PVT & Fluid Models

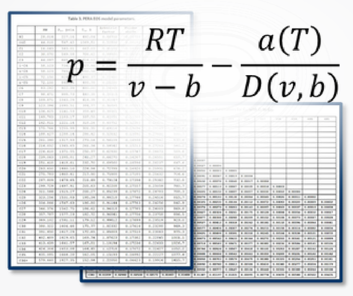
A Petroleum Engineering Reference Guide

whitson

Fluid Models

Detailed fluid models are comprised of three main parts:

From the detailed model, we can create consistent child models like black-oil PVT models and lumped EOS fluid models.



$$p = \frac{RT}{v-b} - \frac{a(T)}{D(v,b)}$$

Equation of State (EOS) model

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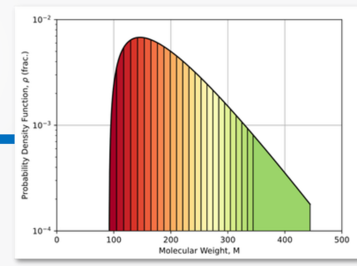

Gamma distribution model

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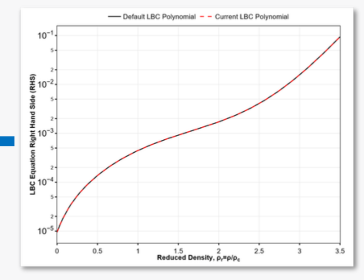


Auxiliary models (eg. viscosity)

Phase Behavior Foundations

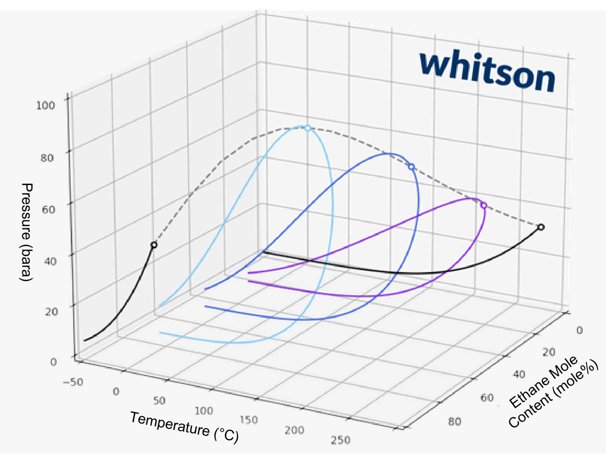
To describe a mixture, we need to be able describe the component properties that drive the phase behavior. We can divide these into two main groups:

Distillation properties

- Molecular weights (M_i)
- Specific gravity (γ_i)
- Normal boiling point (T_{bi})

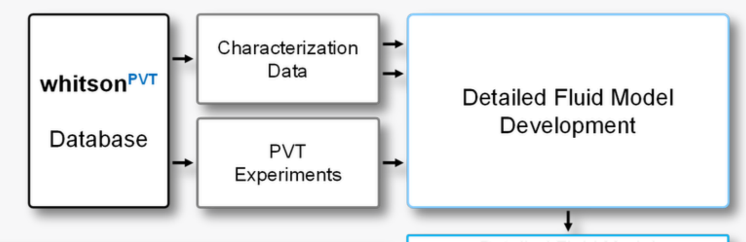
EOS Properties

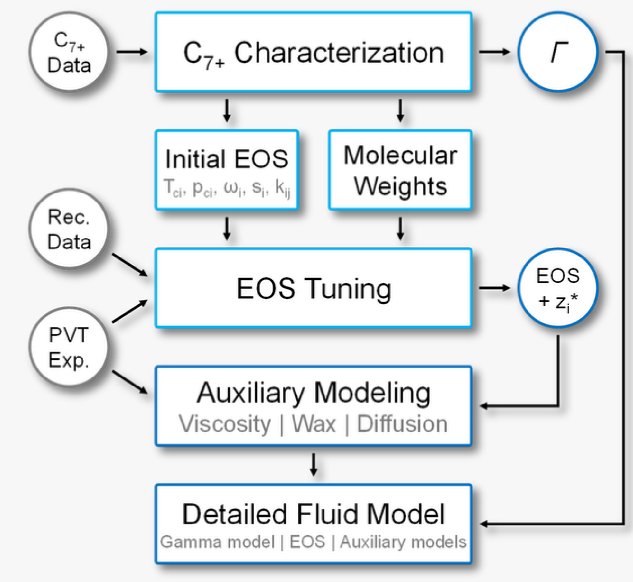
- Critical temperature (T_{ci})
- Critical pressure (p_{ci})
- Acentric factor (ω_i)
- Binary interaction parameters (BIPs | k_{ij})

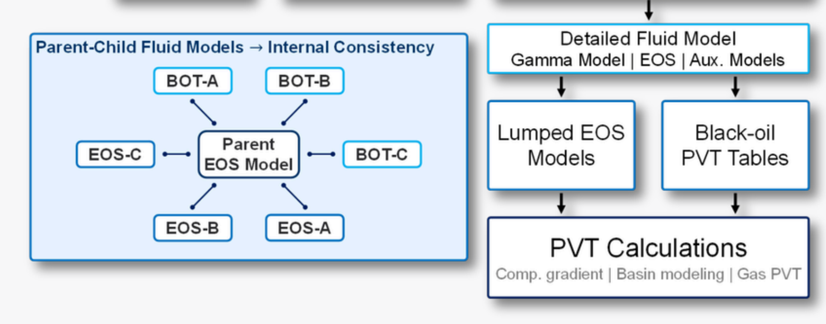


Fluid Model Development

Developing a fluid model that can be used and re-used is a clean and efficient way to make consistent fluid models across multiple disciplines. With a detailed fluid model, you can develop accurate and consistent child models (black-oil PVT tables and lumped EOS models) and perform highly accurate PVT predictions.



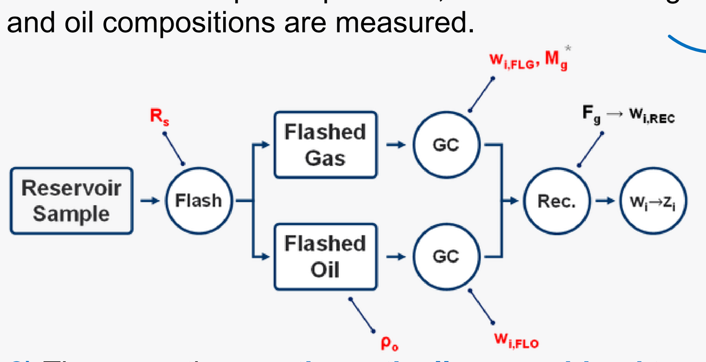




Developing fit-for purpose fluid models requires a good workflow that ensures the perfect mix of accuracy and practicality. The process encompasses several different aspects, from a trusted digital database, to a seamless data transfer system, to detailed fluid model.

Compositions

Reservoir compositions are not measured directly; they are estimated. **1)** Part of the reservoir fluid is **flashed** to atmospheric pressure, and the flashed gas and oil compositions are measured.



2) These are then **mathematically recombined** to estimate the reservoir composition.

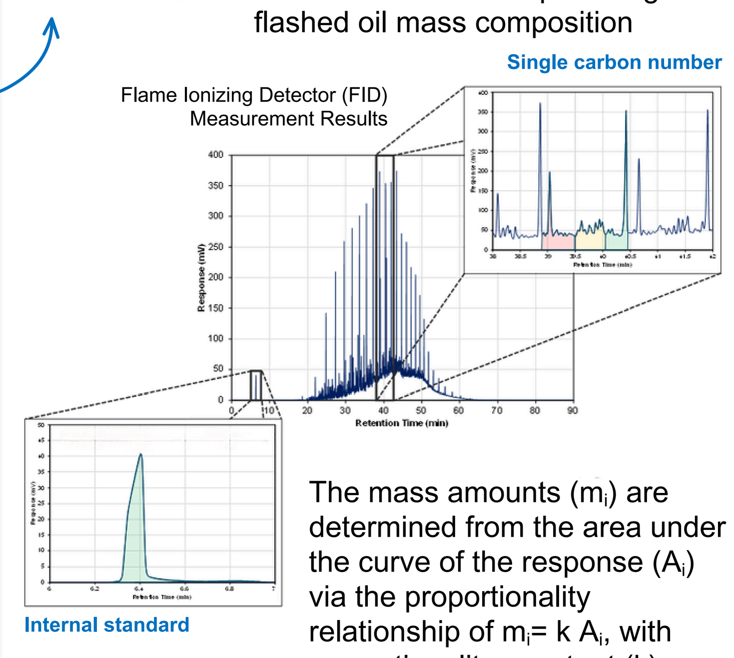
$$w_i^{REC} = w_i^{FLG} \cdot F_g^{mass} + w_i^{FLO} \cdot \left(1 - F_g^{mass}\right)$$

$$F_g^{mass} = \left[1 + (RT_{SC}/p_{SC}) \cdot (\rho_o/M_g)/R_s\right]^{-1}$$

$$z_i^{REC} = \frac{w_i^{REC}/M_i}{\sum_i (w_i^{REC}/M_i)}$$

GC Example

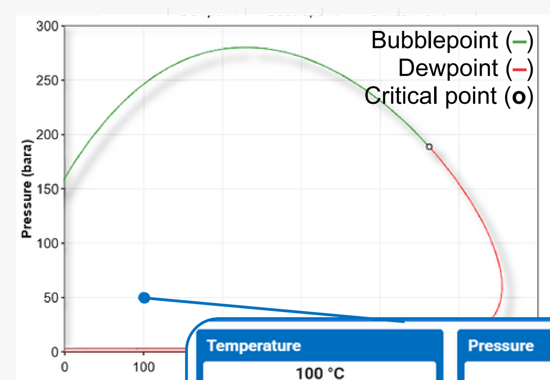
Gas chromatography (GC) measurement results providing the flashed oil mass composition



The mass amounts (m_i) are determined from the area under the curve of the response (A_i) via the proportionality relationship of $m_i = k\ A_i$, with proportionality constant (k)

Flash Calculation

The isothermal flash calculation is the workhorse of computational thermodynamics! The flash calculation is composed of two loops, an inner material balance loop, and an outer loop that tries to reach the equilibrium constraint.



Rachford-Rice Equation

$$h(F_v) = \sum_{i=1}^{N_c} \frac{z_i \cdot (K_i - 1)}{1 + V \cdot (K_i - 1)}$$

Equal Fugacity Constraint

$$f_{v,i} = f_{l,i} \rightarrow K_i^{n+1} = K_i^n \cdot \frac{f_{l,i}^n}{f_{v,i}^n}$$

Temperature	Pressure	Number of Phases
100 °C	50 bara	Two-Phase

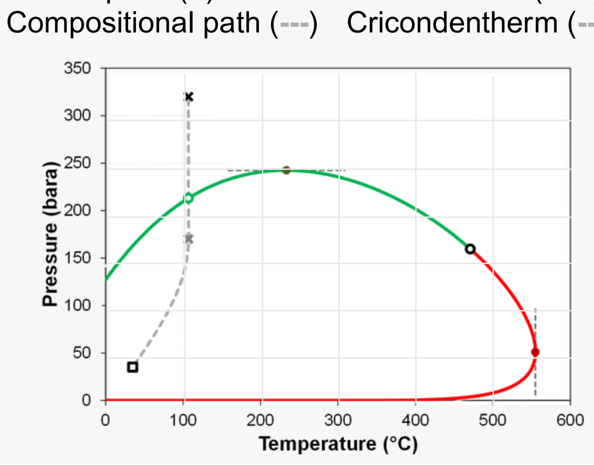
Phase Properties

Phase	Relative Moles	Molecular Weight	Z-factor	Density
	-	-	-	kg/m3
Total	1.0000	111.9209	0.6199	290.9639
Gas	0.4550	23.0984	0.9204	40.4437
Oil	0.5450	186.0864	0.3690	812.7602

Phase Envelope

Phase envelopes can be visualized using different variables, but the most common is the pressure-temperature phase envelope. This figure gives us a "roadmap" of the fluid phase behavior we are dealing with.

Bubblepoint (–) Reservoir conditions (×)
Dewpoint (–) 1st Stage separator (□)
Critical point (o) Cricondenbar (–•–)
Compositional path (---) Cricondentherm (–•–)



Gamma Model

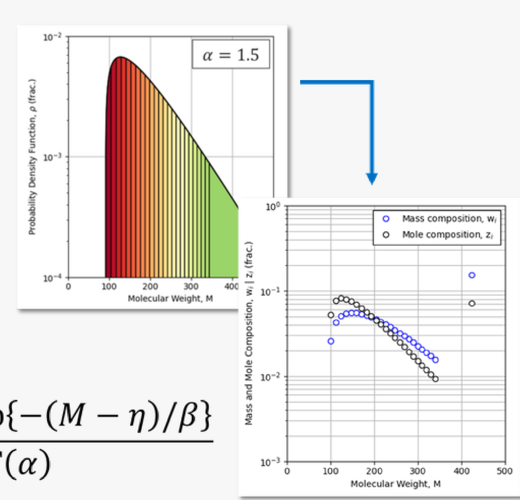
The gamma molar distribution model, or gamma model for short, was first proposed by Curtis Whitson as a method to accurately describe the distribution of the C7+ components compositions for a wide range of fluids.

Gamma model parameters

- Shape parameter (α)
- Bound (η)
- Component lower molecular weights ($M_{L,i}$)

$$\beta = \frac{\bar{M} - \eta}{\alpha}$$

$$p(M) = \frac{(M-\eta)^{\alpha-1} \cdot \exp\{-(M-\eta)/\beta\}}{\beta^\alpha \cdot \Gamma(\alpha)}$$

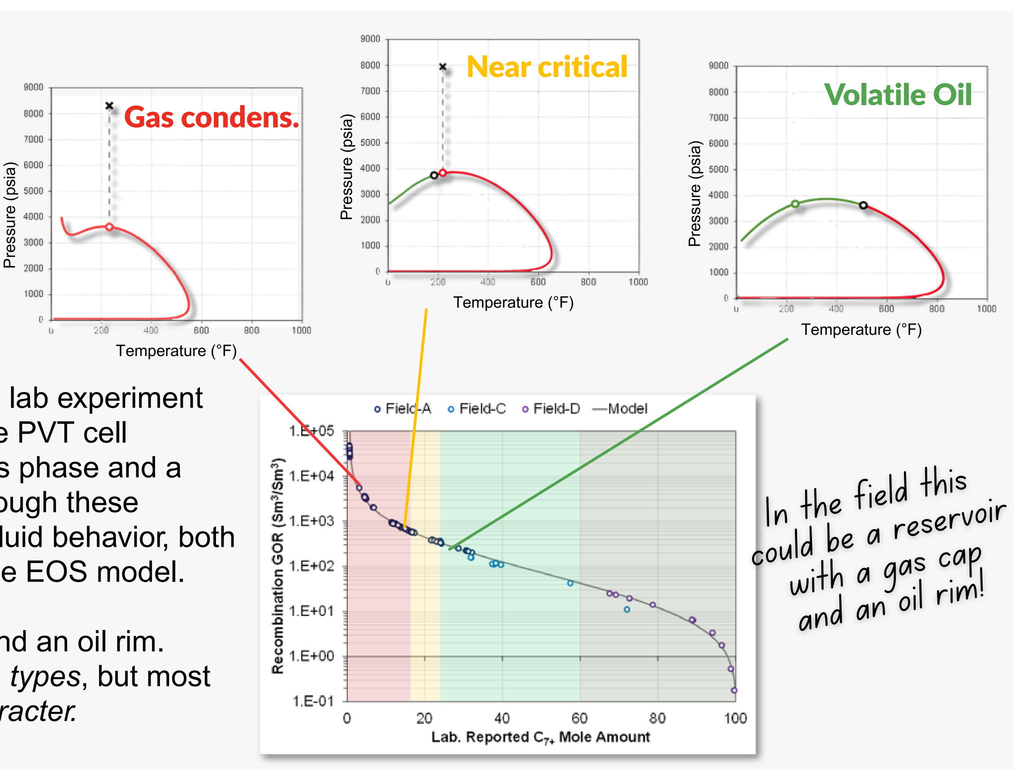


Fluid Type

Fluid type (black-oil, gas condensate, etc.) is driven by mole composition — but different fluid types do not require different EOS models!

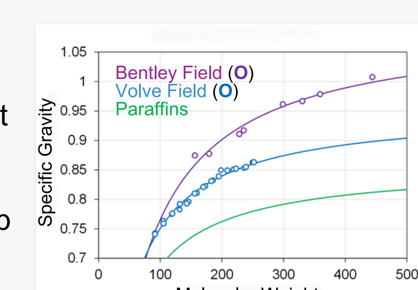
As an example, during a CCE lab experiment below saturation pressure, the PVT cell contains both a high-GOR gas phase and a lower-GOR liquid phase. Although these phases exhibit very different fluid behavior, both are still modeled using a single EOS model.

A similar case, is a gas cap and an oil rim. These fluids are different fluid *types*, but most likely have the same fluid *character.*

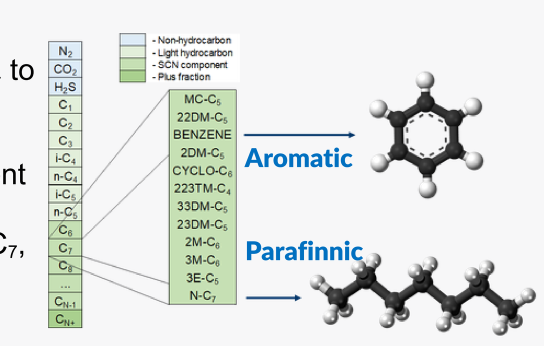


Fluid Character

The reason we need a different EOS model for two different fluids is not because of the fluid type, but because of the **fluid character** - the proportion of paraffinic and aromatic components that make up the single carbon number (SCN) components starting at C_7.



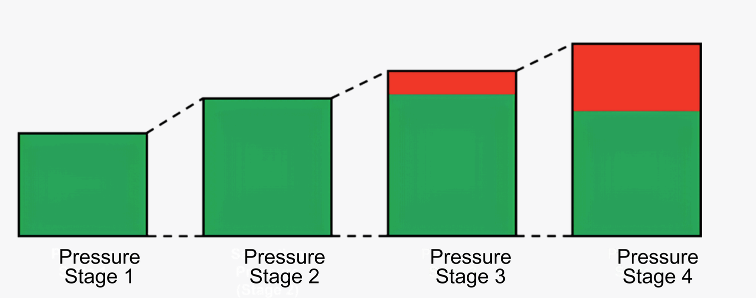
C_{7+} Characterization involves splitting the C_{7+} to a heaviest component (typically C_{36+}) and estimating the component properties for the SCN components staring at C_7, and beyond.



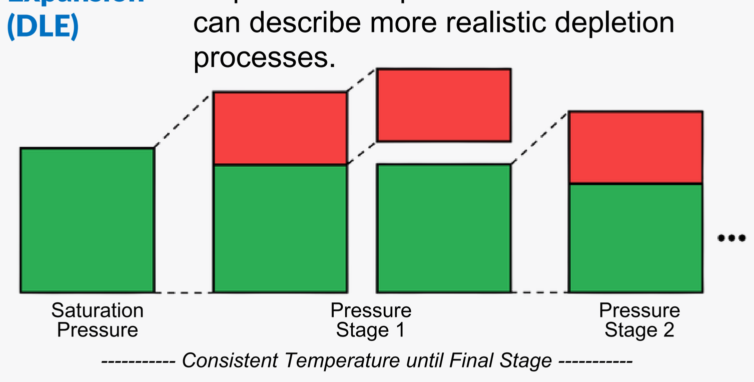
Standard PVT Experiments

The standards PVT experiments, were initially developed to try and emulate the reservoir depletion but are now used to develop an EOS model.

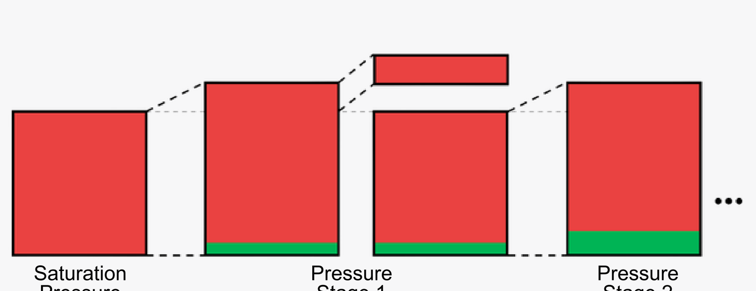
Constant Composition Expansion (CCE) The main output of the CCE is the saturation pressure and type, which defines if we label our fluid as a reservoir gas or reservoir oil.



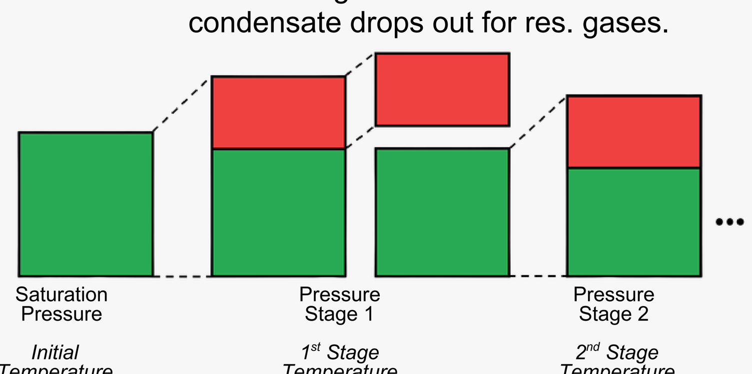
Differential Liberation Expansion (DLE) The DLE emulates a solution gas drive reservoir depletion process and helps us develop our EOS model that can describe more realistic depletion processes.



Constant Volume Depletion (CVD) The CVD emulates the depletion of gas condensates and gives useful information of the CGR variation during depletion.



Multi-Stage Separator (MSS) The MSS gives data that helps accurately model the surface process depletion! This is critical to understand the shrinkage of res.oils and how much condensate drops out for res. gases.



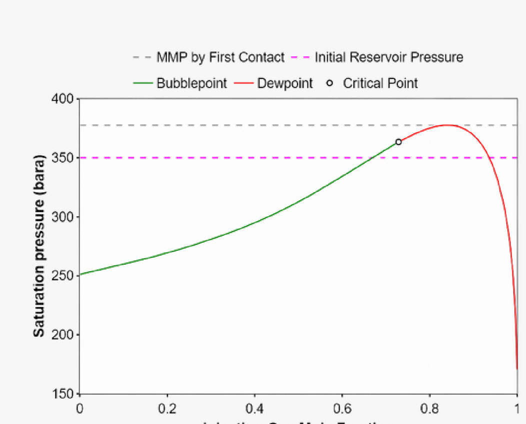
Gas EOR PVT Experiments

When injecting gas as part of gas EOR projects, it is essential to have data that we can use to calibrate our EOS model. This can be the deciding factor for whether or not the gas EOR project will be profitable or not!

Swelltest Experiment In the swelltest, we inject gas in our reservoir fluid, and measure how the phase behavior changes with increasing amounts of injection gas.

Slimtube Experiment The slimtube experiment is the only experiment that can measure the developed minimum miscibility pressure (MMP).

Huff-n-puff Experiment The huff-n-puff experiment is a PVT experiment meant to help make the best decision for gas EOR projects, developed with the help of whitson during the unconventional boom!

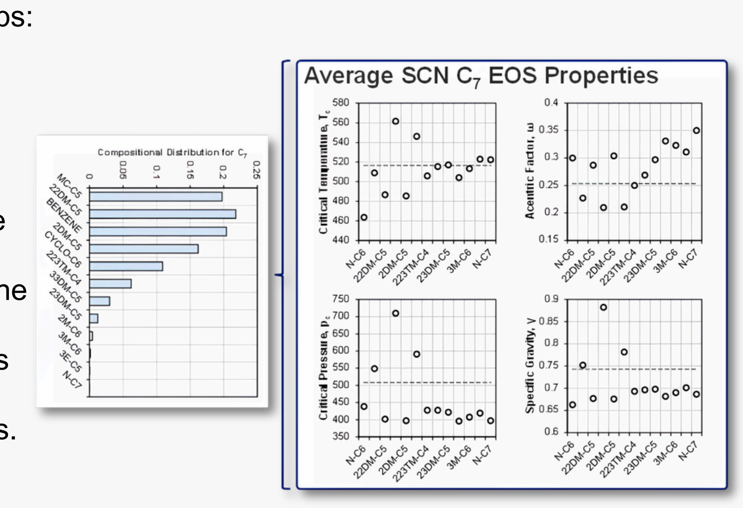


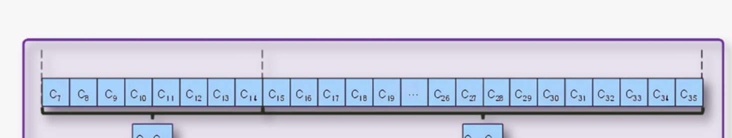
EOS Model Lumping

Developing an accurate lumped EOS model without being required to re-tune an equation from scratch every time requires two key steps:

Averaging Method

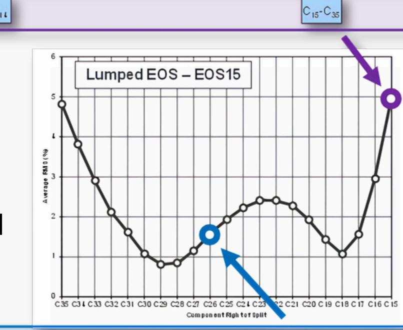
An accurate method for averaging the SCN components into lumped components.

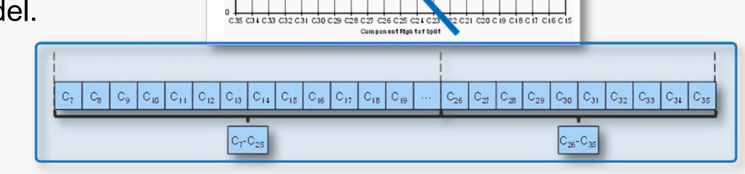




Optimal Lumping Scheme

Finding the optimal selection of components to lump together that yield the best replication of the detailed model.





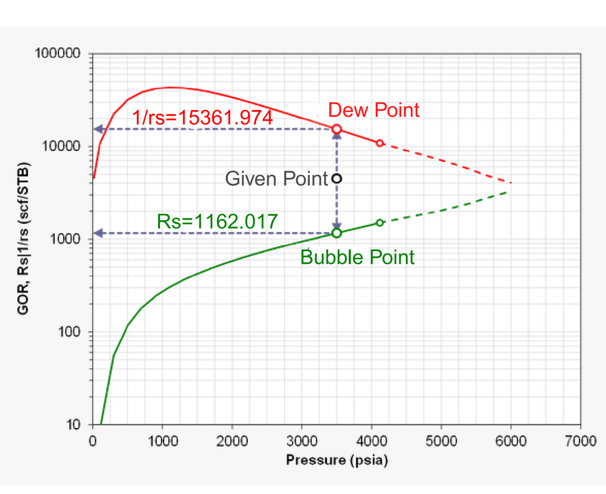
Black-Oil PVT Table Generation

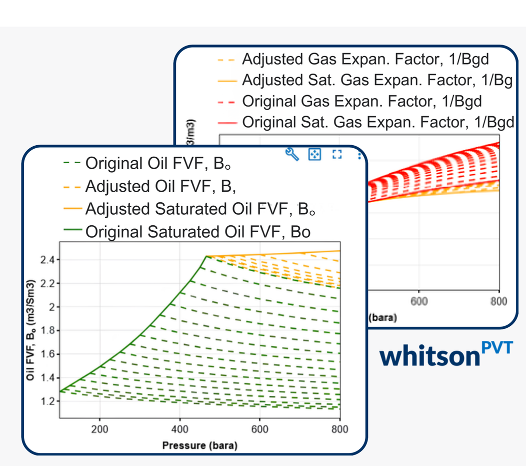
Generating black-oil PVT (BOPVT) tables helps to significantly reduce runtime for complex and large PVT calculations, like reservoir simulation.

Physically consistent extrapolated BOPVT tables help to avoid errors and warnings in the simulators, and results in more accurate fluid descriptions for different depletion scenarios.

Required inputs:

- Fluid composition (z_{boi})
- Reservoir temperature (T_{res})
- Surface process (P)
- PVT experiment used to simulate the BOPVT table





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