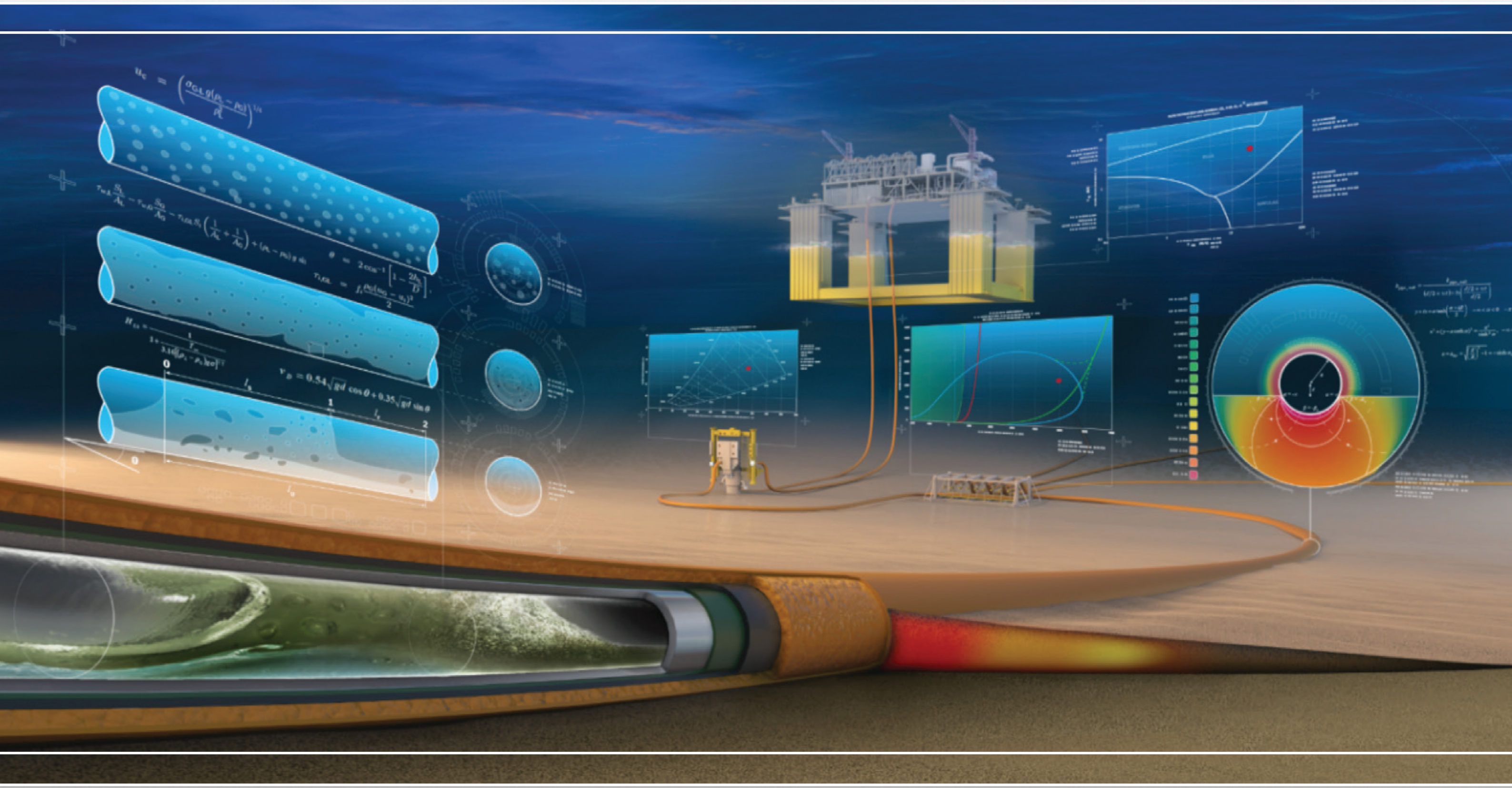

Schlumberger

PIPESIM 2019

Steady-State Multiphase Flow Simulator

Technical Reference
January 2020

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The design of modern production systems requires ensuring that fluids are cost-effectively transported with the highest possible safety from the reservoir to the processing facilities. Harsh environments such as deepwater fields with complex infrastructure or large-scale onshore developments pose many additional factors that must be addressed by the production system design. The ability to accurately simulate such a broad range of scenarios and conditions has established the PIPESIM* steady-state multiphase flow simulator as the industry's leading steady-state multiphase flow simulation tool for production system design.

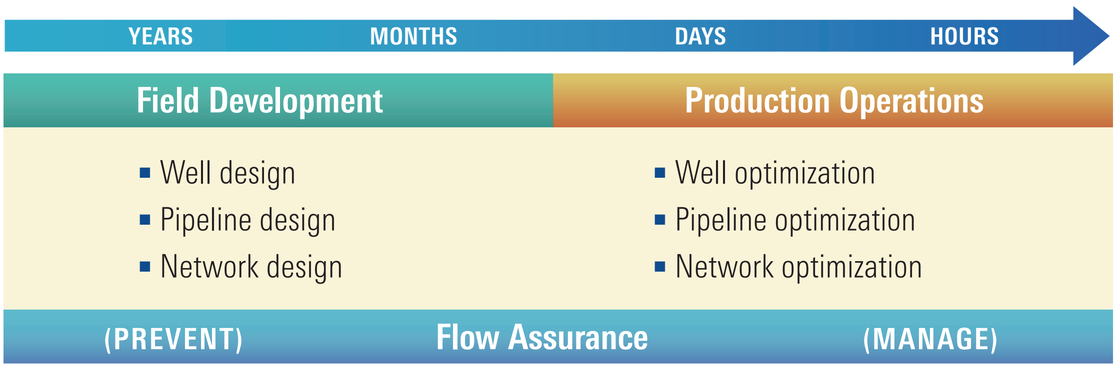
Once production systems are brought into operation, the ability to ensure optimal production is critical to achieving the maximum economic potential. The PIPESIM simulator provides a comprehensive set of workflows ranging from candidate well selection for workovers to identification and mitigation of flow assurance challenges to online optimization of the complete system.

The PIPESIM simulator was first released in 1984 with an initial purpose for designing production systems for harsh environments such as the North Sea. Subsequent versions have maintained the first release's focus on incorporating the latest scientific findings to provide the most accurate predictions possible while implementing continuous improvement and expansion.

The newly redesigned user interface (UI) delivers a step change in user experience, enabling users to build models more quickly and focus on results. The option to work within one application or switch between well-centric or network-centric application layouts simplifies the overall work environment.

From field development to production operations, the PIPESIM simulator enables production optimization over the complete lifecycle by accessing the latest targeted science to address flow assurance challenges.

Production Optimization Over the Complete Lifecycle



PIPESIM Simulator's Foundational Flow Modeling Capabilities

The practice of designing wells and pipelines to ensure that produced fluids are economically transported with the highest possible safety to downstream processing facilities is a major challenge for engineers.

The foundation for accurate modeling of these systems relies on three core areas of science:

- multiphase flow
- heat transfer
- fluid behavior.

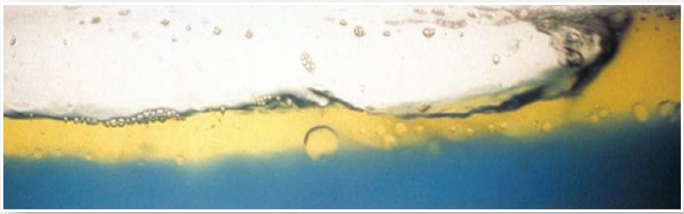
With this foundation, the PIPESIM simulator provides the most advanced steady-state modeling capabilities in the industry.

Multiphase flow modeling

The PIPESIM simulator incorporates a wide variety of industry-standard multiphase flow correlations as well as advanced three-phase mechanistic models, including OLGAS steady-state flow model based on the OLGA* dynamic multiphase flow simulator, LedaFlow point model, and Tulsa University Fluid Flow Projects (TUFFP) unified model. These models enable the calculation of flow regimes, liquid holdup, slug characteristics, and pressure loss for all nodes along production paths at all deviations. With this capability users can design and operate production gathering and distribution systems with confidence.

Detailed flow regime maps are produced by the PIPESIM simulator at designated points of interest.

Predicting hydrodynamic slugs and their size and frequency as a function of the length traversed is another significant capability for optimizing the design of pipeline and processing facilities. The PIPESIM simulator also predicts the risk of severe slugging in risers.



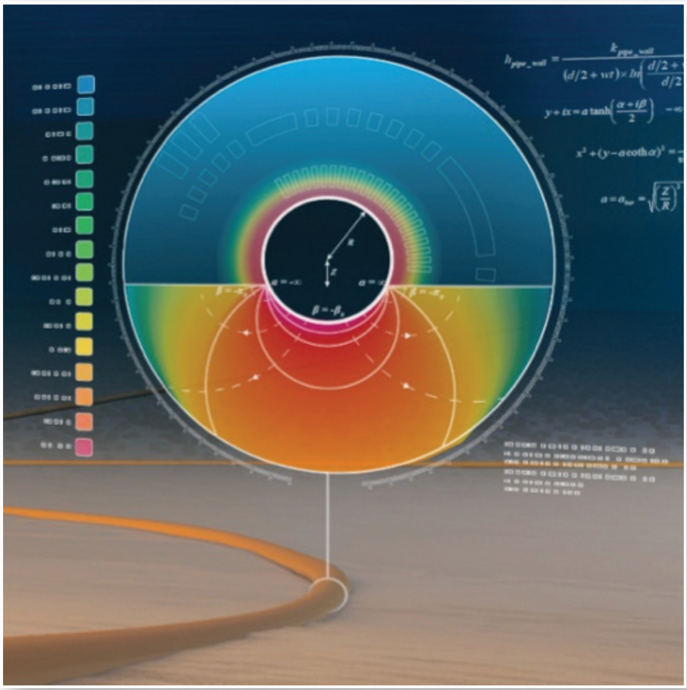
Multiphase Flow Models	
Single-phase flow correlations	■ Moody ■ AGA (with tuning option for drag factor) ■ Panhandle A and B (with tuning options for flow efficiency) ■ Hazen–Williams (with tuning options for C factor) ■ Weymouth (with tuning options for flow efficiency) ■ Cullender-Smith
Vertical multiphase flow models	**Standard** ■ Beggs and Brill (original and revised) ■ Duns and Ros ■ Ansari (mechanistic) ■ Govier, Aziz, and Fogarasi ■ Gray (original and modified) ■ Gregory (Neotec) ■ Hagedorn and Brown (original and revised, with and without Duns and Ros map) ■ Mukherjee and Brill ■ Orkiszewski **Comprehensive mechanistic models** ■ OLGAS 2 and 3 phase ■ TUFFP unified 2 and 3 phase ■ LedaFlow 2 and 3 phase
Horizontal multiphase flow models	**Standard** ■ Beggs and Brill (original and revised, with and without Taitel Dukler map) ■ Baker Jardine revised (for condensate flowlines) ■ Dukler, AGA, and Flanagan (with and without Eaton holdup) ■ Eaton Oliemans (Neotec) ■ Mukherjee and Brill ■ Oliemans ■ Xiao (mechanistic) Dukler ■ No-slip **Comprehensive mechanistic models** ■ OLGAS 2 and 3 phase ■ TUFFP unified 2 and 3 phase ■ LedaFlow 2 and 3 phase
Calibration	The PIPESIM simulator includes a flow correlation calibration feature that can automatically adjust the holdup factor, friction factor, and U-value multiplier to match measured pressures and temperatures. Additionally, the flow correlation comparison operation can quickly sensitize on flow correlations to aid in selecting the most appropriate model.
Flow regime maps	The PIPESIM simulator produces high-resolution flow regime maps at any point in the system selected.
Extensibility	The PIPESIM simulator includes code templates that can assist users in compiling their own 2-phase or 3-phase flow correlations via a plug-in dynamic link library (DLL).

Heat transfer modeling

Accurate prediction of heat transfer is critical for calculating temperature-dependent fluid properties, predicting solids formation, and supporting the overall thermal design of a system. The PIPESIM simulator performs comprehensive energy-balance calculations that account for a variety of heat transfer mechanisms, including

- convection (free, forced)
- conduction
- elevation
- Joule-Thomson cooling and heating
- frictional heating.

Heat transfer models supported by the PIPESIM simulator include a flow-regime-dependent inside film coefficient model and an analytical heat transfer model for convection in buried and partially buried pipes that has been shown to closely match more complex finite-element numerical methods.



Heat Transfer Calculations	
Wellbore heat transfer	■ User-specified heat transfer coefficient
Flowline and riser heat transfer	■ User-specified heat transfer coefficient ■ Calculated heat transfer coefficient taking into account pipe and ground thermal properties and the properties of multiple layers of pipe coatings (optional) ■ Conductive and convective (free and forced) heat transfer rigorously calculated for pipes that are fully buried, partially buried, and fully exposed
Inside fluid film heat transfer coefficient	**Available methods:** ■ Kreith model ■ Kaminsky model (flow regime dependent)
Flow assurance related	**Other calculations to aid accurate insulation and flow assurance studies** ■ Calculation and reporting of hydrate subcooling ■ Calculation and reporting of asphaltene subcooling ■ Calculation and reporting of wax subcooling ■ Electrical heating of flowlines

PIPESIM Simulator's Foundational Flow Modeling Capabilities

Fluid property modeling

An accurate description of fluid behavior is critical for correctly modeling the production system. The PIPESIM simulator offers industry-standard black oil correlations or a range of equation-of-state (EOS) compositional models. Depending on the type of application, users can select from an extensive set of features to model a wide variety of fluid types.

Fluid Property Modeling	
Black oil	■ Latest industry-standard fluid property correlations that cover all types of petroleum fluids, from extra heavy oil to light oil and condensate—can also be used for simplified gas, utility fluids, and others ■ Wide range of viscosity correlations with options for user-specified dead oil and emulsion viscosities ■ Wide range of emulsion correlations covering tight to light emulsion types with optional specification of emulsion tables and optional specification or calculation of the inversion point ■ Ability to plot fluid properties at laboratory or reservoir conditions ■ Specification of gas contaminants used for compressibility factor adjustment and corrosion calculations ■ Specification of thermal data for all phases of a black oil fluid for accurate thermal modeling and some of the standard methods for fluid enthalpy calculation for accurate energy-balance prediction ■ Comprehensive fluid mixing rules
Calibration	■ Multilevel calibration from simple bubblepoint matching to advanced fluid calibration matching of multiple sets of laboratory data measurements

Compositional	■ Choice of Schlumberger-developed and third-party flash EOSs, including
	  ■ ECLIPSE* Compositional
	  ■ Multiflash
	  ■ GERG 2008
	■ Standard library for packages of components and binary interaction parameters—most with the ability to define and calculate properties of pseudo-components for accurate modeling of fluid properties in the absence of detailed fluid characterization
	■ Wide range of EOSs and transport properties correlations available based on selected flash packages:
	  ■ EOSs: Peng-Robinson (standard and corrected), SRK (standard and corrected), Cubic Plus Association (CPA), BWRS, GERG-2008, and others, with correction for volume shift and acentric factors as applicable
	  ■ Binary interaction parameters: flash package defaults or user specified
	  ■ Viscosity models: Pederson, LBC, Aasberg-Peterson, NIST, and others
	  ■ Emulsion methods: Woelflin, volume ratio, continuous phase, none

Solids precipitation†	■ Generation of phase envelopes, including quality lines and formation curves for hydrates, waxes, and asphaltenes ■ ScaleChem PVT file for generation of scale appearance and disappearance lines for $CaCO_3$, $CaSO_4$, $BaSO_4$, NaCl, and others ■ Quick flash calculations to examine fluid properties at specified pressure-temperature flash and separation conditions ■ Phase ratio matching for water, oil, and gas based on field measurement—useful for quick updates of fluid composition based on actual measurement of phases at the field separator ■ Salinity analysis based on ion, salt components, and total dissolved solids (TDS) (Multiflash)

PVT files	■ Interpolation of fluid and transport properties using numerous Schlumberger and third-party applications for generating PVT files, including
	  ■ PVTSim (Calsep)
	  ■ Multiflash (KBC)
	  ■ ScaleChem (OLI Systems)
	  ■ GUTS (MSI)

Steam	■ Modeling of steam as a single-component system using the ASME Steam Tables ■ Applicable to both producers and injectors for single branch and network simulation operations

† Listed features vary depending on selected flash package. Refer to PIPESIM Simulator User Guide for available options in a given flash package.

The PIPESIM simulator provides a thorough, fast, and efficient way to help users increase production and understand their reservoir's potential. It not only models multiphase flow from the reservoir to the wellhead but also considers artificial lift systems including rod pumps, progressing cavity pumps (PCPs), electric submersible pumps (ESPs), and gas lift.

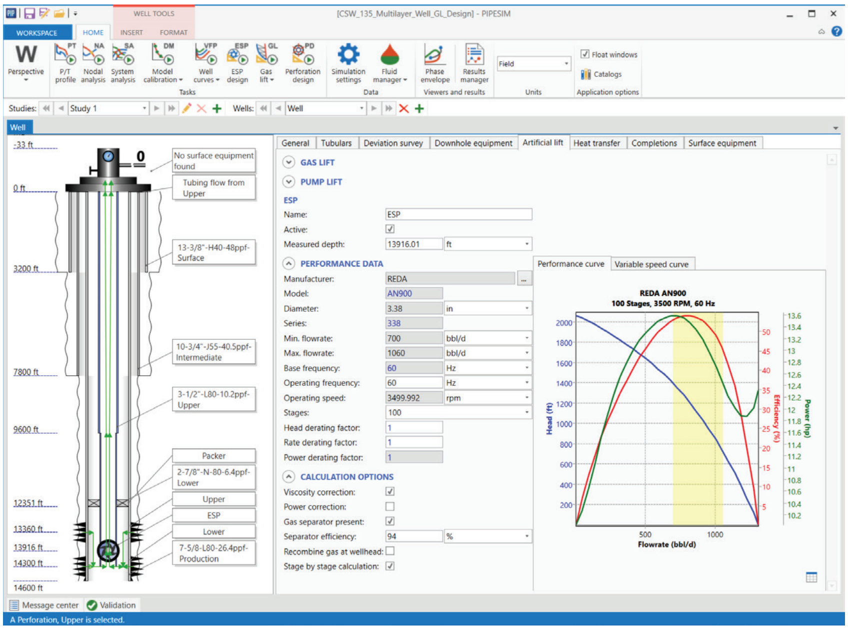
The interactive graphical wellbore schematic enables users to quickly create well models and view the simulated flow path on the diagram. Additionally, surface equipment in the wellstream may be easily defined within the well editor without having to switch to the network schematic.

The PIPESIM simulator enables users to

- design optimal well completions and artificial lift systems
- diagnose problems that are limiting the well's production potential
- optimize production from existing wells by quantifying actions to increase flow rates.

Typical well performance applications

- Select the optimal tubing or casing size
- Perform a completion design with detailed quantification parameters of skin effects
- Design water or gas injection wells
- Select the optimal perforation gun system and configuration to maximize productivity
- Determine the optimal horizontal completion length
- Model multilayer wells, including effects of crossflow between zones or velocity strings
- Quantify expected production improvements by reducing skin effects
- Diagnose liquid loading in gas wells and evaluate measures to alleviate the problem
- Tune completion parameters and pressure-temperature profiles to match field data using automated regression
- Generate vertical flow performance (VFP) tables for reservoir simulators
- Perform detailed sensitivity analysis to identify what has the most significant impact on production
- Compare the relative benefits of various artificial lift methods (rod pumps, PCPs, ESPs, Jet pumps and gas lift)
- Design artificial lift systems including Jet pumps, PCPs, ESPs, and gas lift
- Model the effect of coiled tubing gas injection
- Identify wellbore flow assurance issues such as erosion, corrosion, and solids formation (scale, wax, hydrates, and asphaltenes)
- Model tubular, annulus, or mixed flow
- Model downhole equipment such as chokes, subsurface safety valves, separators, and chemical injectors
- Calculate Worst Case Discharge (required by BOEM for US offshore drilling permits)



Building wells is now much easier, using a new, interactive graphical wellbore schematic shared by other Schlumberger software applications. Construction of wells with complex flow paths (tubing/annulus) and horizontal completions is greatly simplified.

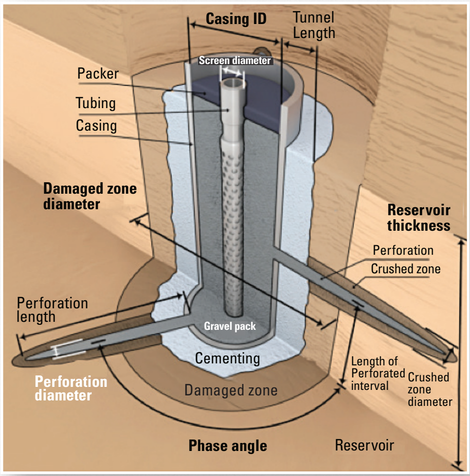
Well Performance

Modeling completions

The PIPESIM simulator includes all the standard completion model types for vertical, horizontal, and fractured wells and supports modeling complex multilayered completions using a wide variety of reservoir inflow parameters and fluid descriptions.

Modeling Completions

Inflow performance modeling



Vertical Completions:

- Well productivity index (PI) (gas)
- Well PI (liquid, with and without taking into account Vogel correction and correction for water phase)
- Fetkovich (liquid only)
- Jones (gas and liquid)
- Vogel (liquid only)
- Backpressure (gas only)
- Forchheimer (gas only)

All the preceding equations enable the calculation of dependent parameters based on user-supplied well test data, as available.

- Hydraulic fracture model (gas and liquids, with and without transient calculation)
- Darcy model
  - Pseudo steady-state and transient modes
  - Gas-basis options including pressure-squared and pseudopressure formulations
  - Liquid-basis options include the Vogel correction below bubble point and use of oil/ water relative permeability tables
  - Relative permeability tables
- Coning tables to account for water and gas coning effects

Horizontal completions (single-point PI models)

- Steady-state Joshi model for liquid and gas-based inflow performance relationship (IPR) calculation
- Pseudo steady-state Babu and Odeh model for liquid- and gas-based IPR calculations

Horizontal completion (distributed PI models that take into account the introduction of fluids along the horizontal completion interval)

- Steady-state Joshi model for liquid- and gas-based IPR calculation
- Pseudo steady-state Babu and Odeh model for liquid- and gas-based IPR calculations
- Simple distributed PI model
- Trilinear IPR (transient IPR model for unconventional resources)

Skin calculations

Support for several standard completion options:

- Openhole perforated
- Gravel pack (openhole and perforated)
- Perforations
- Fracture packing (vertical only)

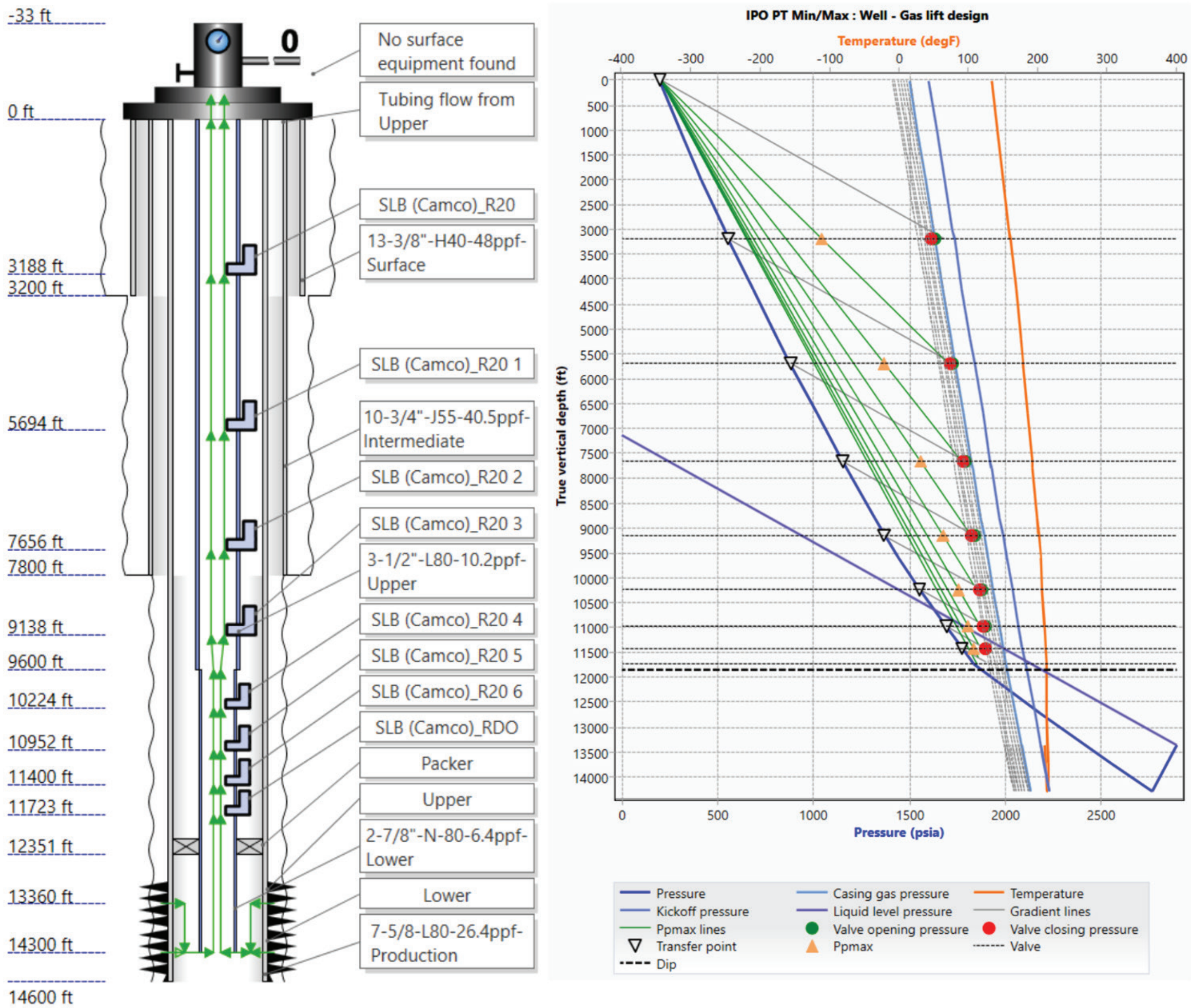
Availability of most of the parameters responsible for skin contribution for use in sensitivity and uncertainty analysis

User option for both horizontal and vertical completions to override skin calculations by specifying the skin factor obtained from well test data

Artificial lift design

The PIPESIM simulator enables users to determine the most suitable artificial lift method and then perform detailed design for gas lift or ESP. The sophisticated sensitivity tools allow artificial lift parameters (injection gas and ESP stages) to be analyzed so that optimal production can be obtained.

For gas lift, the PIPESIM simulator includes new and installed mandrel spacing and valve selection design functionality to help users determine the best depth to install the valves using industry-standard methods for gas lift design. It also includes a manufacturers' valve database for ready access to accurate information for making the best decisions. Additionally, users can redesign valve placement with mandrels in place.



PIPESIM provides rigourous and detailed gas lift design capabilities which are used daily within Schumberger for optimizing gas lift system design.

Well Performance

Artificial Lift Design and Simulation	

Gas lift systems	The PIPESIM simulator uses advanced methods to perform design and diagnostics for gas-lifted wells. The installed gas lift system may then be used in a variety of well and network simulation operations including full-field optimization. Key features include the following.
	Gas lift valve database
	■ Extensive database of gas lift valves of several types or series and sizes from a variety of manufacturers
	■ Easy addition of new valves to the database by users
	Gas lift design
	■ Several design methods available (IPO-surface close, IPO-PT min/max, and PPO)
	■ Valve sizing for both new mandrel spacing calculations and existing mandrel spacings
	■ Bracketing options to account for future performance
	■ Design basis on pressure boundary conditions or at a fixed-target production rate
	■ Accounting for frictional pressure loss for injected gas through the annulus
	■ Configurable design bias and safety factors to control design
	■ Flexible control of the choice of valve manufacturer, size, and series
	■ Redesign option available to change spacing, one or more valves, design temperature profile, and other factors
	■ Design results and plots including
	  ■ Recommended valve information, including model, spacing, and size
	  ■ Recommended test rack opening pressure for all valves
	  ■ Valve throughput calculations (Thornhill–Craver equation)
	  ■ Pressure and temperature profiles in the tubing and annulus
	  ■ Formatted report including input data, design results, and gradient/valve plot
	Gas lift diagnostics
	■ Gas lift diagnostics taking into account injection gas conditions and operating boundary conditions to provide operational status of each valve (open, closed, or throttling)
	■ Graphical diagnostic results providing production and injection profiles, including valve status
	■ Tabulated performance datasheet reporting the operating status of each valve
	■ Nitrogen temperature correction factors including Winkler-Eades and DAK-Sutton for high pressure
	■ Specification of both the total gas injection rate and injection pressure to enable tuning the valve equations to ensure that valve performance equations match measured data
	Related operations
	■ Deepest injection point: Determination of how deep gas can be injected based on the associated production rate for given fluid and operating conditions
	■ Lift gas response: Performance analysis of a well under gas lift for various conditions such as changing fluid data, injection and operating conditions, and varying injection depths

Electric submersible pumps	The PIPESIM simulator uses advanced methodology to perform ESP design and associated operations. Key features include the following.
	ESP database
	■ Extensive database of ESP performance curves covering a wide range of production rates
	■ Performance curves easily added by users from any manufacturer for design and simulation purposes
	ESP selection and design calculations
	■ Pumps recommended by the design calculation in the order of decreasing efficiency based on target production rates and size constraints
	■ The required number of stages (taking into account losses between stages) calculated with a report of the head, differential pressure, intake gas volume fraction, and power required
	■ Effects of downhole separation, head factor tuning, and viscosity corrections considered in the design and staging calculations
	■ Design results and plots including
	  ■ Standard performance curve with operating conditions annotated
	  ■ Multispeed pump performance curves at operating conditions indicating gas volume fraction at pump intake
	ESP well simulation
	■ All the PIPESIM simulator's standard operations available to model ESP wells (e.g., pressure-temperature profile, nodal analysis, system analysis, and network simulation)
	■ ESP parameters (speed, number of stages, and power) available as sensitivity variables

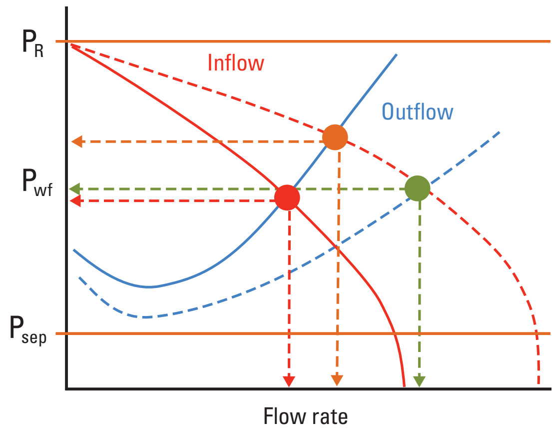
Artificial Lift Design and Simulation continued	
Rod pumps	**Rod pump simulation** ■ Simulation of rod pumps as downhole equipment including the ability to recombine annulus gas at the wellhead and optional support for a downhole separator ■ Available for all types of the PIPESIM simulator's standard operations, including network simulation

Progressive cavity pumps	The PIPESIM simulator enables simulating PCPs. Key features include the following:
	■ PCP performance curves for various sizes and nominal rates available from the following manufacturers:
	  ■ Schlumberger—KUDU PCPs
	  ■ PCM
	  ■ Weatherford
	  ■ Performance curves from any manufacturer easily added by users
	■ PCP well simulation
	  ■ Support for PCPs with both top- and bottom-drive configurations
	  ■ Options for adjusting the slip, rate, and head factors, viscosity correction, and gas separation

Jet Pumps	**Jet pump simulation (via plugin):**
	  ■ Design downhole jet pumps by selecting optimal nozzle and throat sizes
	  ■ Determine optimal power fluid injection pressure and rate
	  ■ Report cavitation limits and critical flow conditions

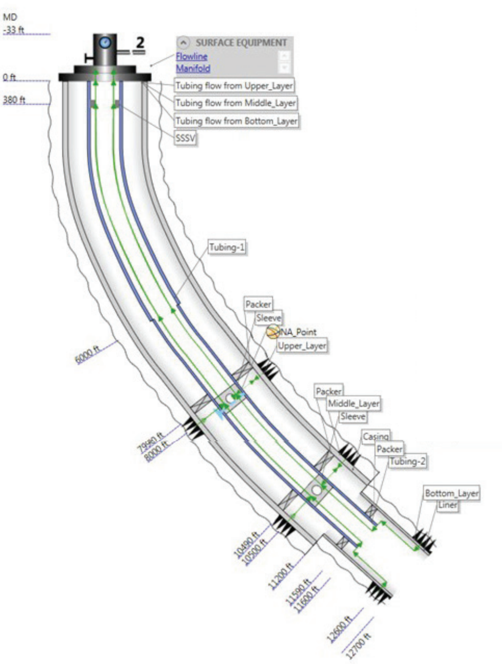
Nodal analysis and other operations

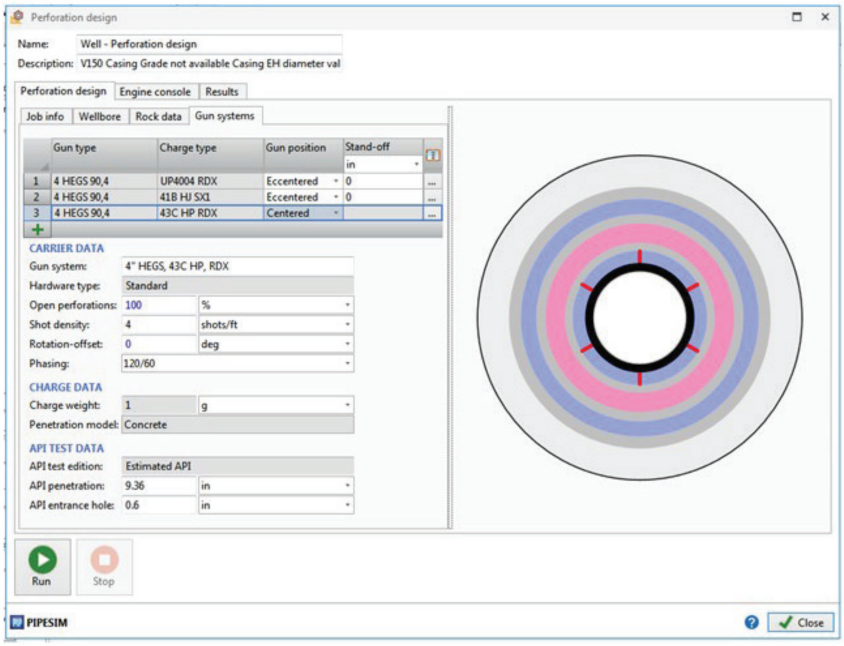
Long the established method of evaluating well performance, nodal analysis is critical to understanding the behavior of a system. The PIPESIM simulator's nodal analysis enables users to create inflow-outflow plots at any point in the system and perform sensitivity analyses on any system variable. These capabilities provide an understanding of where production enhancement opportunities may exist. In addition to nodal analysis, the PIPESIM simulator provides a variety of other well-specific simulation tasks to address a wide range of well modeling workflows.



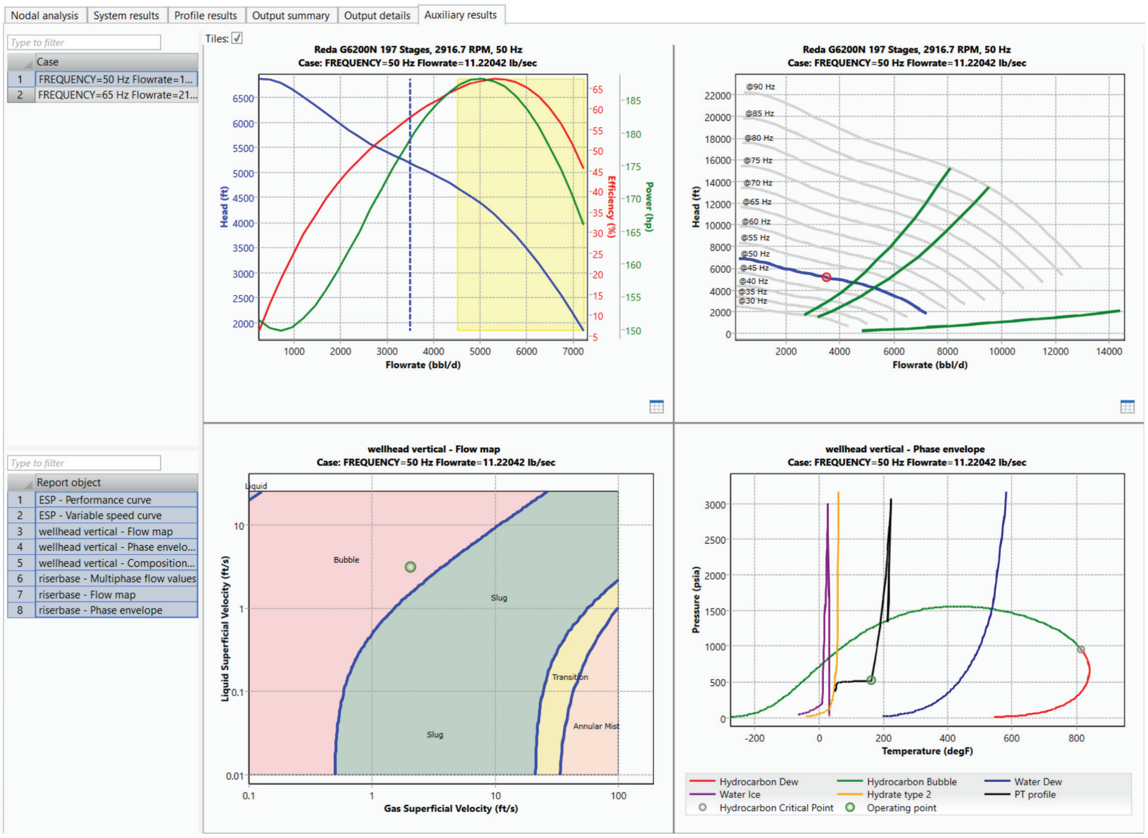
Well Performance

PIPESIM Simulator: Single-Branch Operations	
Pressure-temperature profile	Reporting of many detailed variables (e.g., flow rate, pressure distribution, fluid properties, thermal properties, multiphase flow characteristics, and flow assurance parameters) over the length of the flow path: ■ Solving for the unknown boundary condition (pressure or flow rate) ■ Solving for equipment operating conditions if both pressures and flow rate are provided ■ Sensitivity analysis for model objects, fluid properties, and boundary conditions ■ Profile plots with hundreds of potential result variables available
Nodal analysis	Standard performance analysis applicable to a simple wellbore system with applications including well and completion design, artificial lift selection and design, equipment sizing, system debottlenecking, flow assurance analysis, and many others. Features available include ■ Inflow and outflow sensitivities ■ Nodal plot (with several plot control options)
Data matching	Advanced tool that uses optimization techniques to select and tune the best-suited flow correlations to match field pressure and temperature data by simultaneously adjusting friction, holdup, and heat transfer factors. Results can be quickly visualized and inspected before applying the correction factors to the model, which can then be used to construct more accurate optimization scenarios or future performance predictions.
Perforation design	Rigorous perforation design for determining the optimal perforating gun selection, phasing, and spacing. In addition to the standard concrete method based on API RP 19B test data, the SPAN Rock* stressed-rock perforating analysis model developed by Schlumberger is available. The resulting design can be used to update the well model with the entrance hole diameter and penetration depth data, which are needed to calculate the skin factor of the vertical or horizontal completion.
System analysis	One of the most versatile analysis tools in the PIPESIM simulator, the system analysis tool enables users to analyze the performance of production and injection systems (well, pipeline, and other components) in detail. It has advanced sensitivity options that support the variation of multiple parameters through either permutations or on a case-by-case basis.
Reservoir tables	Generation of vertical lift performance curves for both production and injection wells including sensitivities for flow rates, fluid properties, outlet pressure, and artificial lift quantities. Results are generated in specific formats for industry-standard reservoir simulators.





The Perforation Design task is used daily within Schlumberger to select the optimal perforation gun and associated characteristics.



Gain additional insight by viewing pump performance plots, flow pattern maps, phase diagrams and other spot reports as auxiliary results for simulation tasks

Flow Assurance

Some of the most severe operational hazards are associated with the transportation of fluids. When oil, water, and gas simultaneously flow in a well or pipeline, many problems can arise. These problems may be related to flow instabilities, solids formation that may block the flow path, and erosion and corrosion that can even result in pipeline ruptures.

The PIPESIM simulator provides the industry's most comprehensive steady-state flow assurance workflows, both for front-end system design and production operations. The PIPESIM simulator is frequently used to identify situations that require more detailed transient simulation using the OLGA dynamic multiphase flow simulator and includes a utility to convert models to the OLGA simulator. Such situations may include shut-in, start-up, ramp-up, terrain-induced slugging, severe slugging, slug tracking, hydrate kinetics, and wellbore cleanup. Together, the PIPESIM and OLGA simulators offer the most comprehensive modeling solution for studying multiphase flow systems.

The PIPESIM simulator enables users to

- design and optimize pipelines and equipment such as pumps, compressors, and multiphase boosters to maximize production and capital investment
- develop mitigation strategies for systems in operation
- rigorously model multiphase flow, heat transfer, and fluid behavior to ensure that fluids reliably reach the delivery point

The PIPESIM simulator enables optimal design of pipelines and facilities to ensure fluid flow from pore to process.

Typical flow assurance applications

- Size pipelines to minimize backpressure while maintaining stable flow rates and operating within the maximum allowable operating pressure (MAOP)
- Size pumps, compressors, and multiphase boosters to meet target flow rates
- Balance pipeline size against flow boosting to maximize accounting economics by using sophisticated sensitivity options
- Model the benefits of parallel flowlines
- Calculate optimal burial depth and insulation requirements
- Identify risk for severe riser slugging
- Manage pipeline integrity with erosion and corrosion prediction
- Accurately characterize fluid behavior with a wide variety of black oil and compositional fluid models
- Size separation equipment and slug catchers to manage liquids associated with pigging operations, ramp-up surges, and hydrodynamic slug volumes
- Identify the risk of potential solids formation including hydrates, asphaltenes, and scale
- Assess the operational risk from deposition of wax in flowlines over time
- Determine the amount of methanol to inject to avoid hydrate formation
- Perform accurate pressure drop calculations for emulsion formation
- Perform comprehensive sensitivity analyses at any point in the hydraulic system with either multiple parameters in permutations or on a case-by-case basis for sets of conditions
- Match specified pressure and temperature data through automatic regression of holdup, friction, and heat transfer factors
- Report many detailed variables (e.g., flow rates, pressure distribution, fluid properties, thermal properties, multiphase flow characteristics, and flow assurance parameters) over the length of the flow path
- Visualize detailed reports at any point of interest including flow pattern maps and phase envelopes.

Surface facilities

The PIPESIM simulator includes models for a variety of common surface facility equipment to determine their impact on system design. The sophisticated sensitivity options in the PIPESIM simulator can be used to design systems by varying key operating parameters, thus enabling determination of the optimal pipeline and equipment sizes.

Flow Assurance for Surface Facilities	
Flowlines and risers	The PIPESIM simulator supports both simple and detailed modes for defining flowlines and risers. Options include the following: ■ Define pipe undulations to account for uneven ground (flowlines) and to model both risers and downcomers ■ Specify data required from simple through detailed heat transfer calculation (see the "Heat Transfer Modeling" section for more details) ■ Specify measured pressure and temperature (if available) for use in model tuning using sophisticated regression algorithms ■ Model electrical heating of flowlines ■ Visualize schematics to illustrate flowline and riser geometry profiles ■ Inherit globally defined ambient fluid properties for both land and subsea environments ■ Populate elevation profiles on land or subsea automatically, when used on GIS map
Sources and sinks	■ Define points of fluid entry into and exit from the system instead of for individual production and injection wells ■ Specify network sources with pressure and flow (PQ) curves to represent wellhead responses
Chokes (surface and downhole)	The PIPESIM simulator provides the capability to model chokes and flow restrictions both at surface and downhole. Options include the following: ■ User-specified or calculated choke bean size ■ User-specified or calculated critical pressure ratio across choke ■ Various correlations for the calculation of pressure losses for both critical and subcritical flow ■ Advanced options to tune choke performance by specifying flow coefficients for liquid and gas phases, discharge coefficient, the ratio of specific heat at constant pressure and volume (C_p/C_v), gas expansion factor, and others
Pumps	■ Control of pump performance by applying limits for ΔP, power, and other individual factors or a combination of these ■ Calculation of pump parameters (such as ΔP and power) for single or multiple sets of operating conditions ■ Simple thermodynamic model or user-specified curves ■ Availability of most pump performance parameters (including head, ΔP, power, number of stages, speed, and efficiency) as sensitivity variables for design or uncertainty analysis ■ Viscosity correction (Turzo method)

Multiphase boosters	■ Generic multiphase booster (treated as pump and compressor in parallel)
	■ OneSubsea, a Schlumberger company, multiphase pumps and wet gas compressors
	  ■ Model catalog
	  ■ Tuning factors
	  ■ Models in series versus parallel and recirculation behavior
	  ■ Generation of detailed performance maps
	■ Control of booster performance by applying operational limits in various combinations
	■ Availability of most compressor performance parameters—head, ΔP, power, number of stages (if applicable), speed (if applicable), efficiency, and others—as sensitivity variables for design or uncertainty analysis

Compressors and expanders	■ Modeling of centrifugal and reciprocating compressors, as well as expanders ■ Compressor performance control by applying limits for ΔP, power, or others or a combination of these ■ Various thermodynamic routes—adiabatic, polytropic, or Mollier ■ Multiple stages for reciprocating compressors with the option to add an intercooler temperature condition for modeling compressor performance across a series of discharge pressure settings ■ User ability to add vendor performance curves to the PIPESIM simulator database ■ Availability of most compressor performance parameters—head, ΔP, power, number of stages (if applicable), speed (if applicable), efficiency, and others—as sensitivity variables for design or uncertainty analysis

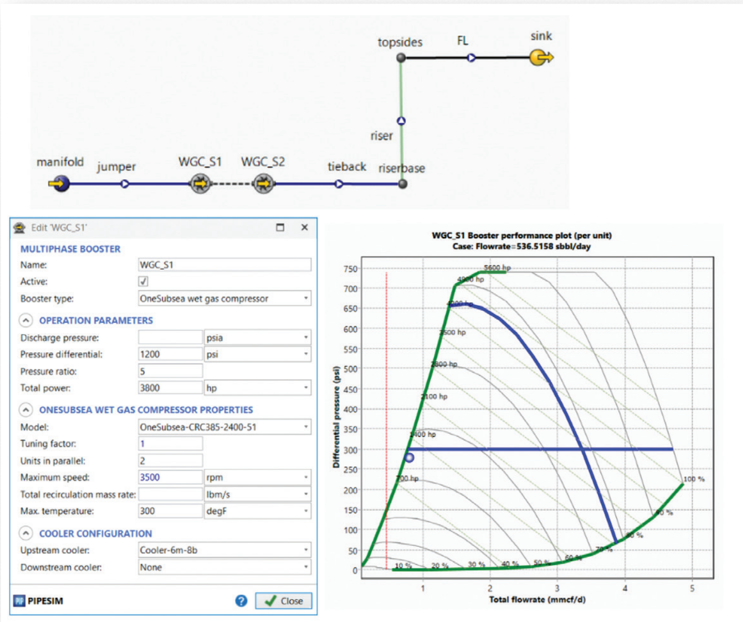
Flow Assurance for Surface Facilities continued	

Generic equipment	The Generic Equipment object enables users to model devices not available in the PIPESIM simulator’s equipment library. Key features include the following:
	■ Equipment modeling with one or more combinations of the following settings:
	  ■ Temperature differential or fixed discharge temperature
	  ■ Pressure differential or fixed discharge pressure (regulators)
	  ■ Device with a fixed duty
	■ Choice of various thermodynamic processes—isothermal, isenthalpic, and isentropic

Separator (inline for both surface and downhole and network)	The PIPESIM simulator has several options for modeling separators, including the following: ■ Separation defined with the rigorous PIPESIM simulator engine’s flash calculations performed for all types of fluid definitions based on in situ pressure and temperature conditions ■ Inline separators (downhole or surface) that discard liquid, gas, or water with a user-specified separation efficiency ■ Network separators that track both product and separated streams by adjusting for pressure continuity across separators to allow boundary-condition matching for each outlet stream ■ Separator configuration in series or parallel arrangements to model conditions for multistage separation trains

Heat exchangers	Heat exchangers can be used to model both heaters and coolers. Key features include the following:
	■ Equipment modeling with one or more combinations of the following settings:
	  ■ Fixed discharge temperature, temperature differential, or duty
	  ■ Fixed discharge pressure or pressure drop
	■ Ability to sensitize on all of the preceding parameters
	■ Wide range of reports for both inlet and outlet conditions

Fluid injection	The PIPESIM simulator allows modeling of fluid injectors in the surface network. Fluid injection can be used to inject chemicals or other fluids to handle flow assurance issues. Key features include the following: ■ Ability to inject any type of petroleum fluid—black oil, compositional, and MFL files (generated from Multiflash stand-alone) ■ Ability to model riser-base gas lift ■ Seamless mixing of injected fluid with the main fluid to predict mixture properties
Adders and multipliers	Adders and multipliers are used as a tool to simulate the performance of a flowing production or injection system to account for many scenarios. Examples include the following: ■ Designing a pipeline system to account for future added capacity ■ Simulating turndown scenarios in surface pipelines ■ Designing parallel pipelines
Check valves	■ Use check valves to block flow



Modeling of multiphase pumps and wet gas compressors from OneSubsea.

Corrosion and erosion

Understanding corrosion fundamentals is essential to designing sound strategies that effectively control corrosion. Corrosion occurs because an aqueous phase is almost always present in oil and gas fluids. Corrosivity depends on the concentration of CO_2, temperature, pressure, flow regime, and flow rate.

The PIPESIM simulator identifies locations prone to corrosion and specifically predicts CO_2 corrosion rates. The de Waard corrosion model calculates a corrosion rate caused by the presence of CO_2 dissolved in water. The concentration of CO_2 is obtained from fluid property definitions (black oil or compositional).

Erosion is also potentially very damaging. It can occur in solids-free fluids but is exacerbated by entrained solids (sand). The rate of sand production is the main determinant of the erosion rate. With the PIPESIM simulator, engineers can model erosion to select appropriate equipment and materials.

The PIPESIM simulator's erosion-modeling methods include the API 14E and Salama models. The erosional velocity limit is calculated based on the prevailing flow conditions and presented as a ratio of the fluid mean velocity to the estimated erosional velocity, in which case, values of one or greater indicate the degree of risk. Additionally, the Salama model predicts the rate of material loss due to erosion from fluids containing sand. Results along the flow profile, maximum erosion rates in the branches, and velocity ratios are reported in an output file and in plots.

Emulsions

Emulsions resulting from oil and water mixtures can lead to processing problems and higher treatment costs. High liquid viscosities resulting from emulsion formation can cause high pressure losses in wells and flowlines. A number of emulsion correlations are available within the PIPESIM simulator, including Woelflin, Brinkman, Vand, Richardson, and Leviton and Leighton. The inversion point that defines the continuous phase can be specified by the user or calculated using the Brauner-Ullman equation.

Hydrates

Water and hydrocarbon fluids can form hydrates, which, if left untreated, can cause blockages. The physical properties of hydrates are similar to those of ice, but hydrates can form at relatively high temperatures in high-pressure systems. Once a plug is formed, intervention is required that may result in significant downtime.

It is, therefore, important to design and operate an offshore pipeline system to effectively manage hydrate risk. The PIPESIM simulator includes the following hydrate mitigation strategies:

- Thermal insulation: The best way to mitigate hydrate risk is to maintain the fluid temperature inside the pipeline above the hydrate formation temperature. By considering detailed heat-transfer mechanisms, the effects of insulation and pipeline burial can be investigated for front-end design.
- Chemical inhibition: If flowline insulation is not sufficient to maintain temperatures above the formation point, thermodynamic inhibitors such as methanol and monoethylene glycol (MEG) can be modeled to determine the necessary dosage rates to prevent hydrates.

Hydrate curves can be calculated by using the PIPESIM simulator with the Multiflash Hydrates module and superimposed on the phase envelope. These curves are useful for subsea pipeline design and operations, identifying the pressure and temperature conditions the system should maintain to avoid hydrate formation. Additionally, the hydrate subcooling equipment is reported along the profile as well as the maximum subcooling value for each branch.

Liquid slugging

Slugging can cause major operational problems for downstream processing facilities. Slugging refers to varying or irregular flows and surges of gas and liquid in a pipeline. The PIPESIM simulator models two types of slug flow:

- Severe slugging: This can occur in a multiphase transport system consisting of a long flowline followed by a riser. The PIPESIM simulator determines the likelihood of severe riser slugging by employing the Pots correlation, which computes the ratio between the pressure buildup rate of the gas phase and that of the liquid phase in a flowline followed by a vertical riser. Values less than one indicate that severe riser slugging is likely to occur.
- Hydrodynamic slugging: Slugs are formed by waves growing on the liquid surface to a height sufficient to completely fill a horizontal or near-horizontal pipe. The repeated impacts of hydrodynamic slugging can cause pipeline fatigue, and large slugs may overwhelm surface facilities, such as the slug catcher, if they are not designed to handle such large liquid volumes. The PIPESIM simulator calculates the mean slug length as a function of the distance traveled. A probabilistic model is then applied to determine a distribution of slug lengths and frequencies. The calculated size of the slugs can be used to design liquid separators and slug catchers.

Waxes and asphaltenes

Wax and asphaltene deposition can become so severe that it can completely block a pipeline and may cost millions of dollars to remediate. When the temperature of crude oil is reduced, heavy solids such as paraffin and wax (C_{18}–C_{60}) may precipitate and deposit on the pipe wall. The decreased internal diameter results in a higher pressure drop.

The PIPESIM simulator includes wax and asphaltene precipitation models as an extension to the Multiflash PVT package.

Auxilary profile calculations

The new user auxilary plug-in architecture enables extending the PIPESIM simulator with your science to perform additional calculations of interest along the flowpath. This plug-in takes standard output variables and produces additional profile and branch results using a direct engine extension written in Fortran or C++ and compiled as a dynamically linked library (DLL). Several examples are included in PIPESIM Labs, a new collection of plug-ins that installs with PIPESIM simulator—demonstrating the power of extensibility.

Flow Assurance

PIPESIM Simulator's Flow Assurance Capabilities	
Liquid loading	■ Perform liquid loading analysis (primarily to determine the minimum stable flow rate for vertical gas wells) ■ Tune prediction calculation by applying a correction factor ■ Analyze a well or network for locations susceptible to liquid loading
Hydrates	■ Use the Multiflash compositional package to generate hydrate formation curves on the phase envelope ■ Create a production profile superimposed on a phase envelope to predict the occurrence and location of hydrate formation ■ Report hydrate formation temperatures and hydrate subcooling delta-temperatures to determine the occurrence and location of hydrate formation in a single well or large network ■ Analyze effects of hydrate inhibitor and determine the required treatment quantity to prevent hydrate formation
Asphaltenes	■ Use the Multiflash compositional package to generate asphaltene formation curves on the phase envelope ■ Create a production profile superimposed on a phase envelope to predict the occurrence and location of asphaltene formation ■ Report asphaltene formation temperatures and asphaltene subcooling delta-temperatures to determine the occurrence and location of asphaltene in a single well or large network

Waxes	■ Use the Multiflash thermodynamic prediction module to
	  ■ Generate a wax formation curve on the phase envelope
	  ■ Superimpose a production profile on top of the phase envelope to predict the occurrence and location of wax
	  ■ Report critical wax formation temperatures and subcooling delta-temperatures to determine the occurrence and location of wax in a single well or large network

Scales	■ Generate a PVT file with ScaleChem to predict the occurrence, type, location, and severity of scale formation

Emulsion modeling	■ Select from emulsion models including the following:
	  ■ Continuous phase viscosity
	  ■ Volume-weighted mixture viscosity
	  ■ Woelflin loose, medium, and tight models
	  ■ Brinkman
	  ■ Vand (Vand coefficients, Barnea, and Mizrahi coefficients or user-specified coefficients)
	  ■ Richardson (with tuning for K factor)
	  ■ Leviton and Leighton
	  ■ User-specified emulsion table
	■ Specify or calculate the inversion water cut using the Brauner-Ullman equation

Corrosion modeling	■ Predict CO_2 corrosion using the de Waard corrosion model ■ Employ tuning options for efficiency ■ Override pH calculation or derive from ScaleChem PVT files ■ Account for the effect of corrosion inhibitors (MEG, diethylene glycol [DEG]) ■ Obtain the corrosion rate, pH, glycol inhibition factor, and many other variables

Erosion modeling	■ Select from erosion models including the following:
	  ■ API 14E
	  ■ Salama (for sand-laden fluids)
	■ Employ tuning options for efficiency
	■ Obtain the erosional velocity limit, erosional velocity ratio, erosion rate, and many other variables

Slug and pigging analysis	■ Perform calculations for
	  ■ Slug length
	  ■ Slug growth
	  ■ Probabilistic slug length distribution
	  ■ Severe riser slugging indicator
	  ■ Pig-generated slug volume, transit time, and dumping time

PIPESIM Simulator Network Simulation and Optimization

A detailed understanding of the thermohydraulics of a production system is critical to pipeline and facility design and coping with flow assurance challenges. The PIPESIM simulator provides users with an advanced network simulator for analyzing complex production and injection networks. A unique benefit of the PIPESIM simulator's network solver is that it shares a common software environment with the well, pipeline, and flow assurance modeling capabilities to deliver the most rigorous field-wide solution available on the market. The network solver has been designed to solve networks of virtually any size and topology, including complex loop structures and crossovers. Modeling the entire production or injection system as a network is necessary to properly account for the interdependency of wells and surface equipment and to determine the deliverability of the system as a whole. The 64-bit network solver runs in parallel for maximum performance and scalability.

The GIS network canvas helps deliver true spatial representation of wells, equipment, and pipeline networks. The engineer subsequently gains a much better understanding of the actual field environment, which enables smarter decision making for previously unseen physical obstacles or other considerations.

Users can construct networks interactively on the GIS canvas and quickly populate pipeline elevation profiles using a web service for both onshore and offshore environments. Large networks can also be constructed very quickly by converting existing Shapefiles into pipeline systems, thereby eliminating the need to manually trace pipe profiles. Well models can easily be imported or exported which allows specialists to perform detailed well design tasks independently.

The PIPESIM simulator enables users to:

- engineer the best well, pipeline, and facilities design for the complete system
- identify production bottlenecks and constraints
- optimize production from complex networks.

Typical network modeling applications

- Design and operate oil and gas gathering systems while honoring multiple system constraints
- Quickly identify locations in the system that are the most prone to flow assurance issues such as erosion, corrosion, and hydrate formation
- Quantify the benefit of adding new wells, compression, contractual pipelines, and other components
- Determine optimal locations for pumps and compressors
- Design and operate water or gas injection networks
- Analyze hundreds of variables such as pressure, temperature, and flow assurance parameters through complex flow paths
- Evaluate the benefit of loops and reduce backpressure
- Calculate full-field deliverability to ensure that delivery rates can be met
- Optimize the allocation of lift gas, ESP/PCP speeds and choke settings to maximize overall oil or gas production rates while honoring multiple constraints

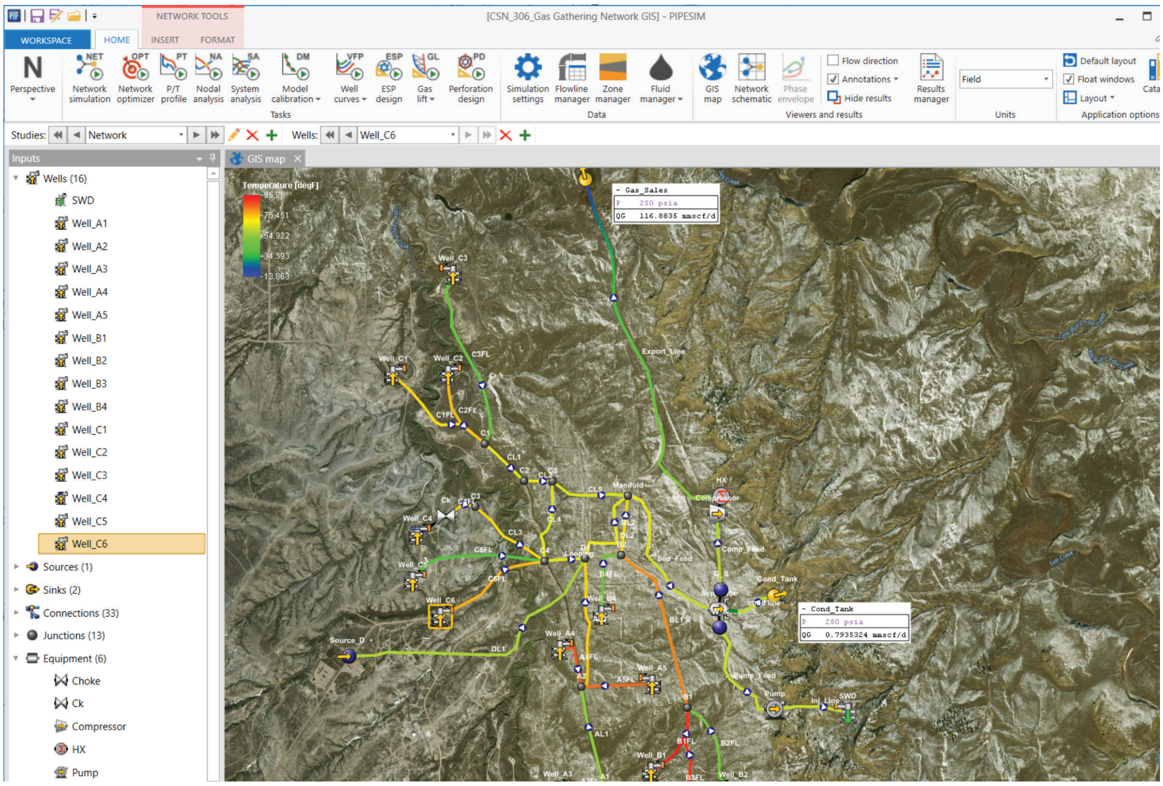
PIPESIM Simulator Network Simulation and Optimization

PIPESIM Simulator's Network Simulation and Optimization	
Key features	■ Solving for unspecified boundary conditions (pressure and flow rate) ■ Scaling for networks up to 10,000 wells or sources ■ Performance-optimized solver employing parallelization to use multiple CPU cores ■ Multiple rate constraints handled ■ Flexible plotting functionality with hundreds of potential variables to select from and configuration of multiple y-axes ■ Interactive network simulation result tables ■ Visualization of results as color gradients on the GIS canvas ■ Summary and detailed output reports

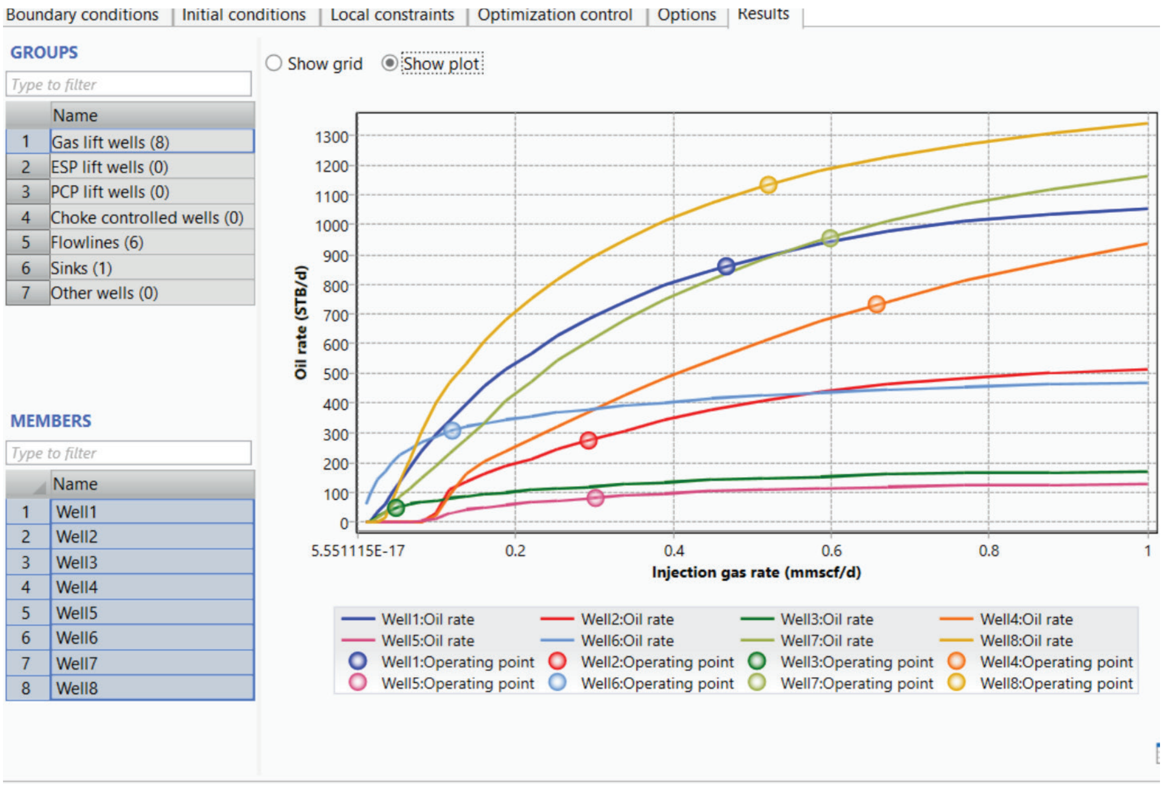
PIPESIM offers very powerful optimization capabilities to maximize production from a network of wells subject to a variety of constraints. This optimizer has been successfully applied to large networks containing hundreds of wells.

Key features:

- Optimize oil or gas production based on:
  - Lift gas allocation (for gas lifted wells)
  - Wellhead choke settings (to honor constraints)
  - ESP frequency or PCP pump speed (overall power allocation)
- State-of-the-art optimization algorithm developed by Schlumberger Cambridge Research
- Comprehensive constraint handling capabilities:
  - General: Well stability, Min/Max flowrates (liquid, water), well drawdown limits, bubble point pressure margin, etc.
  - Flow assurance: erosion control, CO2/H2S limits
  - Operational constraints: Available lift gas, available power, facility capacity limits, etc.
  - Gas Lifted Wells: Lift gas limits (min/max), casing head pressure, dual string wells
  - ESP/PCP Lifted Wells: power available, minimum frequency/speed, maximum frequency/speed
  - Wells on Choke: Min/max choke setting



Interactively construct networks, sample elevation profiles and view results on the PIPESIM GIS map canvas.



Optimal allocation of lift gas to maximize field oil production.

Extensibility

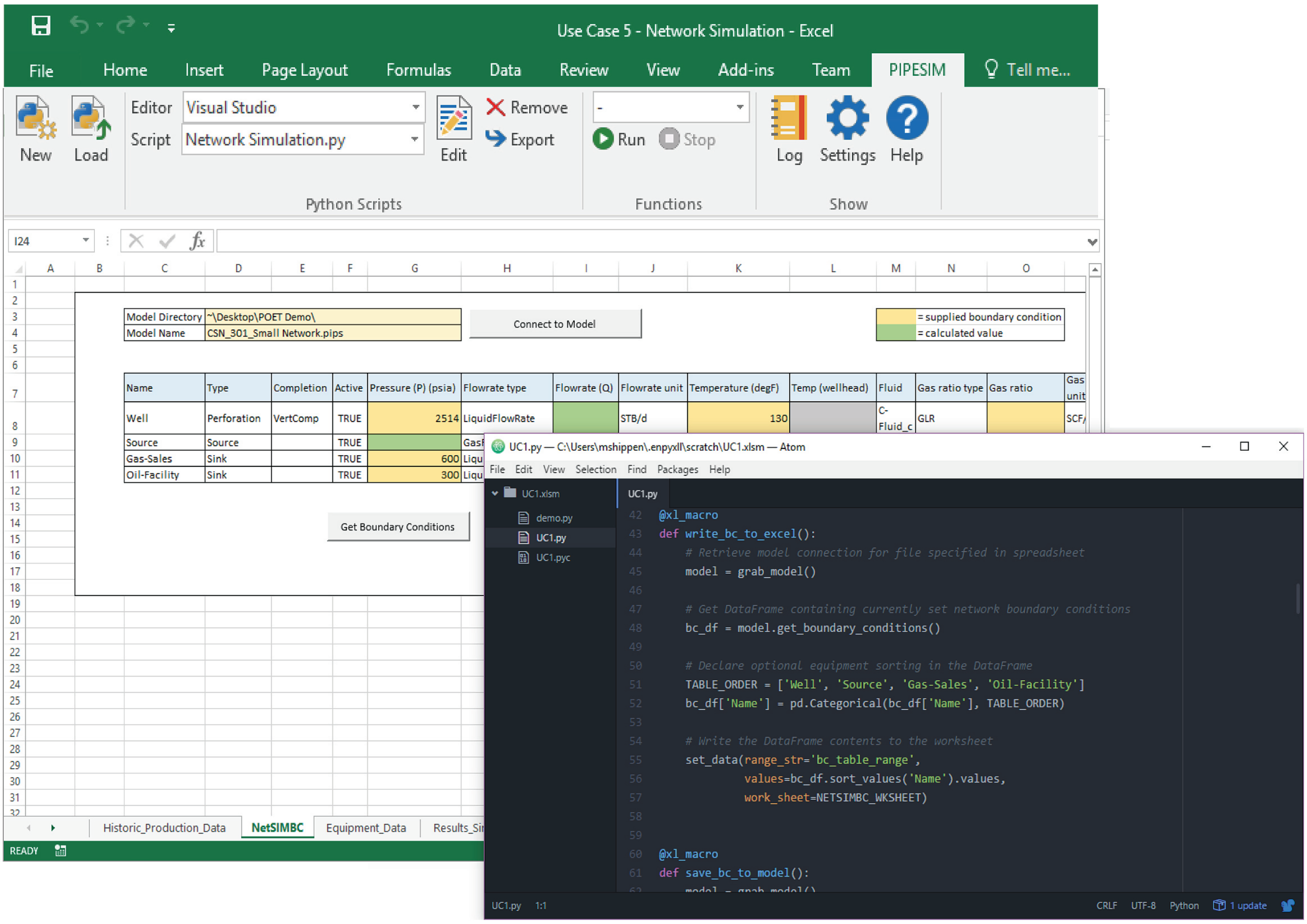
The Python toolkit introduced with PIPESIM enables you to automate PIPESIM simulator workflows using Python scripts through a well-documented software development kit (SDK). This empowers you to perform many functions very quickly, ranging from model building and calibration to running simulations, without opening the PIPESIM simulator UI. This is particularly useful for performing repeated actions such as bulk model updating and batch simulation running. The Python toolkit replaces the PIPESIM OpenLink application program interface (API) in PIPESIM 2012 and earlier versions.

Additionally, with the wide variety of freely available Python packages, engineers can leverage the latest advancements in data science, machine learning, and other fields through the Python toolkit. The power and flexibility of the Python ecosystem enable complex, multistep workflows to be readily scripted and shared.

The Python toolkit includes the Enthought Canopy Python 3.5 distribution with many of the latest and most popular science and engineering libraries. Its integrated development environment (IDE) helps you quickly write and debug Python scripts while the Canopy Package Manager makes the installation of additional packages simple and seamless.

The Python scripts can be embedded and managed in Excel using the PIPESIM simulator ribbon tab. The Python scripts provide similar functionality to visual basic for applications (VBA) scripts in distributing integrated workbooks and assigning macros. The Excel integration also supports user-defined functions and message logging.

The Python toolkit may be used to automate network simulation, PT profile, and nodal analysis tasks.

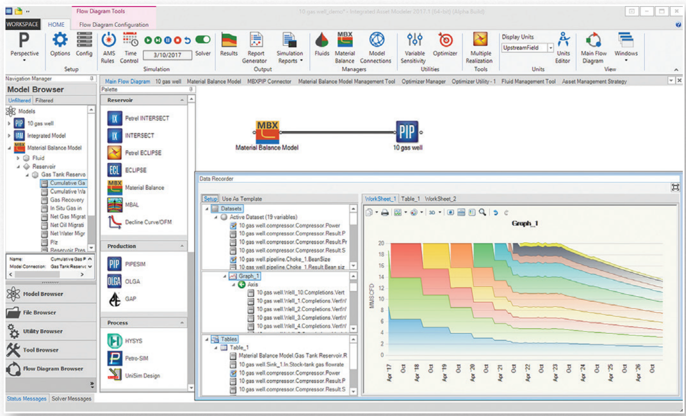


The Python toolkit includes Microsoft Excel integration, which provides a dedicated ribbon toolbar.

IAM* field development planning and operations software provides the most complete and flexible framework for making critical decisions about an asset's development and operation over its life. IAM software enables the coupling of domain models—reservoir, production, process, and economics—into a total system model for asset-level decision making.

PIPESIM simulator combined with IAM software enables you to

- achieve more accurate forecasts by accounting for the interactions of the subsurface deliverability with surface backpressure constraints
- optimize the use of artificial lift, enhanced oil recovery (EOR), and improved oil recovery (IOR) injection
- plan gas storage operations by predicting deliverability and optimizing compressor design
- determine field development plans to optimize revenue based on capex and opex
- enable multi-disciplinary work processes by leveraging up-to-date and fit-for-purpose models spanning the complete hydrocarbon pathway from Pore to Process.



IAM software unites subsurface and surface understanding to enable better decisions for the entire asset.

Typical IAM software applications

- Dynamically couple to reservoir models including ECLIPSE industry-reference reservoir simulator, INTERSECT* high-resolution reservoir simulator, MBX material balance model, and decline curves for life of field forecasting.
- Dynamically connect to process simulation models including HYSYS, UniSim, and Petro-SIM to account for facility constraints.
- Connect to economic models including Microsoft Excel and Merak* PEEP for calculation of economic benchmarks such as cash flow and NPV.
- Control the forecast schedule using either date-based rules or conditional logical (e.g., if Qgas < target, then drill next well).
- Govern facility and well rate constraints over time.
- Run drilling schedules of wells to meet rate targets.
- Report flow assurance risks over time.
- Apply economic limits (e.g., shut-in well zone if water cut > 95%).
- Control network equipment including compressors and pumps to optimize production over time.

IAM includes the MBX material balance model developed by Schlumberger. MBX enables fast and simple reservoir modeling for cases where rigorous reservoir simulation is not available.

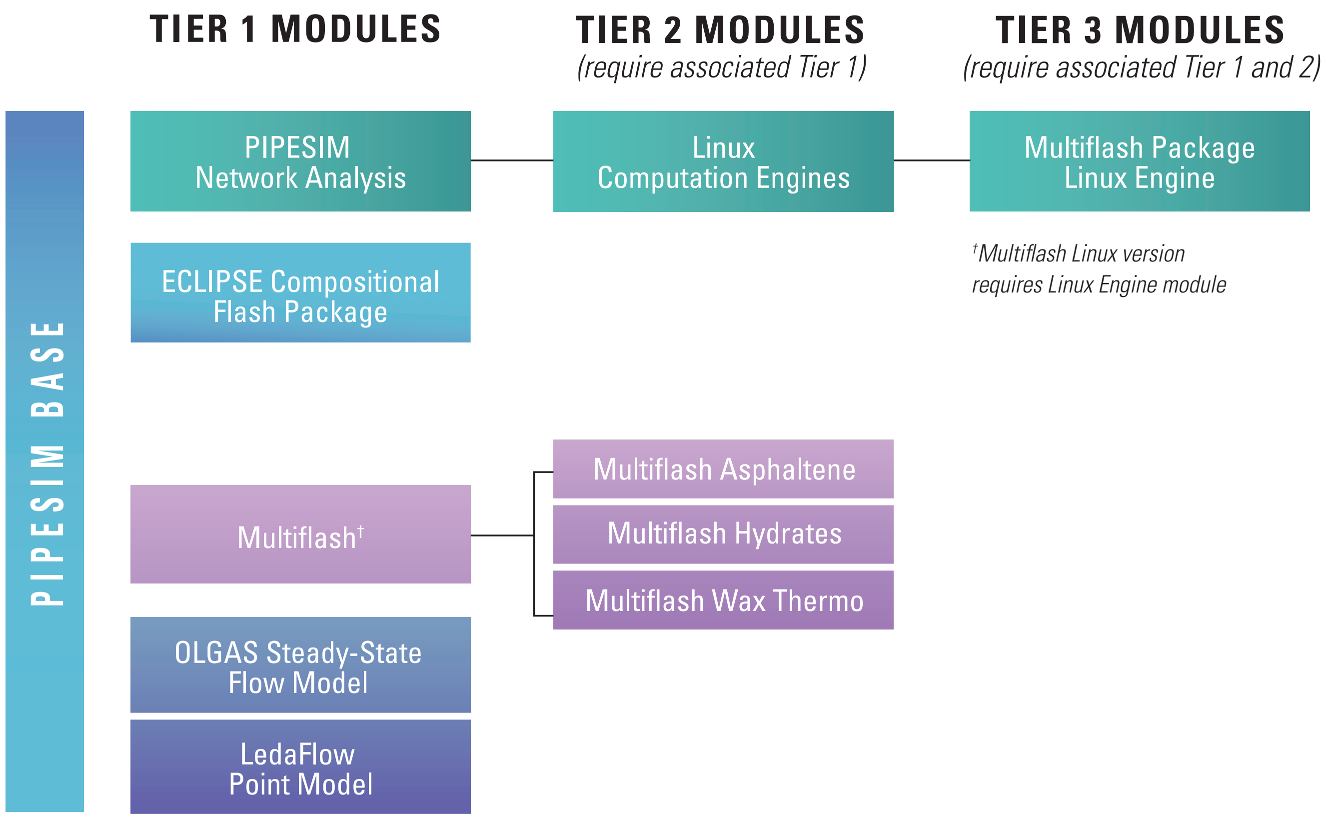
MBX functionality:

- Forecast oil or gas reservoirs with or without water influx.
- Match history at the zone level based on a variety of matching parameters.
- Model black oil or compositional fluids.
- Model for gas and water injection.
- Account for voidage replacement for EOR, such as waterfloods.
- Define cylindrical or depth-dependent reservoir geometry.
- Calculate oil or gas in place using the Havlena-Odeh analytical method.
- Track depth of phase contacts over time.
- Analyze drive mechanisms, such as energy plots.
- Account for transmissibility between multiple tanks to account for faulting and crossflow.
- Calculate gas/oil ratio (GOR) and water cut from a variety of relative permeability models.

Integration

Through integration with other Schlumberger and third-party software products, the PIPESIM simulator enables you to build a fully integrated model of the entire asset, connecting with reservoir and process simulators such as the ECLIPSE, HYSYS, and Uni-Sim simulators as well as real-time data for online optimization.

- Petrel* Well Deliverability module uses PIPESIM simulator to generate VFP tables and perform nodal analysis within the Petrel platform.
- Avocet* production operations software platform is the Schlumberger production operations platform used to manage production data and interface with PIPESIM simulator for model-based surveillance and optimization. PIPESIM simulator well models can be executed and run within the Avocet platform's environment.
- IAM software is an integration platform used to combine the PIPESIM steady-state multiphase flow simulator with the ECLIPSE reservoir simulator and INTERSECT reservoir simulator, MBX material balance tank model, HYSYS, UniSim and PetroSIM process simulators, and economic analysis tools such as Merak Peep or Microsoft Excel for the simulation and optimization of entire assets—incorporating constraints at every level.
- OLGA simulator is the industry leader for transient multiphase flow simulation. The PIPESIM simulator install contains a model conversion utility that enables you to export PIPESIM simulator models into an OLGA simulator format.



Tier 1 Models		Requires
Optional add-on for network simulation and optimization	Optional add-on for modeling networks	
ECLIPSE Compositional Flash package	Optional add-on to the PIPESIM simulator for compositional fluid modeling. Also includes GERG advanced gas equation of state (EOS)	PIPESIM simulator base system
PIPESIM Multiflash package	Optional add-on to the PIPESIM simulator for compositional fluid modeling that uses the third-party Multiflash flash package to provide fluid modeling and advanced flow assurance analyses. The module includes the Multiflash stand-alone interface with extended compositional modeling functionality in addition to the simplified interface available within the PIPESIM simulator.	PIPESIM simulator base system
OLGAS steady-state flow model	Steady-state version of the 3-phase mechanistic multiphase flow model used with the OLGA simulator for transient flow (includes a 2-phase option)	PIPESIM simulator base system

Tier 2 Modules		Requires
Linux computation engines	Optional add-on to PIPESIM Network Analysis that includes single-branch and network computational engines for use in a Linux operating environment (used only with IAM software to couple the PIPESIM simulator to the ECLIPSE industry-reference reservoir simulator running on Linux clusters)	PIPESIM simulator base system Tier 1: PIPESIM Network Analysis (NET)
Multiflash	Optional add-on to the PIPESIM simulator for compositional fluid modeling that uses the third-party Multiflash flash package to provide fluid modeling and advanced flow assurance analyses. The module includes the Multiflash stand-alone interface with extended compositional modeling functionality in addition to the simplified interface available within the PIPESIM simulator.	PIPESIM simulator base system Tier 1: PIPESIM Multiflash package
Multiflash hydrates	Optional add-on to Multiflash package for hydrate analysis	PIPESIM simulator base system Tier 1: PIPESIM Multiflash package
Multiflash wax thermodynamics	Optional add-on to Multiflash package for wax thermodynamic predictions	PIPESIM simulator base system Tier 1: PIPESIM Multiflash package
Multiflash asphaltene	Optional add-on to Multiflash package for asphaltene predictions	PIPESIM simulator base system Tier 1: PIPESIM Multiflash package

Tier 3 Modules		Requires
Multiflash package Linux engine	Optional add-on to the PIPESIM simulator's Linux computation engines to allow use of the Multiflash package on Linux operating systems (used only with IAM software to couple the PIPESIM simulator to the ECLIPSE simulator running on Linux clusters)	PIPESIM simulator base system Tier 1: PIPESIM Network Analysis (NET) Tier 2: PIPESIM Multiflash package

Tier 1 Models		Requires
LedaFlow point model	Third-party steady-state version of the 3-phase mechanistic multiphase flow model from Kongsberg, developers of the LedaFlow transient simulator (includes 2-phase option)	PIPESIM simulator base system

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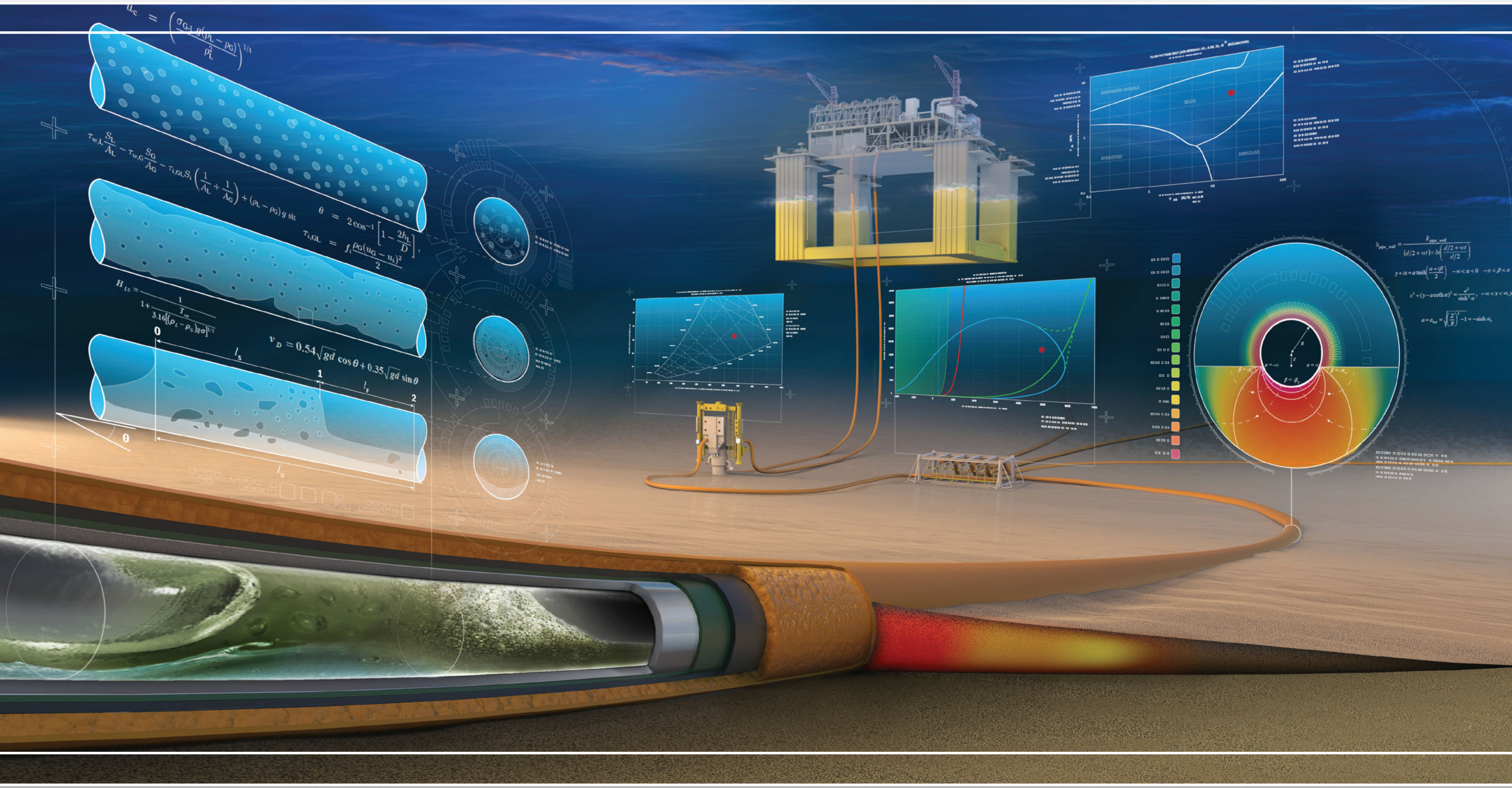
PIPESIM 2019 Steady-State Multiphase Flow Simulator



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