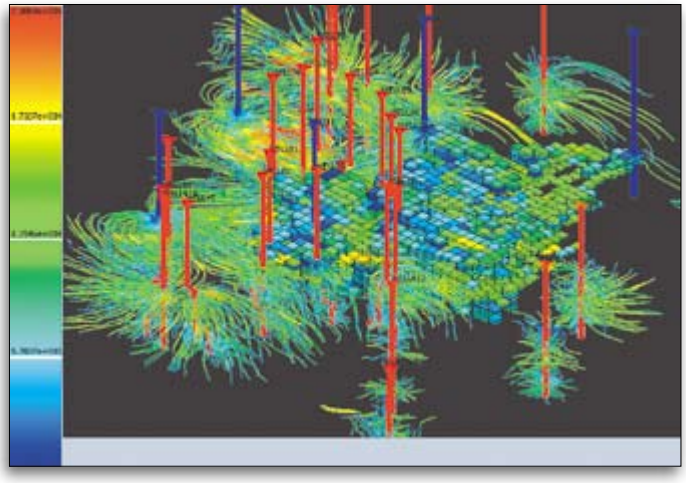


Runtime graph of injection efficiency for all the injector wells in the model. The amount of water injected – X axis, effective oil production rate associated with a given injector – Y

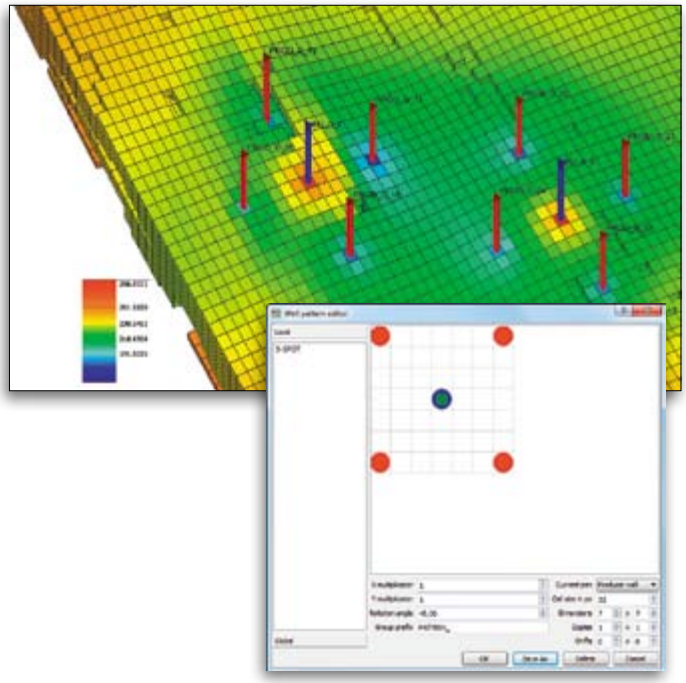
Production Forecast

- **Configure forecast model instantly in one simple step.**
- **Add new vertical, horizontal wells and complex well patterns with a few mouse clicks.**
- **Load and compare simulation results of different forecast models.**

tNavigator allows for generating a forecast model from any time step with one mouse click. A variety of rate and pressure well controls as well as their combinations applied for top and bottom holes can be used in the forecast model. The interactive changes in the model can be applied immediately by restarting the model with the time slider. Complex well distribution schemes can be assembled with the help of a user defined well pattern builder module, which allows to define standard 5-spot or 7-spot or any other arbitrary well pattern.



The effectiveness of the modified flooding system can be easily evaluated using 2D-3D streamlines, drainage matrix, injection efficiency graphs, injector-producer coupling, and effective production rate allocation tables.



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