EMERSON.
Process Management

Production Management Solution

Contents

1. Introduction: METTE – Part of the Roxar Software Solutions Portfolio

METTE is a powerful platform for performing life of field thermo- hydraulic calculations that has recently been brought into the Roxar Software Solutions portfolio as a result of Emerson Process Management's acquisition of Norwegian company Yggdrasil. METTE has been developed with a focus on applicability through all phases of field life (see figure 1).

METTE is an integrated production management solution that provides operators with flow performance calculations for wells and flow lines, integrated field modeling for life of field simulation and optimization, and virtual metering for the allocation of production to wells. Key benefits to operators include flexible production performance calculations, fast network simulation and improved life of field integrated flow assurance.

The combination of data from predictive reservoir models, production modeling and field instrumentation will enable operators to monitor production continuously and use information from the field when forecasting future reservoir performance and making operational decisions. The result is an integrated production management solution.

In the words of Kjetil Fagervik, managing director of Emerson's Roxar Software Solutions: *"This integration will help our customers align their modeling, uncertainty quantification and simulation data with production; optimize their field development and production plans; and increase oil and gas recovery in today's challenging environment."*

This paper will provide an overview of METTE, its functionality, the input files and their hierarchical structure, the branch performance module, the network simulation module, the virtual metering module, and the transient simulation module.

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2. The software's Functionality

This solution is used for integrated flow assurance tasks, production optimization and transient analysis. Within a single application it includes functionality for branch performance, network performance, network simulation, virtual metering, transient analysis, and cased hole log interpretation.

1. **Branch Performance**
   o Well and flow line performance calculations.
   o The creation of profile data.
   o Gas lift hydraulic analysis.
   o The calculation of component (item) set point values.
   o The generation of vertical flow performance (VFP) tables.
2. **Network Performance**
   o Finding operating points and network performance data.
   o Performing what-if simulations.

3. **Network Simulation**
   o Life of field optimized network solutions.
   o Connecting online to multiple reservoir processes.
   o Using events for run time changes in boundary conditions.
   o Automatic or manual well opening.
   o A quasi-dynamic pigging module interfaced to steady state instance.
   o The simultaneous solution of production and service networks with mass transfer.
   o Different optimization strategies.
4. **Virtual Metering**
   o The calculation of *in situ* well flows from sensor measurements.
   o Tune system responses to observed behaviour.
5. **Transient Analysis**
   o Transient momentum and thermal calculations.
   o Transient thermal and steady state momentum.
   o Heat-up and cool-downs for insulation and inhibitor needs.
   o Measuring the effects of choke collapse and inadvertent valve openings.
   o Blow downs for flare rates and liquids produced to sump.
   o Forces and dynamics for predefined start-up slug lengths.
6. **Cased Hole Log Interpretation (consultancy only):**
   o The filtering and organizing of raw data.
   o The pre-processing of filtered data.
   o The generation of get well performance parameters from pre-processed data.

METTE focuses on the maximum reuse of input files across application modes. This reuse ensures consistency and efficiency in data management with minimum file maintenance. The commonality in input data simplifies the sharing of data/files between disciplines performing different flow assurance tasks.

The platform comes with built-in three phase pressure loss models. However, it is simple to use third party models in dll's for specific purposes, such as multiphase pumping and pressure loss/liquid hold-up.

Input fluid data can be "black oil" model parameters or in the form of fixed tables in the format used by OLGA. METTE also has extended fluid handling that explicitly accounts for mono ethylene glycol (MEG) or methanol (MeOH) and saturation water. Non-Newtonian fluids can be described using tabulated shear dependent viscosities, yield stress data and parameters for the implemented Pal & Rhodes emulsion model. Whenever required, run time averaging of key fluid properties are performed for all branches at mixing junctions.
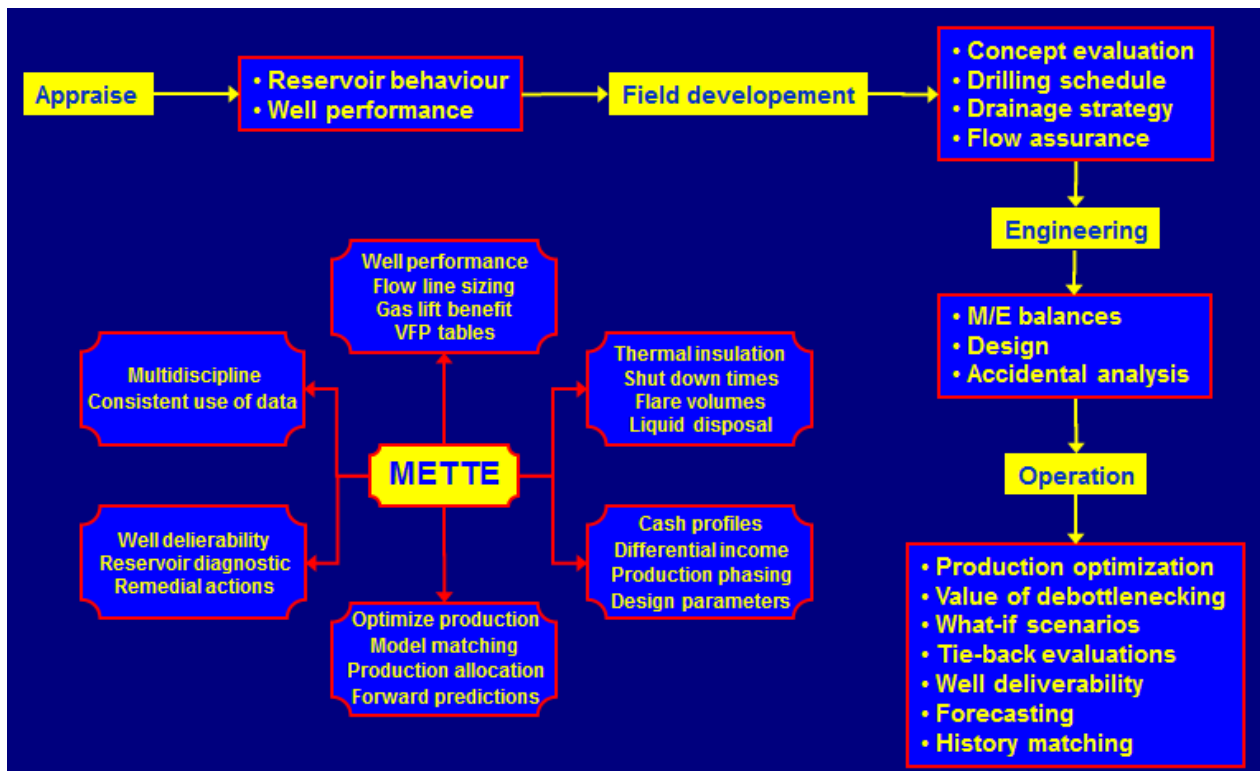
Figure 1: METTE has been developed with a focus on applicability through all phases of field life.

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3. The Input Files

The key input files within the software include the following (figure 2 also illustrates a hierarchical structure of METTE input data):

- **Item specification files.** The parameterizations of components, such as chokes, compressors, pumps, heat exchangers etc.
- **Wall specification files.** Parameterizations for pipe walls.
- **Branch files.** Well and flow line trajectory descriptions with component locations and definition of fluid property files.
- **PVT data.** Fluid property data, either as black oil parameters or as OLGA format property tables.
- **Network files.** Defining well and flow line interconnections and which components that should be used for parameterizing networks.
- **Time series file.** Describing explicit time-dependent changes in boundary conditions for transient simulations.

- **Setup files.** Containing all required information to perform a network simulation, virtual metering or transient calculation. Such files hold all events executed during a simulation.
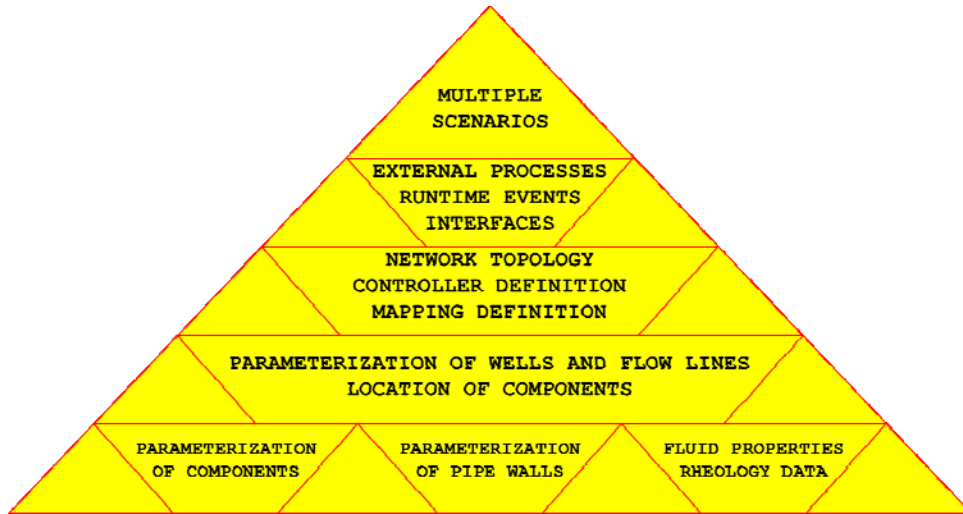

Figure 2. The hierarchical structure of METTE input data.

Dependent on option selections, input may also be required for:

- **Rheology files.** Contains data, such as yield stress, shear dependent viscosity and parameters for Pal and Rhodes emulsion models.
- **Mapping files.** Describes one-to-one branch mapping between a production and service network.
- **Tank model files.** Define wells belonging to a tank and pointer to a file holding production data for the tank.
- **Production data for tank files.** Holds data for the prediction of formation pressure and phase fractions for a given tank.
- **Case file.** Defines multiple simulation scenarios that are submitted for background calculations.

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4. The Branch Performance Module

The branch performance module is used to calculate responses for wells and flow lines from user-defined boundary conditions (figure 3 illustrates the user-interface for performance calculations). Users must specify either:

- Inlet pressure and flow.
- Outlet pressure and flow.
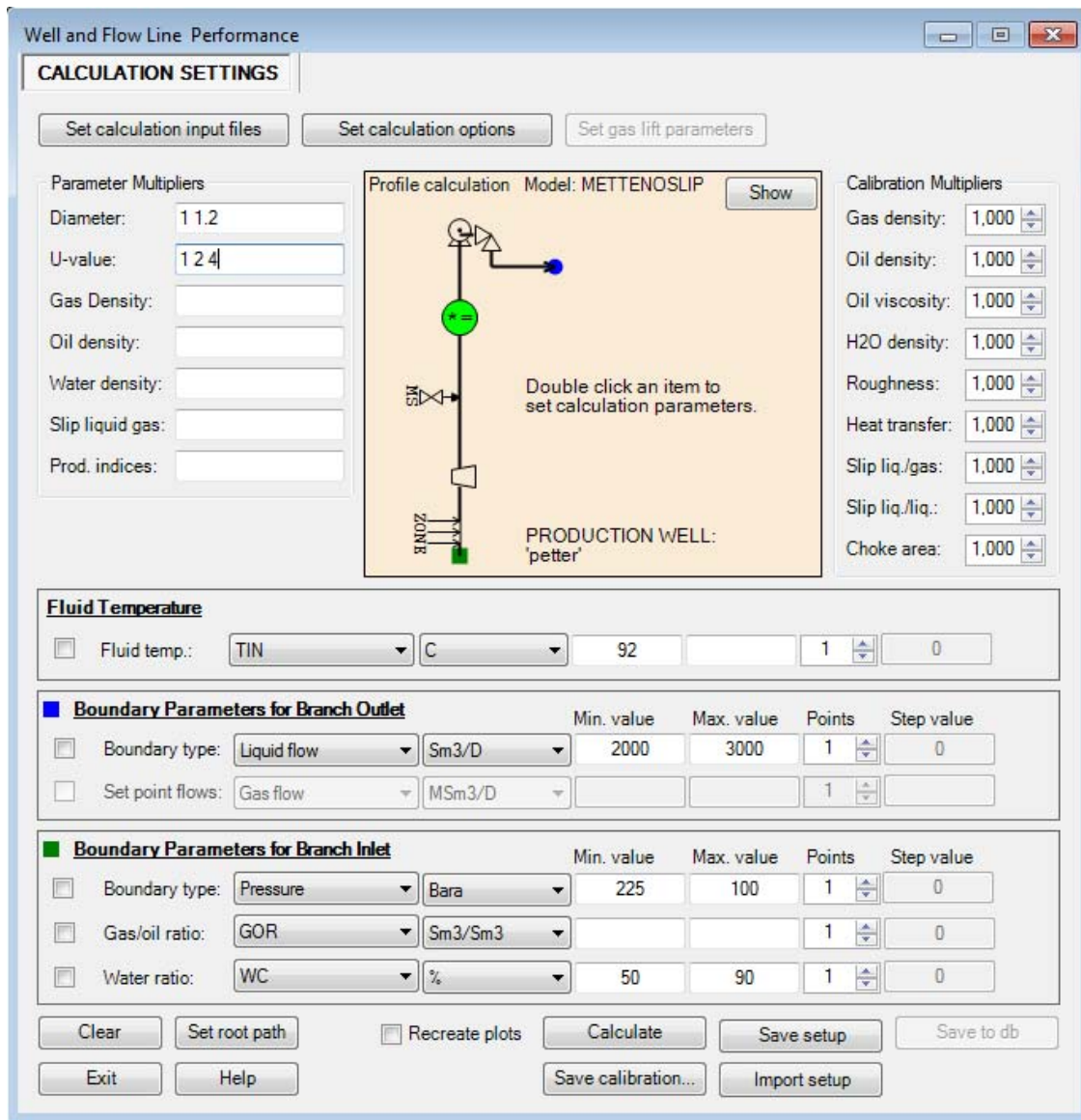- Inlet and outlet pressure.
- Inlet, outlet pressure and flow.

Figure 3: The user interface for performance calculations. With a given flow trajectory and fluid data users can specify boundary conditions to calculate well or flow line responses, calculate the effect of gas lift or determine set-points for gas lift valves or chokes for defined conditions, and use multipliers to get quick answers to the effects of parameter changes.

Multiple boundary conditions can be used, including variations in Gas to Oil Ratio (GOR), Water Cut (WC) and component set points to provide datasets that are easily available for visualization.

METTE supports the use of multipliers for key parameters, such as diameter, heat transfer numbers and phase densities, making it simple to see the effects on system behaviour. Profile data visualizing changes along the flow trajectory is also readily available as an option.

The effects of gas lift use can also be investigated to see the effects of setting depth and volumes used. The required lift gas delivery pressure and a determining of the sweet point can also be calculated. Figure 4 shows the effect of gas lift on oil production potential for different mandrel setting depths.

Component set points can be calculated by specifying flow rates and in- and outlet pressures.

Calibration multipliers are available for adjusting key thermo hydraulic parameters, such as roughness, phase densities, oil viscosity and phase slip factors. The multiplier settings can be permanently stored to relevant branch files for use with other simulations.
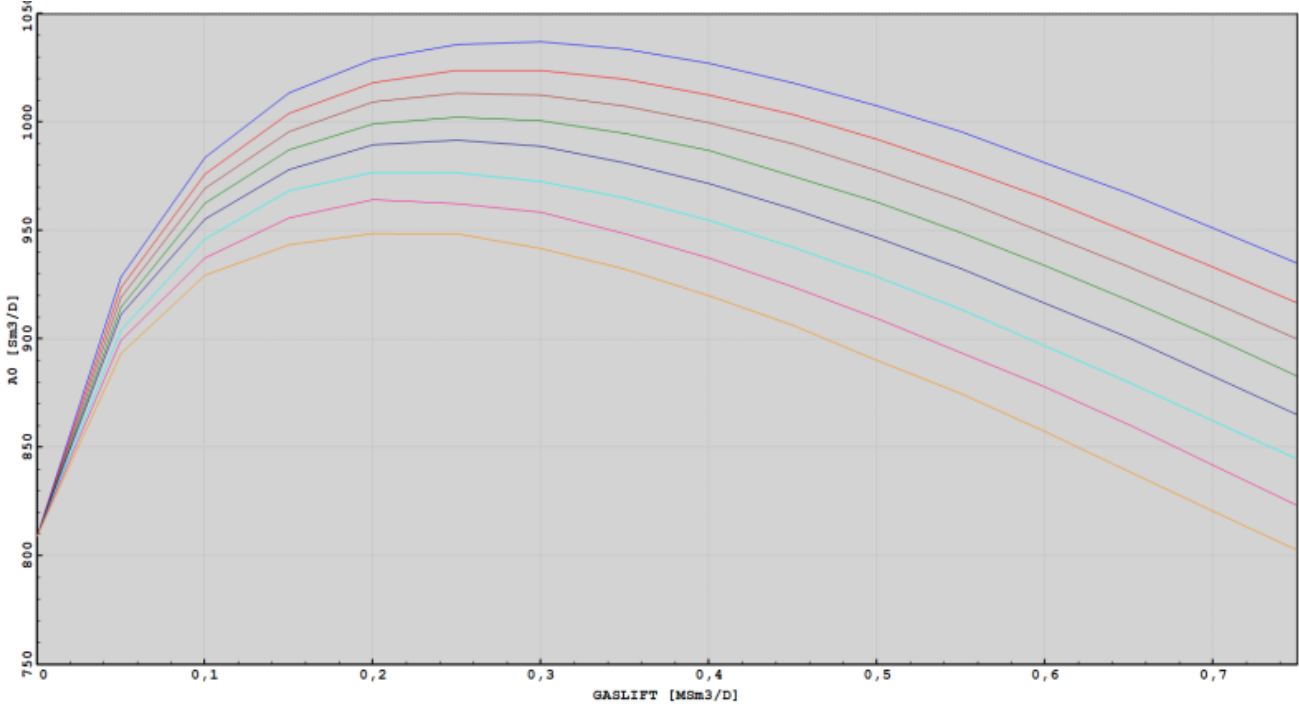

Figure 4: The effect of gas lift on oil production potential for different mandrel setting depths. Oil potential increases with setting depth and have a maximum at given rates of lift gas, increasing with setting depth.

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5. The Network Simulation Module

The network simulation module within the software is an advanced engineering tool for mono- and multiphase flow systems. It relies on a very fast and robust algorithm with demonstrated capabilities that have been in extensive use on the Ormen Lange field development offshore Norway and the Shtokman field in the Russian part of the Barents Sea. The software has also been deployed in a number of other projects in Norway, Russia and Africa.

With online connections to multiple reservoir processes, the software provides concept-dependent production profiles reflecting production targets and constraints in the production network.

Users can obtain: i) life of field variations in mass and energy balances; ii) calculate optimum valve set-points, power and gas lift use for fields in production; iii) determine well routing, the effect of pigging and scheduling for infill wells or third party tie-backs; iv) quantify the effect of boosting equipment and determine when added energy is

needed; and v) see the effect of subsea separation, optimize gas lift use and minimize inhibitor requirements.

METTE on the Shtokman Field

METTE has been in extensive use during field development work for the Shtokman field.

With several hundred-kilometer long transfer lines to shore, the field is dependent on extensive compression as it matures. METTE was used to predict times for compression needs together with optimization of compression power usage.

For flow lines of such lengths, pigging will significantly impact liquid hold-up and thereby transfer losses. To quantify this effect a quasi-transient pigging module was developed to solve project needs. The module was interfaced with the steady state solver, ensuring that the effect of pigging was reflected in the steady state production profiles.

The field will require continuous injection of anti-freeze liquid to combat hydrates. All production network simulations were carried out interfaced with a service network with mass transfer of anti-freeze across networks to ensure proper loss calculations in the production network. Automated well openings linked to production targets were also used to predict well phasing.

Well boundary conditions are generated by reservoir simulation data, providing phase fractions flowing bottom hole pressures. Additional internal and external network pressure and flow constraints are all user specified. The constrained problem is solved using available controllers based on chokes, gas lift, pumps, compressors and heat exchangers as active components.
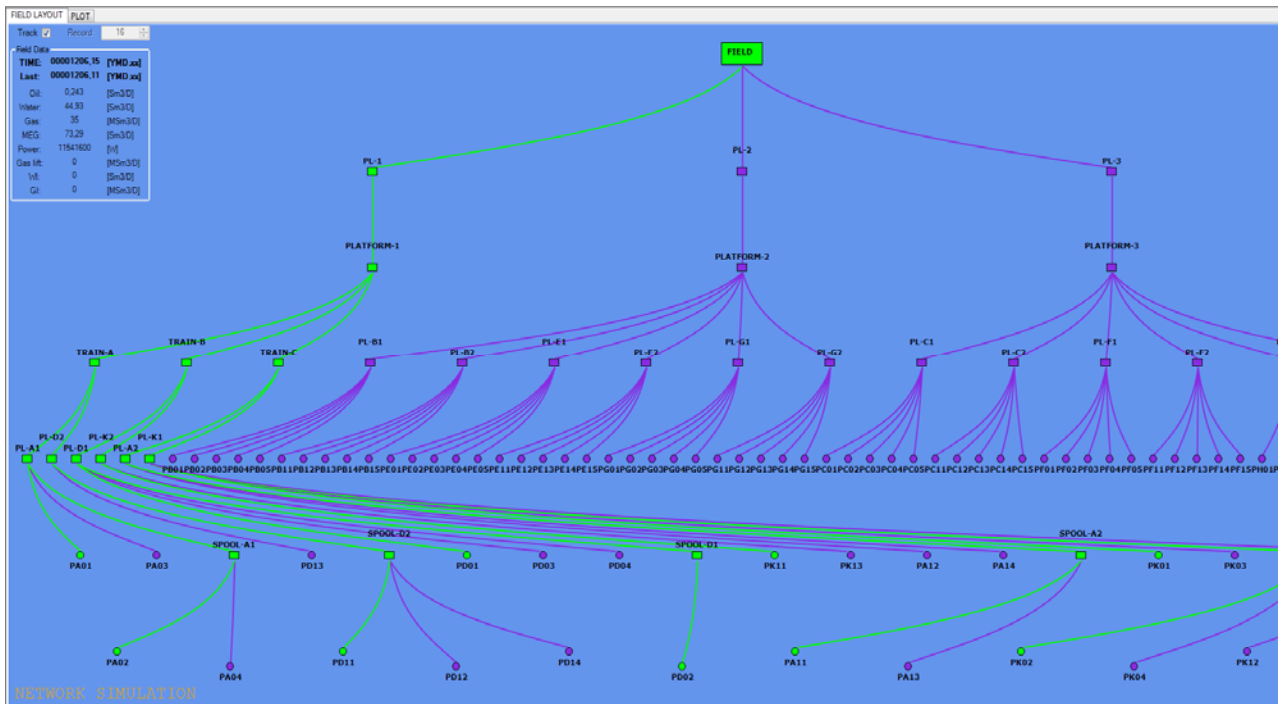
Figure 5: METTE has a demonstrated capability for handling large and complex networks, either coupled online to one or more reservoir processes or by using METTE type tank models for well inlet boundary conditions.

The calculation speed of the software is also impressively high, with life of field simulation times typically measured in minutes. Using METTE type tank models (decline curves), multi case production profiles can be made very fast and independently of reservoir simulations. Figure 5 demonstrates METTE's ability to handle large and complex networks, either coupled online to one or more reservoir processes or by using METTE type tank models for well inlet boundary conditions. Figure 6 shows how field life simulation can be measured in minutes.
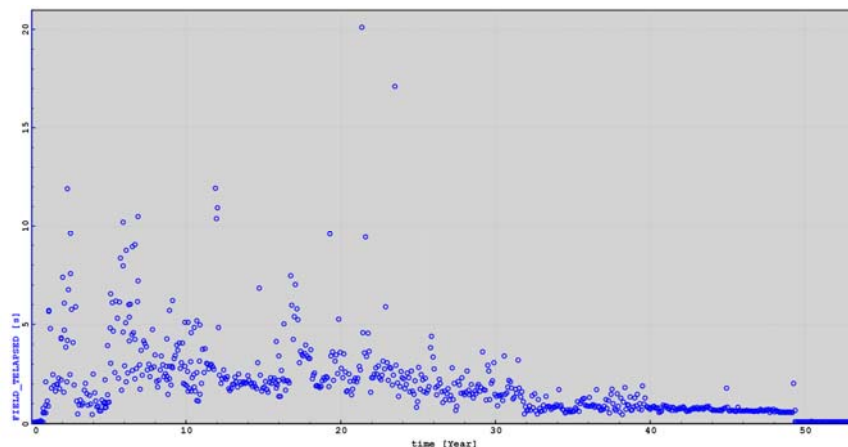

Figure 6: Using METTE, field life simulations are typically measured in minutes. Any given frame is normally solved within a few seconds, even when performing gas lift optimization. The figure depicts time consumption for each frame in seconds for a fifty-year field simulation.

The network solution reflects full convergence at all network junctions accounting for defined constrains, fluid systems and applied components (actuators). The well and field production potentials[1] are calculated in parallel with the constrained case.

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[1] Production potential is defined as the network production capacity where all **group** constraints are disregarded while well constraints are maintained.
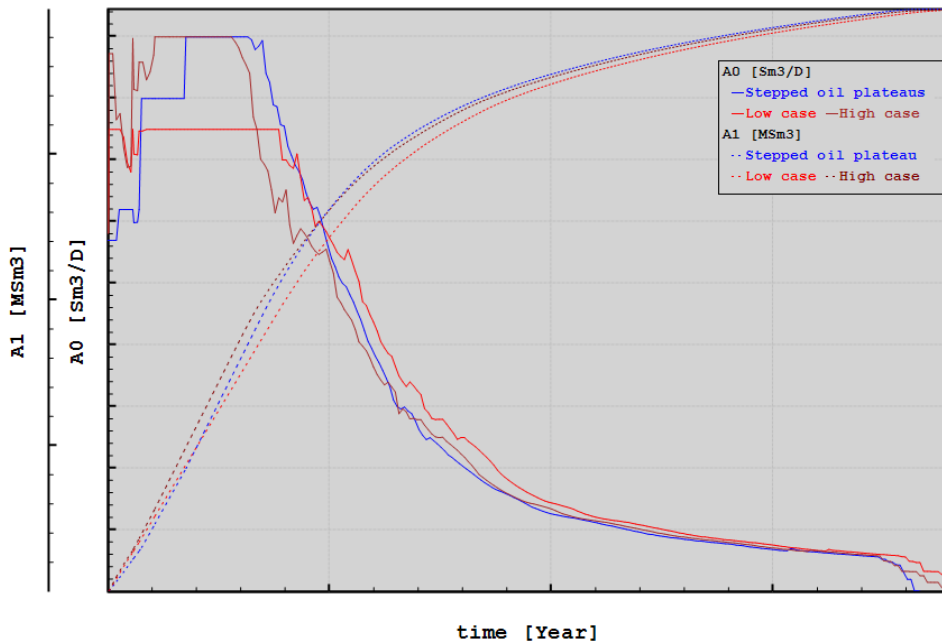
Figure 7: Use case files to run several scenarios with different parameter settings to see consequences on predicted production.

Multiple interfacing networks can be calculated simultaneously. Two relevant examples are gas condensate fields with continuous network distribution of MEG injected or gas distribution to gas lifted wells.

Well boundary data from reservoir simulations can be provided from file or via duplex communication with multiple reservoir simulation processes. For the latter case METTE feeds back guide rates to the reservoir simulation(s). The well guide rates are used as set points for the next time step. METTE currently supports interfacing to the ECLIPSE ('OPEN ECLIPSE' protocol), IMEX/GEM and MORE (MPI protocol) reservoir simulators. METTE has a demonstrated capability for ~500 wells interfaced with several simultaneous reservoir processes. Setup for coupled simulations is simple, requiring only the input of reservoir simulation run files. METTE spawns the processes and acts as master with process time synchronization.
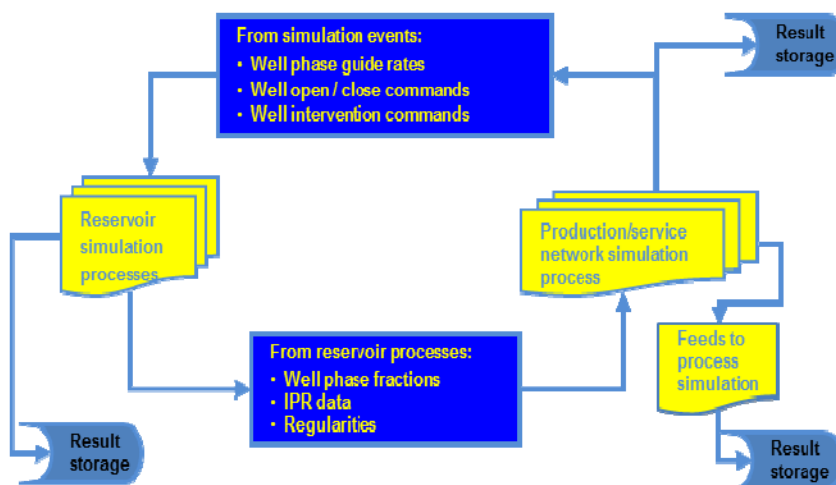

Figure 8: With coupled METTE reservoir simulation, METTE acts as a master process generating reservoir simulations and ensuring time synchronicity during simulation. Flow rates from a converged network solution are fed to the reservoir processes as target rates for the next time step.

5.1 User-Defined Targets and Constraints

In a network simulation, well inlet boundary conditions are dictated by reservoir simulation data. The network optimization problem can be further constrained by user-defined input, employing events for the setting of parameters related to:

- Well / flow line pressures.
- Velocities.
- Phase flow rates.
- WC and GOR.
- Optimization.
- Activating/deactivating equipment items.
- Equipment parameters.

Constraints can be defined at well, flow line and group levels and can be in the form of target/maximum/minimum values. Controller elements with feedback to the constraints are required to realize the production plan settings. A controller element defines an active component to be used in finding an optimized solution. The following component types can be used:

- Chokes.
- Pumps.
- Compressors.
- Mass source (like gas lift)
- Heat exchangers.

With no control components the system defaults to flow control.

Local well phase rates are applied to meet defined targets and constraints. For example, if a user defined water constraint is active, wells actually producing water will be proportionally affected according to their well water delivery. The optimization with respect to phase flow constraints can be based on different criteria including:

- Bottom hole pressure, actal or gradient.
- Well head pressure, actal or gradient.
- Oil, actal flow or gradient.
- Water, actal flow or gradient.
- Gas, actal flow or gradient.
- GOR, actal or gradient.
- WC, actal or gradient.
- Pro rata.

The criteria can be based on actual values or gradient information from a user-defined time window and are applied to production groups consisting of multiple wells.

5.2 Events

Events are a powerful feature integral to METTE. Events are used to change boundary conditions, well and network configurations, the opening/closing/routing of wells, activating/deactivating items, and much more. Events are executed during simulation time, enabling realistic life of field scenarios in a single run (see figure 9).

An event consists of a conditional test based on: Time and/or Measurable values for given parameters. A condition is combined with actions to execute if the event condition is fulfilled. Examples of actions are

- New targets/constraints.
- Opening/closing of wells + rerouting.
- Redefinition of well configurations.
- New network configurations.
- Change of component parameter values.
- Setting of new facility parameter values.
- Auto opening of wells to maintain production profiles.
- Loading new fluid property files.

Events can be used for simple tasks, such as defining new pressure targets, or for more complex actions, such as determining the need for opening new wells to maintain a target production rate within defined drill windows or loading new configuration files with different control structures. Different events can be grouped into parallel or sequential event series. Multiple event series can be defined for a simulation.
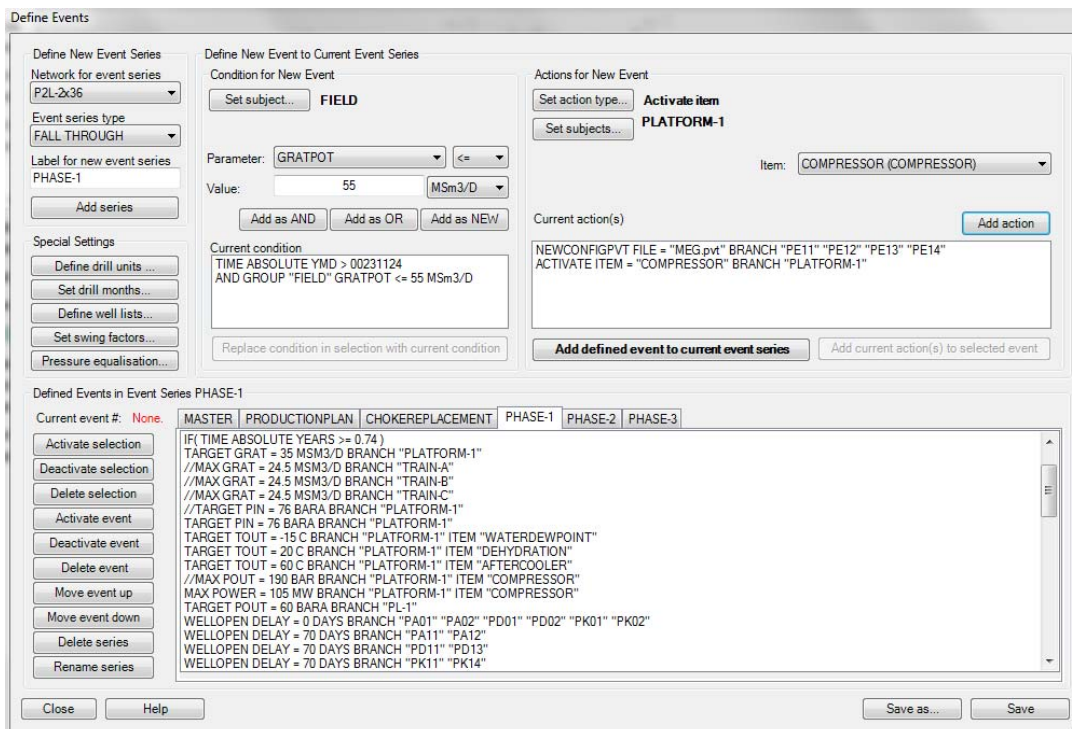

Figure 9: The event module in METTE is a very powerful tool, enabling changes to boundary conditions during run time. Events enable realistic life of field simulations reflecting expected operational conditions.

5.3 Pig Tracing

METTE includes a module for the time tracing of pigs and slip fronts managed by its own event structure. The pig tracing module is a semi-transient flow versus pressure and liquid hold-up model. A network simulation represents a steady state solution at a discrete time point. The pig tracing module is integrated with the network simulation, giving the pressure rate solution for the actual liquid hold up in the network pipelines. The launching of pigs and concurrent slip front tracing may be triggered by different combinations of in situ parameters at or within pipe trajectories:

- Oil hold-up.
- Water hold-up.
- MEG hold-up.
- Total liquid hold-up.
- Pressure limits.
- Inability to meet defined production target.
- Predefined time intervals.

Several pig fronts can be defined in parallel in a flow network. The calculations are fast and provide for an efficient alternative to fully dynamic models in large and small production networks. The method was used extensively with Norsk Hydro's (now part of Statoil) work on the Shtokman field. In that case the use of dynamic OLGA was not practically feasible, due to the computation times involved.

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6. The Virtual Metering Module

Virtual Metering (VM) calculates flow rates from steady state measured sensor data in wells and flow lines. The functionality includes the use of measured quantities for comingled flows, such as the total oil, water and gas produced. METTE employs metering groups consisting of all wells contributing to specific comingled quantities. Well flow rates are calculated using an iterative vector (mass rate) search approach.
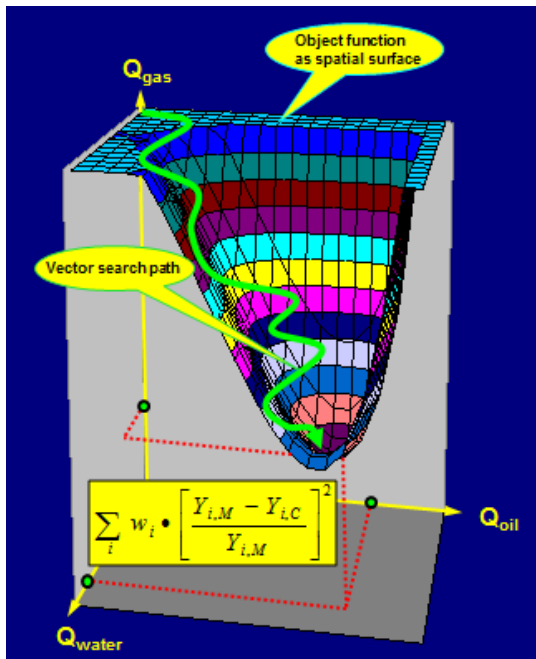
Flows of oil, gas and/or water are used as free search variables to minimize the difference between measured and calculated sensor responses. Figure 10 below depicts the principle.

Figure 10: Phase flows are calculated iteratively using oil and/or gas and or water flow as independent variables minimizing the difference between measured and calculated sensor responses. The surface reflects the value of the object function for different combinations of phase flows. The green curved arrow indicates the search path during the iterative minimization process. The minimum in the function corresponds to a given combination of phase flows. The object function represents the difference between measured and calculated sensor responses summed over all sensors defined active.

Dependent fluid system water and/or gas or oil fractions may be kept constant during calculations. This model-based approach to multiphase metering is highly cost-effective with a single computer capable of serving a large number of wells. It is well-suited for use in combination with multiphase meters and can exploit sensor data from these meters.

The event module in METTE can be used with VM to activate/deactivate sensors, change sensor weight factors and dictate fixed fractions. The resulting data from the VM calculations can be performed online via a data acquisition system or off line with the post processing of batch data.

Figure 11 depicts a practical application with calculated gas flows from sensor data and corresponding cumulative values from the allocation routine employed for the field.
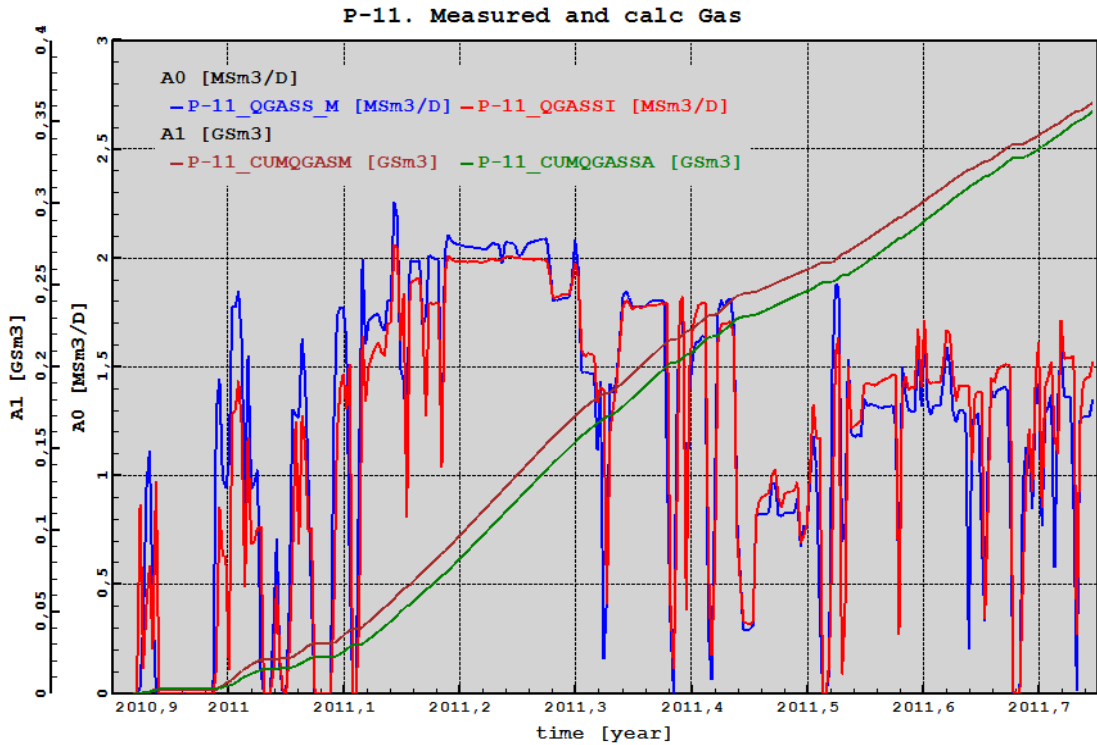

Figure 11: Calculated gas flows (red = flow rate, green = cumulative) and corresponding allocated values from the allocation system used (blue = rates, green = corresponding cumulative).

With well-known phase fractions, the powerful network module in METTE can be employed to calculate optimized component set points, such as valve positions and gas lift use to meet defined production targets (see figure 12). The METTE VM and forecasting modules can be employed in combination as an advisory system and/or in a closed loop PID control. The flow results from METTE VM are formatted so that they can be applied directly in simulation mode for reservoir history matching purposes.
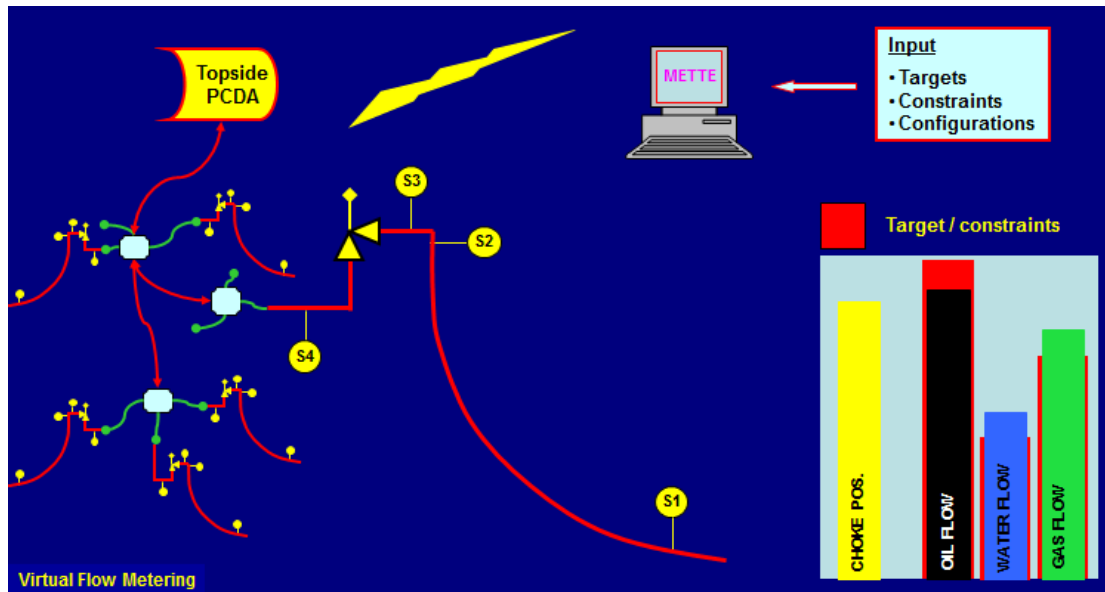
Figure 12: Knowing well phase fractions. METTE can be used to calculate an optimized network solution providing set points for active components, such as chokes, compressors and gas lift use, to meet production targets and honor defined constraints. The system can be used in advisory mode or in closed loop PID control.

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7. The Transient Simulation Module

METTE includes a module for transient thermal and momentum simulations of mono and multiphase fluid systems. As an option, METTE allows the momentum to be calculated at steady state while thermal mode applies a transient schematic. This is relevant for some types of simulations to save time.

The transient module is very flexible in defining initial conditions using the efficient built-in steady state pre-processor. The system can also be initialized by manually setting parameters, such as temperature, pressure and phase fractions along the flow trajectory. Functionality for PID control and phase front tracing is included in the module. The impact of critical flow is also taken into consideration. A system set up for steady state simulations is directly applicable for transient analysis purposes by including time series definitions of boundary conditions.

Typical applications for transient simulations include:

- Start-up and shutdowns for insulation and inhibitor needs.
- Depressurization for flare and liquid disposal volumes.
- The consequences of choke collapse and inadvertent valve openings.
- Well start-up with gas lift for required pressures and volumes.
- Closed loop circulation of dead fluids for heat-up purposes.
- Estimating start-up slug forces on bends from predefined slugs.
- Tracing of gas or liquid fronts along the flow trajectory.

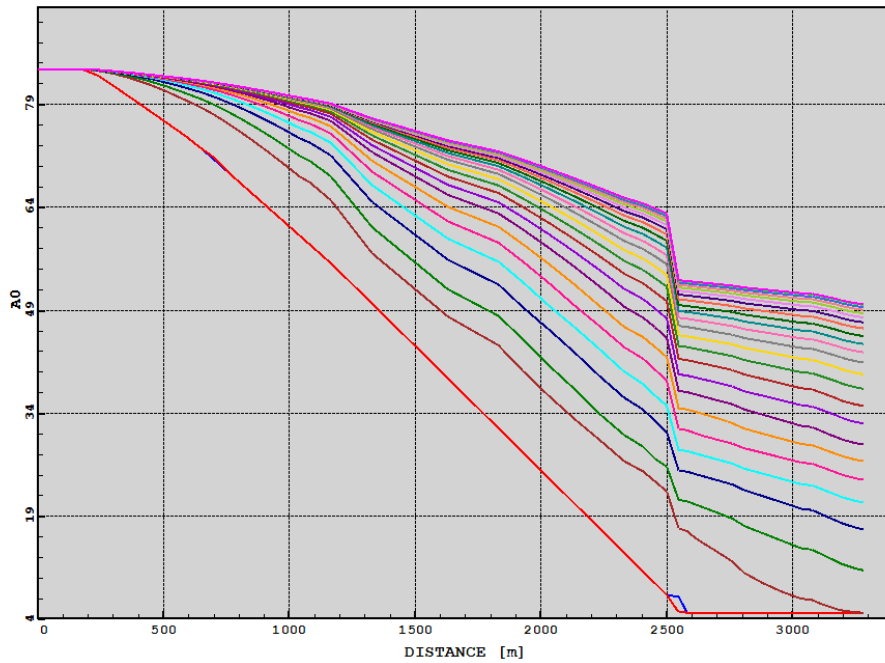Figures 13 to 15 below show typical METTE executed transient examples.

Figure 13: Thermal profile development in the well after start-up from cold conditions. Profiles shown for 15 minute intervals. The emerging sharp drop at approximately 2500 m MD reflect thermal loss across a choke.
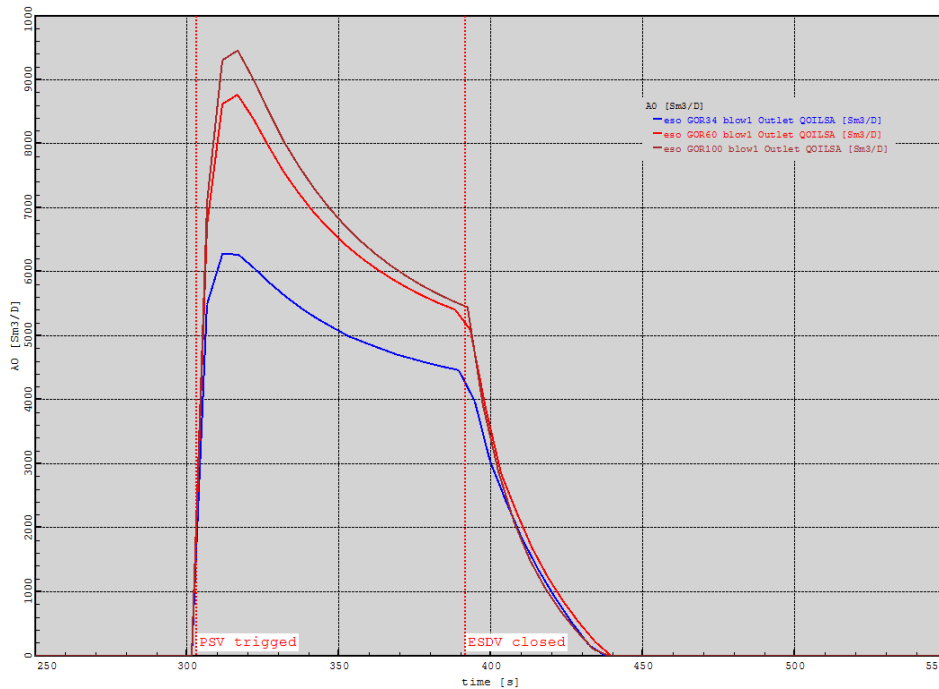

Figure 14: Liquid disposal rates resulting from inadvertent topside valve opening during field shut-in at time 300 s. After some 90 s the emergency shutdown valve is closed with a rapid decline in rates. The different curves reflect different in situ GOR's.
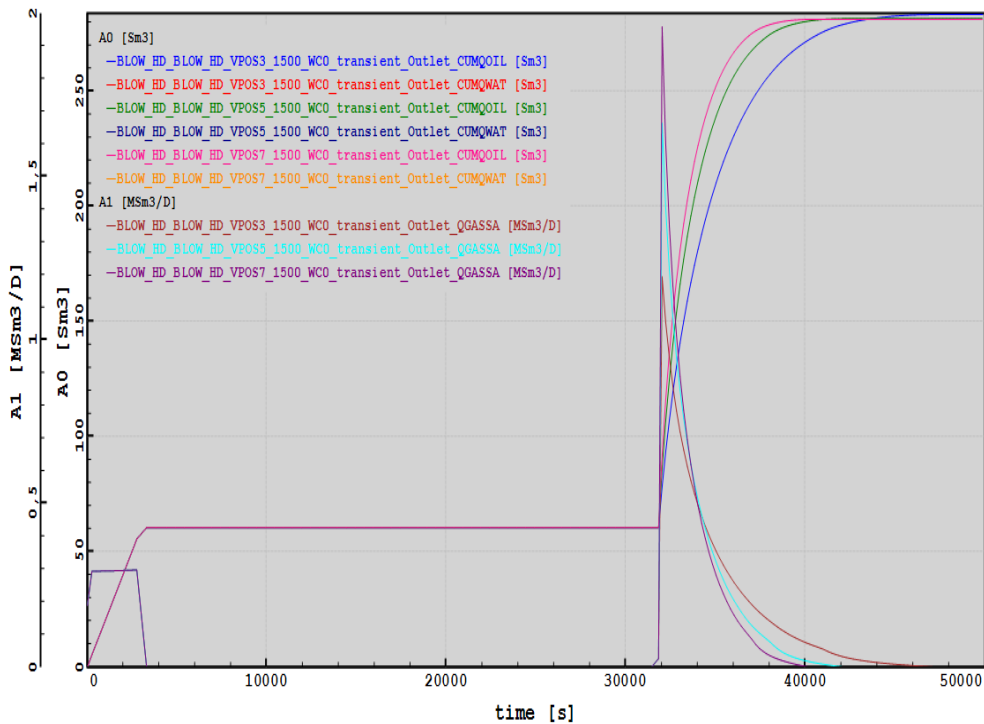
Figure 15: Blowdown of a flow-line after shut-in. The peaked curves trailing off to zero are instantaneous gas rates for different relief valve sizes. Cumulative drained liquid is shown as increasing curves. Greater valve size results in higher gas flow rates.

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8. Summary

This paper has provided an overview of the different elements of the integrated production management solution, and how the software can provide the oil and gas industry with the very best tools for designing and optimizing production systems.

From well and flow line performance calculations through to transient simulations, network optimizing and virtual metering, the software provides a complete production management solution. Working alongside the Roxar Software Solutions portfolio, operators can look forward to:

- Manage their network design in order to increase efficiency and production, respond quickly to exceptions and events and take advantage of working on a single interface dedicated to production management for better risk mitigation and production optimization.
- The ability for operators to monitor production continuously and use information from the field when forecasting future reservoir performance and making operational decisions.
- The ability for customers to align their modeling, uncertainty quantification and simulation data with production; optimize their field development and production plans; and increase oil and gas recovery.