PVTsim Technical Overview
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INTRODUCTION

WHAT IS PVTSIM?

PVTSim is a versatile equation of state (EOS) modeling software that allows the user to simulate fluid properties and experimental PVT data. PVTSim is the primary commercial software owned, marketed and developed by Calsep thereby ensuring continued and long term improvements to the software.

PVTSim is divided into a number of modules. Clients can purchase Standard PVTSim Packages tailored for different application areas, or customize a package according to their actual needs.

WHY CHOOSE PVTSIM

Since its first release in 1988, PVTSim has been used by over 300 of the world’s leading oil & gas producing and operating companies, service companies and PVT lab specialists. More than 30 years of extensive data collection and joint industry projects has made PVTSim one of the most versatile and reliable petroleum fluid simulators. Distinguishing PVTSim features include:

- Advanced flash and regression algorithms making PVTSim a very robust simulator
- Reliable & predictive reservoir fluid characterization
- 9 variations of cubic equations of state (EOS) and PC-SAFT EOS
- Self-regulating plus fluid regression designed to minimize manual tuning
- Regression history and audit trail automatically cataloged
- Advanced fluid handling including flexible lumping, mixing, and characterization of multiple fluids to a common EOS.
- Straightforward graphical user interface designed for fast and efficient work flow
- Capability to simulate PVT experiments without having experimental data to tune to
- Export to many different types of popular reservoir, pipeline, and process simulators for consistent fluid data across disciplines
- Fully compositional simulation of wax deposition along pipelines
- Open structure technology to create customized software solutions using PVTSim thermodynamics in 3rd party software
FLUID PREPROCESSOR

Easy to use and accurate reservoir fluid characterization is what PVTsim has gained recognition for. The Fluid Preprocessor is the base module in PVTsim where either raw or characterized fluid compositions can be input. By default, PVTsim characterizes fluid components up to C80, but a ‘heavy oil’ characterization option can be selected to handle components up to C200. By characterizing a plus fraction type of fluid, all component properties needed in subsequent simulations are established. The C7+ components are grouped into pseudo-components, which can be lumped according to user preference. Nine variations of the Peng-Robinson and Soave-Redlich-Kwong cubic equations of states (EOS) are supported with the option to use constant or temperature dependent volume translation. The PC-SAFT EOS is available for general flash and PVT simulations as well as in asphaltene simulation.

Fluid compositions will vary with depth and horizontal location in the reservoir. However, if these fluids are from the same reservoir, it is expected that they can be represented using the same equation of state model. With the common EOS option in PVTsim, it is possible to characterize up to 50 fluids with different compositions to a common EOS.

Key features included with the Fluid Preprocessor module are:

- Fluid property database
- Input of plus, no-plus, or characterized fluid compositions
- Flexible lumping options and preset lumping schemes
- Recombination of separator oil & gas
- Clean contaminated samples for mud
- Mix up to 50 different fluids
- Weave up to 50 different fluids while maintaining original fluid components
- Generate property tables
- Characterize up to 50 different fluids to a common EOS
QC (QUALITY CHECK)

Ensure fluid data is reliable before characterization using this comprehensive tool, which generates a straightforward and easy to read Word report listing possible reasons for fluid quality failure. Because the reliability of PVTsim outputs depends on the quality of input fluid data, it is critical to ensure the input data is accurate and representative of the desired fluid.

In case of failure, it is possible to have reasons for failure and suggested cures printed to a QC report.

Information required by the QC Module is:

- Fluid sample type: Bottomhole or separator
- Compositional analyses of the fluid samples
- Gas/oil ratio and STO oil density
- Fluid sample type: Gas, gas condensate, near critical, oil, or heavy oil

FLASH & UNIT OPERATIONS

Plot phase envelopes including the option to search for 3 phase regions and perform several different flash operations:

- PT (Pressure, Temperature) including options for non-aqueous fluids, aqueous fluids, or multiphase (up to 4 phases)
- PH (Pressure, Enthalpy)
- PS (Pressure, Entropy)
- VT (Volume, Temperature)
- UV (Internal energy, Volume)
- HS (Enthalpy, Entropy)
- K-factor (Specify K-factor)
- Split-factor (Specify a split factor)
- P-Beta (Pressure, Vapor mole fraction of non-aqueous phases)
- T-Beta (Temperature, Vapor mole fraction of non-aqueous phases)
- Saturate with water (Saturate the current fluid with water at given pressure and temperature)

The PT non-aqueous, K-factor, and Split-factor flash options consider only non-aqueous components two phases (gas and oil). The PT multi-phase option considers up to four fluid phases. The remaining flash options consider gas, oil, and aqueous phases. Simulation results are presented in a tabular format that can be exported to a built-in worksheet where the data may be manipulated and plotted inside PVTsim or the output data can be exported to Excel. Output from a flash calculation includes:
- Phase amounts (mole%, weight%, and volume%) and compositions
- Molar volume, density, and Z-factor
- Enthalpy, entropy, Cp and Cv
- JT coefficient and velocity of sound
- Viscosity, thermal conductivity, and surface tension
- Ability to save phase compositions from a flash for use in new simulations

Volumetric properties in the output are derived from the selected equation of state. Thermal properties are derived from a combination of special ideal gas models and the selected equation of state. The viscosity and thermal conductivity are calculated using either a corresponding states model (Pedersen modification) or the Lohrenz-Bray-Clark correlation.

This Flash & Unit Operations module also includes simulation capabilities for various unit operations such as compressor, expander, valve, pump, heater, and separator. The compressor option may further be used to simulate polytropic compressions or, more correctly, compression paths of a constant thermal efficiency.

PVT SIMULATION & REGRESSION

Simulate all standard experiments carried out in PVT laboratories including:

- Constant mass (or composition) expansion
- Constant volume depletion
- Differential liberation
- Swelling test
- Equilibrium contact
- Multiple contact
- Slim tube
- Separator test
- Viscosity experiments

Up to five data sets for each type of experiment may be stored with each fluid composition. Injection gases used in EOR PVT experiments can be entered with a fluid and assigned to particular EOR PVT experiments. The data input includes measured phase compositions for experiments where phase compositions are reported. The user may define the standard (stock tank) conditions compliant with the actual PVT experiments. In the PVT simulation input menus, the entered temperatures and pressures are shown as default values when the experiments are simulated, and plots comparing experimental and simulated data are shown. However, it is important to note that no experimental data is required to simulate these experiments.

Input menus for storing the PVT data are arranged to comply with standard PVT reports, allowing for direct cut and paste of data from PVT reports available as soft copy. The output results are presented in a user-friendly format and can be exported to a worksheet where the data may be manipulated and plotted inside PVTsim or the
output data can be exported to Excel. Detailed output of physical properties and compositions at each pressure stage may optionally be shown.

Using the Save Phase option, the phase composition at each stage may be stored in the database and used for subsequent calculations. This, for example, allows for studying the change in GOR of the liberated gas from a Constant Volume Depletion simulation as function of depletion pressure.

The extensive data output allows the PVT laboratories to cross check the experimental data with simulated values. PVTsim can generate a comparison of all experimental and simulated PVT data input for a fluid in one click using the “Compare with Experimental PVT Data” button. Plots and tables comparing simulated and measured PVT data and equilibrium phase compositions along with percent deviation are provided as output.

Regression may be needed when developing an EOS model to match available PVT data. This is a primary step for a heavily lumped fluid model to be exported to a compositional reservoir or flow simulator. Regression in PVTsim may start with a plus fluid composition or an already characterized composition. Fluid regression results in a tree structure in the database where regressed fluids are child fluids of the original root fluid. This process allows the user to keep track of the history of tuned fluids. The child fluid is indexed in the database through a multilevel list where the result of a regression of fluid #2 would be a child fluid indexed as fluid #2.1, and so on. After each regression, the result is stored as a temporary fluid. Temporary fluids can be saved permanently in the database.

The regression history of a fluid, including adjusted parameters and selected weighting, is automatically written and kept with a fluid in the Reg History tab.

It is also an option to develop a common EOS model for multiple fluids while regressing to PVT data available for each of the individual fluid compositions. Anywhere from 2 to 50 different plus and/or no-plus fluids can be characterized to a common EOS.

Experiments used to study miscibility of fluids are time consuming and expensive. Careful planning of which experimental conditions to use is therefore important. A multi contact experiment may be performed, or a slim tube experiment may be simulated, to help narrow in on the pressures needed to get the part of the recovery curve of interest. The multi-component MMP option gives a fast and reliable answer about the minimum pressure required to develop a miscible drive.

Reservoir fluid samples taken for lab analysis are sometimes contaminated with oil-based drilling mud. The Oil Based Mud (OBM) Cleaning option in PVTsim will numerically remove any contaminate to generate a clean reservoir fluid with mud attached. PVT data measured on the contaminated fluid sample may be input for this fluid. The mud will be mixed in when simulating and regressing to experimental PVT data measured on the contaminated fluid. The resulting cleaned and possibly regressed fluid can be saved and used reservoir fluid simulation studies.

The composition varies with depth in a reservoir. Based on a sample composition, sample depth and PT-conditions, PVTsim simulates the variation with depth in composition, pressure, GOR and a number of physical properties along with location of the gas-oil contact, if such exists. Simulations may be carried out isothermally or with application of a vertical temperature gradient modeled using the theory of irreversible thermodynamics.
If samples are available from multiple locations in a communicating fluid column, a regression can be made in order to match the observed compositional variation. The tuning is carried out with each component’s ideal gas enthalpy at a reference state as tuning parameters.

For fluids with asphaltene components the Asphaltene Tar Mat option calculates the variations in composition, saturation point, and asphaltene onset point with depth and identifies the location of a possible tar mat.

**ASPHALTENE**

Simulate the conditions at which asphaltene precipitates for a given fluid composition, tune to asphaltene onset pressure, perform a PT flash, and determine weight % of asphaltene components in stock tank oil (STO). For a given temperature, you may also determine the pressure range at which asphaltene precipitation occurs for various amounts of injection gas. The effect of gas injection on the asphaltene precipitation conditions can be studied using a Px-curve option. The asphaltene model has been developed based on experimental live oil asphaltene precipitation data and supports the PC-SAFT model.

**WAX**

Evaluate wax formation conditions from an ordinary compositional analysis, quantify the amount of wax precipitate, run flash calculations, and plot wax formation conditions through PT curves. If data is available, it is also possible to tune the wax model to an experimental cloud point or to experimental wax content in the stock tank oil. The amount of wax precipitate may be calculated as a function of P for constant T or as a function of T for constant P and quantitative flash calculations will consider gas, oil and wax. Additionally, there is an option to account for the influence of wax inhibitors.

Oil with suspended wax particles, which exhibits a non-Newtonian viscosity behavior, can be modeled with PVTsim. Viscosity plots can be made of wax in oil suspensions for varying shear rates.

Fluids tuned in the wax module may be used in the PVTsim DepoWax module, a pipeline simulator considering wax deposition and the effect on viscosity of wax particles suspended in the oil phase.
DEPOWAX

Analyze the nature and extent of wax deposition along a pipeline by calculating pressure drops, temperature profile, position and thickness of wax deposited with a fully compositional profile. Wax appearance temperature and wax amount can be tuned in the wax module prior to initiating a wax deposition simulation. The wax deposition model is well suited for field studies as well as test loops. Being fully compositional, DepoWax is well suited for pipelines with multiple inlets.

With the fluid properly characterized all the user has to input is pipeline geometry, (xy-coordinates, inner diameter, roughness, ambient temperature, and insulation) inlet P&T, and inlet flow rate. Default values are automatically set up for remaining properties (i.e. section lengths, wax diffusion coefficients, and laminar film thickness), but the user also has the option to manually input parameters.

To properly account for the heat of phase transitions (evaporation, condensation and solidification) the temperature profile in the pipeline is determined by carrying out PH (Pressure-Enthalpy) flash calculations. The deposition mechanism is assumed to be molecular diffusion across the laminar sub-layer near the wall.

The influence on the viscosity of wax particles suspended in the oil phase is considered via a shear rate dependent (non-Newtonian) viscosity model. Influence of wax inhibitors on the viscosity can be accounted for. The module offers the choice between four different methods for calculating heat transfer:

- Sieder-Tate
- Dittus-Boelter
- Petukhov
- Petukhov-ESDU

The simulation results give information with respect to time for pressure drop, temperature profile, and position and thickness of deposited wax.

HYDRATE

PVTsim can accurately simulate hydrate formation conditions of gas and oil mixtures. Depression of hydrate formation temperature of the most commonly used hydrate inhibitors (MeOH, EtOH, DEG, TEG) can be simulated as well as the loss of inhibitors to the hydrocarbon phases. An inhibitor composition may contain water.

- Hydrate formation conditions
- Amount of hydrates formed
- Amount of inhibitor needed to suppress formation
- Effect of salts on hydrate formation

The PT flash option automatically provides amounts and types of hydrates (structures I, II and H) as well as hydrocarbon and aqueous phases, solid salt phases, and ice.
SCALE

Determine the amount of scale (salt precipitate) that will emerge from formation water and seawater mixtures. This module takes into account CO2 and H2S equilibrium pressures in the water, pH, as well as the effect of the other ionic species (primarily NaCl, CaCl2, and KCl).

The PVTsim scale module considers precipitation of most common salts including:

- BaSO₄
- CaSO₄
- SrSO₄
- CaCO₃
- FeS
- FeCO₃

Pitzer’s activity coefficient model is used.

ALLOCATION

Allocate the export streams of gas, oil, and water (aqueous) back to 2 - 50 production streams. Export flow streams are reported at reference conditions, which by default are the selected standard conditions.

OPEN STRUCTURE

Open structure gives access to PVTsim thermodynamics and fluid databases without opening the PVTsim interface. Open structure code can be written in most common programming languages including Visual Basic, C++, C#, and MatLab. This allows the user to work from in-house applications and create customized solutions to unique problems using PVTsim thermodynamics.

3RD PARTY SOFTWARE
OPEN STRUCTURE
PVTsim NOVA
DATA ACCESS LAYER
CONSISTENT RESULTS
**FLASH OPEN STRUCTURE**

Flash Open Structure allows the following flash calculations and can also be used as a property generator:

**Flash Calculation**

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PT non-aqueous</td>
<td>Flash for specified pressure (P) and temperature (T). Considers gas and oil. Water, hydrate inhibitors and salts are not accepted.</td>
</tr>
<tr>
<td>PT aqueous</td>
<td>Flash for specified pressure (P) and temperature (T). Considers gas, oil and aqueous. Salts are not accepted unless water is present.</td>
</tr>
<tr>
<td>PT multi-phase</td>
<td>Considers gas, oil and aqueous (max 4 phases). Salts are not accepted unless water is present.</td>
</tr>
<tr>
<td>K-factor</td>
<td>Flash for specified K-factors. Considers gas and oil. No aqueous components are accepted.</td>
</tr>
<tr>
<td>Split-factor</td>
<td>Flash for specified Split-factors. Considers gas and oil. No aqueous components are accepted.</td>
</tr>
<tr>
<td>P-Beta</td>
<td>Flash for specified pressure (P) and vapor mole fraction (Beta). Beta is the vapor mole fraction of the hydrocarbon phases (i.e. vapor mole fraction not considering aqueous phases). If salt is present, water and at least one non-aqueous component must also be present.</td>
</tr>
<tr>
<td>T-Beta</td>
<td>Flash for specified temperature (T) and vapor mole fraction (Beta). Beta is the vapor mole fraction of the hydrocarbon phases (i.e. vapor mole fraction not considering aqueous phases). If salt is present, water and at least one non-aqueous component must also be present.</td>
</tr>
<tr>
<td>PH</td>
<td>Flash for specified pressure (P) and enthalpy (H). Considers gas, oil and aqueous. Salts are not accepted unless water is present.</td>
</tr>
<tr>
<td>PS</td>
<td>Flash for specified pressure (P) and entropy (S). Considers gas, oil and aqueous. Salts are not accepted unless water is present.</td>
</tr>
<tr>
<td>VT</td>
<td>Flash for specified molar volume (V) and temperature (T). Considers gas, oil and aqueous. Salts are not accepted.</td>
</tr>
<tr>
<td>UV</td>
<td>Flash for specified internal energy (U) and molar volume (V). Considers gas, oil and aqueous. Salts are not accepted. Pure component fluids are not accepted</td>
</tr>
<tr>
<td>HS</td>
<td>Flash for specified enthalpy (H) and entropy (S). Considers gas, oil and aqueous. Salts are not accepted unless water is present. Pure component fluids are not accepted</td>
</tr>
</tbody>
</table>

All open structure calculation options are fully consistent with calculations carried out in PVTSim directly.
### HYDRATE OPEN STRUCTURE

Hydrate Open Structure gives access to the following calculation options:

**Hydrate Calculation**

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PT Hydrate Flash</td>
<td>Flash for specified pressure (P) and temperature (T). Considers gas, oil, aqueous, Hydrate I, Hydrate II, Hydrate H, Ice and pure salt phases.</td>
</tr>
<tr>
<td>Hydrate Formation PT curve</td>
<td>Calculation of the hydrate formation pressure-temperature (PT) curve.</td>
</tr>
<tr>
<td>Hydrate Formation Pressure</td>
<td>Calculation of the hydrate formation pressure (P) for a given temperature (T).</td>
</tr>
<tr>
<td>Hydrate Formation Temperature</td>
<td>Calculation of the hydrate formation temperature (T) for a given pressure (P).</td>
</tr>
<tr>
<td>Minimum Inhibitor</td>
<td>Calculation of the minimum inhibitor amount needed to prevent hydrate formation at given temperature (T) and pressure (P).</td>
</tr>
</tbody>
</table>

### WAX OPEN STRUCTURE

Wax Open Structure gives access to the following calculation options:

**Wax Calculation**

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PT Wax Flash</td>
<td>Flash for specified pressure (P) and temperature (T). Considers gas, oil, and wax phases.</td>
</tr>
<tr>
<td>Wax Formation PT curve</td>
<td>Calculation of the wax formation pressure-temperature (PT) curve.</td>
</tr>
<tr>
<td>Wax Formation Temperature</td>
<td>Calculation of the wax formation temperature (T) for a given pressure (P).</td>
</tr>
</tbody>
</table>
INTERFACES

PVTsim includes modules to generate PVT input tables to a number of external (non-Calsep) programs. Tables may contain physical, compositional, or black oil properties.

Interface modules provide easy export to the following popular reservoir, process, and flow assurance programs:

- Eclipse (100, Gi (200) and 300 (incl. import))
- CMG (IMEX, GEM and STARS)
- VIP (Comp and Black Oil)
- More (EOS and Black Oil)
- Prosper/Mbal
- Saphir
- OLGA
- OLGA Wax
- LedaFlow
- Pipesim
- Multiphase meters
- Pipephase
- Hysys
- PRO/II
- Wellcat
- Weps

Access to each interface can be purchased as a module, individually or in packages.

LICENSING & MAINTENANCE

WHAT IS PVTsim?

PVTsim licenses are available as Local Area Network (LAN) licenses, which are convenient for multiple users at the same site who can access a local server. Network licenses are run using the FLEXlm license manager. Stand-alone licenses are also available as a dongle that can be plugged into the USB drive of any computer.

Calsep offers a maintenance arrangement for an annual fee. This fee covers any updates in PVTsim, bug fixes, and superior technical support from Calsep consultants.

To run PVTsim, minimum hardware requirements include: 1 Gb RAM and 1 Gb free disk space, 1280 x 800 pixels screen resolution, and a Windows operating system including Windows Vista, Windows 7, and Windows 8.
Popular PVTsim modules have been collected into standard packages offered for a lower price when compared to paying for each module individually. The different packages target the needs of different application areas. The following table summarizes the modules and interfaces included with each package:

<table>
<thead>
<tr>
<th>Modules</th>
<th>STANDARD PACKAGES</th>
<th>PVT Lab</th>
<th>Reservoir</th>
<th>Flow Assurance</th>
<th>Open Structure</th>
<th>Wax Deposition</th>
<th>Full PVT</th>
<th>Full Package</th>
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<td>FLASH &amp; UNIT OPS</td>
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<td>PVT SIMULATION &amp; REGRESSION</td>
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