The Society of Petroleum Evaluation Engineers

SPEE Denver Chapter announces its April Luncheon Meeting.

Wednesday, April 12, 2023

Dr. Dilhan Ilk

EVP, Division Manager of North America, D&M

Will be speaking on:

<u>A Survey on Diagnostic Based Methods for Well Performance Analysis and Production Forecasting in Unconventional Reservoirs</u>

Abstract.: This presentation outlines critical concepts associated with diagnostic based well performance analysis and production forecasting methods in unconventional (low-permeability) reservoirs. We will provide background on traditional and recently introduced methodologies adapted/developed for unconventional reservoirs including basis for (modified) Arps' decline models. We will discuss methods and considerations to account for issues associated with data quality and will also introduce techniques to incorporate multi-phase flow and variable flowing pressures into analysis.

Speaker Bio.: **Dilhan Ilk** is an Executive Vice President and Manager of the North America Division at DeGolyer and MacNaughton. Dr. Ilk earned a bachelor's degree in petroleum engineering in 2003 from Istanbul Technical University. In 2005, he received a master's degree in petroleum engineering, and in 2010 he was awarded a doctorate in petroleum engineering, both from Texas A&M University. He specializes in assisting clients with the assessment of unconventional resources and well performance evaluation and forecasting using a systematic workflow that combines diagnostic methods with analytical and numerical techniques. He is a registered professional engineer in the State of Texas.

He is a member of SPE Reservoir Description and Dynamics advisory committee, and currently he is the chair of Well Performance sub-committee of the SPE Reservoir Description and Dynamics advisory committee. He is a contributing author of the SPEE Monograph IV—Estimating Ultimate Recovery of Developed Wells in Unconventional Reservoirs and SPE PRMS Applications Guidelines (2022). He was co-editor of the SPE digital publication series "Performance Forecasting in Shale Reservoirs".

Knowledge Integrity Service

Society of Petroleum Evaluation Engineers

A Survey on Diagnostic Based Methods for Well Performance Analysis and Production Forecasting in Unconventional Reservoirs

Dilhan Ilk | dilk@demac.com

April 12, 2023

Denver, Colorado

DeGolyer and MacNaughton

Worldwide Petroleum Consulting

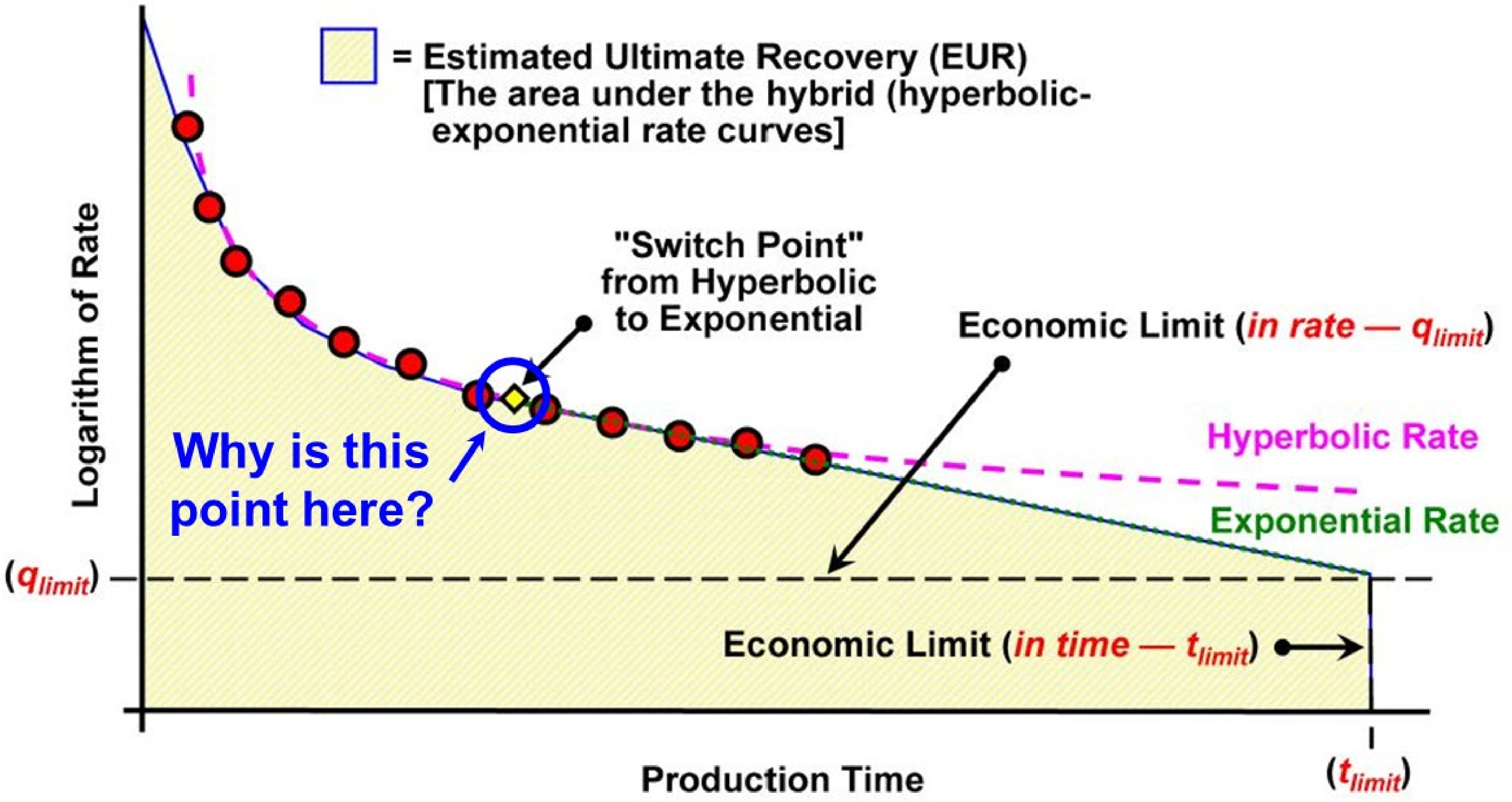
Presentation Outline

This presentation attempts to address various challenges with decline curve analysis using empirical (data-driven) methodologies

- Overview/Introduction
- Diagnostic based decline curve analysis
- Techniques for improving resolution of production data
- Incorporation of pressure data in decline curve analysis
- Multiphase flow decline curve analysis
- Empirical methodology to estimate GOR profile

Time-Rate Analysis — Modified-Hyperbolic Relation

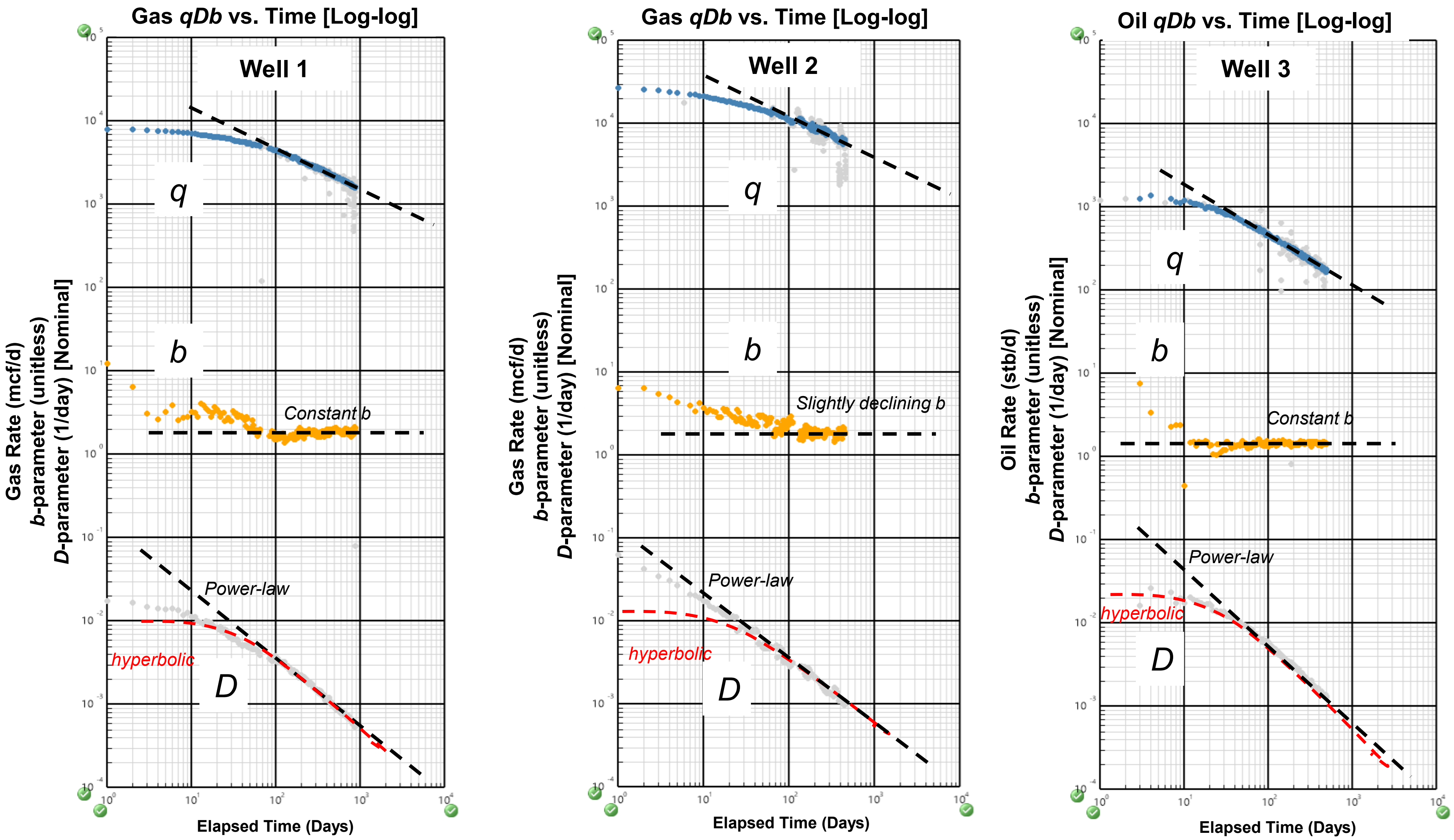
Schematic represents the most common approach to estimate ultimate recoveries



- The schematic represents the most common approach (*i.e.*, modified hyperbolic time-rate model) to estimate ultimate recoveries (EUR).
- This approach could be "non-unique" in the hands of most users, and often yields widely varying estimates of reserves with time.

Time-Rate Analysis — *q-D-b* Plot

qDb plot can be used as basis for formulating a variety of decline curve relations



Diagnostic Formulations

$$D \equiv -\frac{1}{q}\frac{dq}{dt}$$

$$b \equiv -\frac{d}{dt}\left[\frac{1}{D}\right]$$

$$D \equiv At^{-B}$$

→ *Power-law exponential or stretched exponential rate*

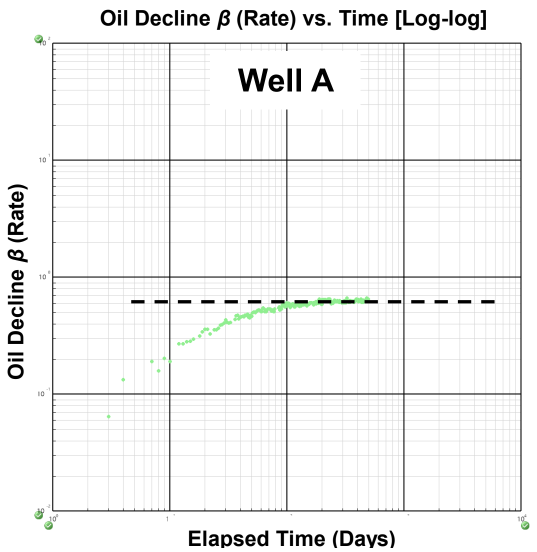
$$D \equiv \frac{D_i}{1 + bD_i t}$$

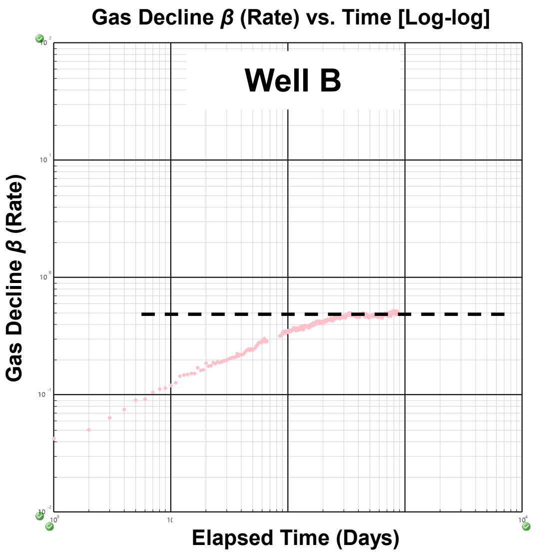
→ *Hyperbolic rate*

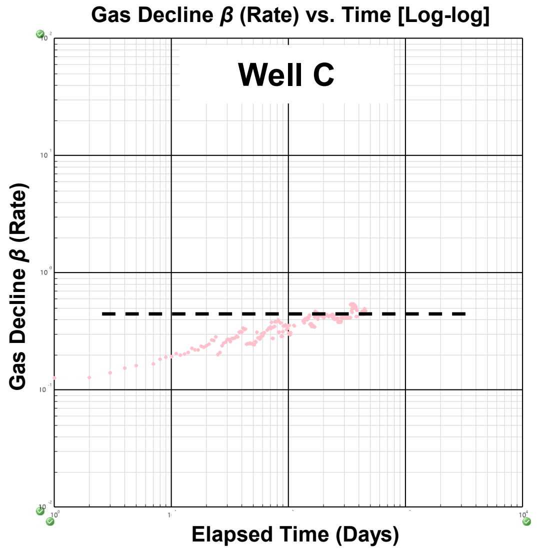
$D \equiv D_i$ → *Exponential rate*

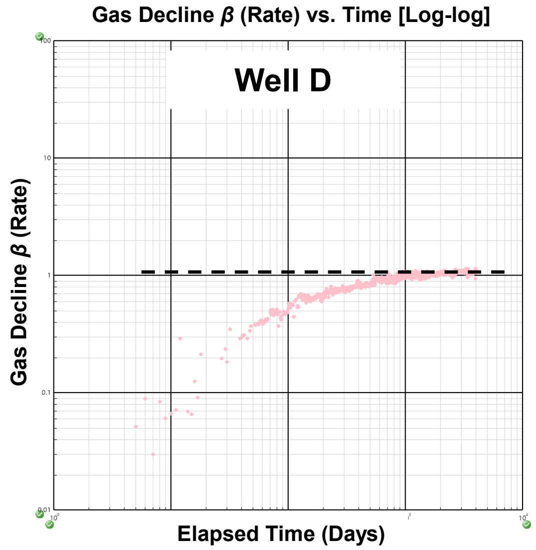
Time-Rate Analysis — *β-Derivative* Plot

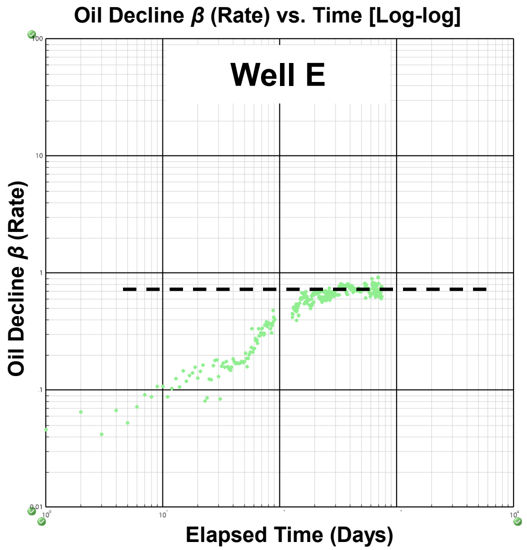
β-derivative is directly related to "power-law" type flow regimes











Diagnostic Formulations

$$\beta \equiv -\frac{t}{q}\frac{dq}{dt}$$

$$\beta \equiv Constant$$

$$\Downarrow$$

$$q \equiv q_i t^{-\beta}$$

$$\Downarrow$$

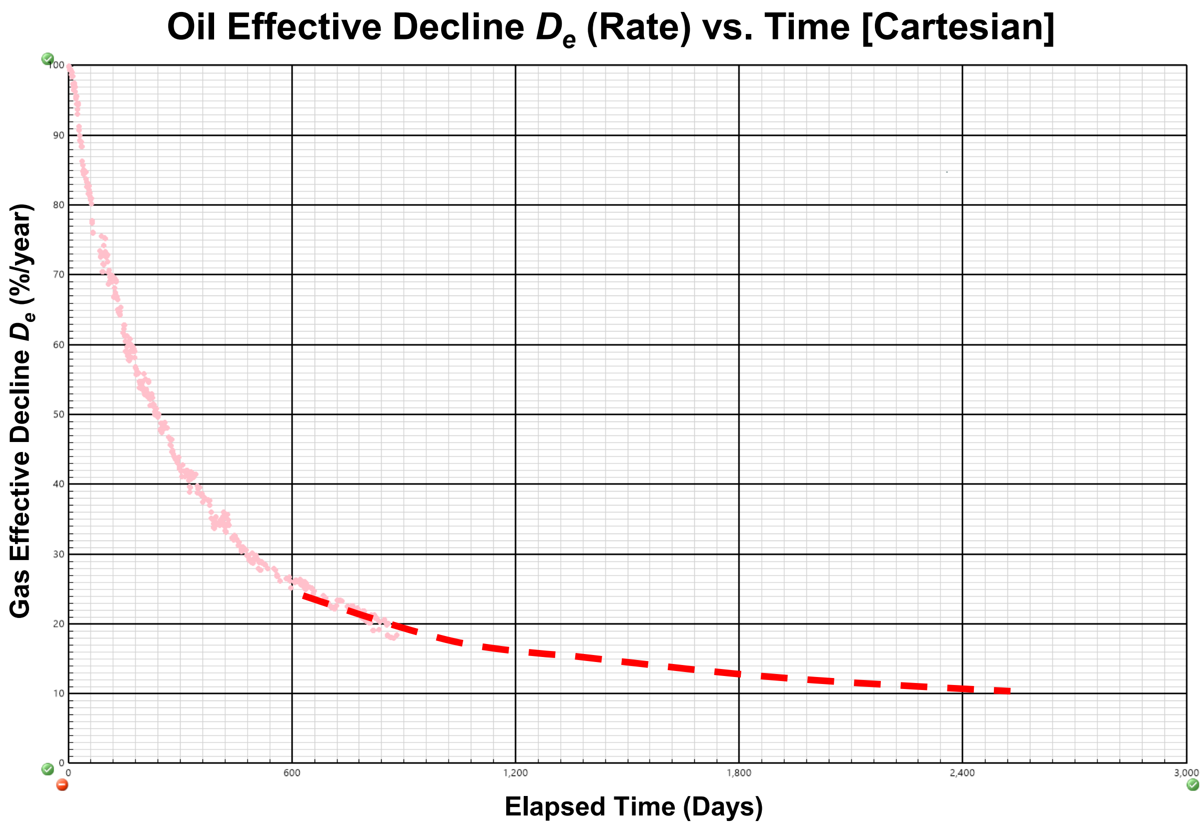
$$q \equiv \frac{q_i}{(bD_i t)^{1/b}}$$

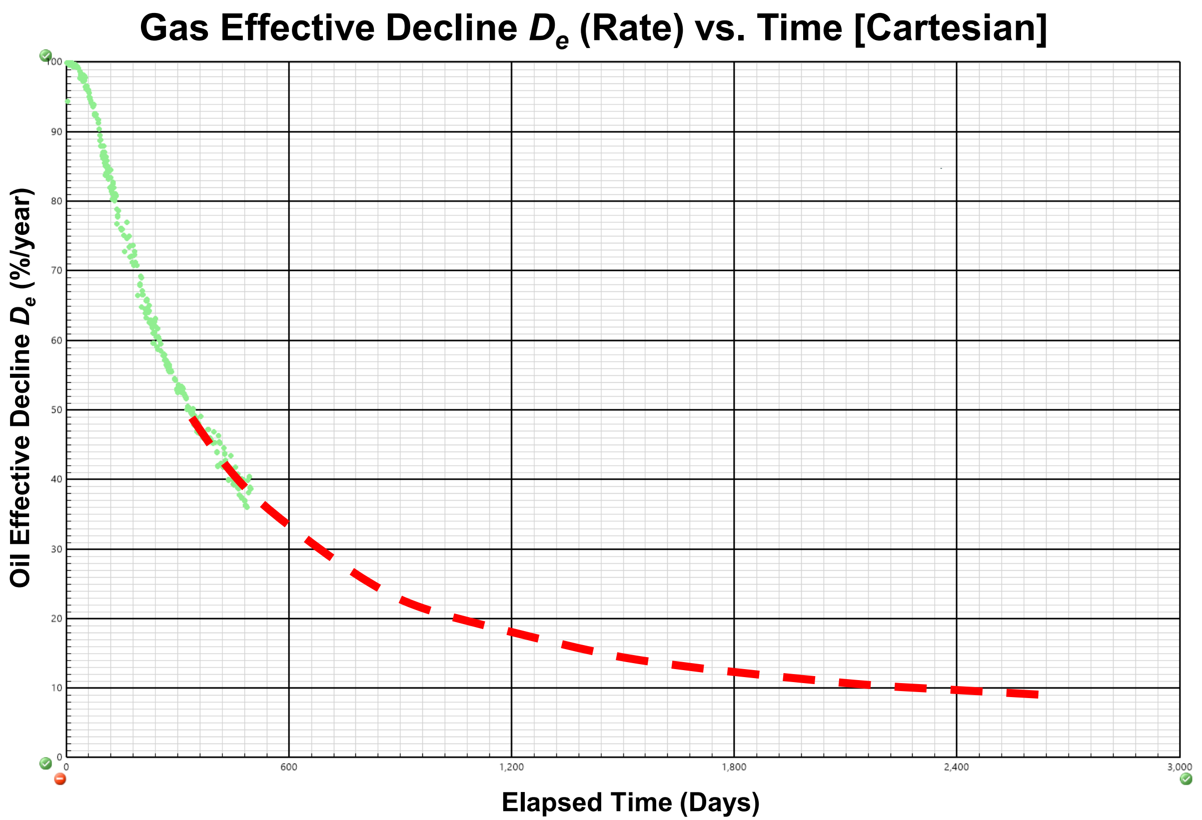
$$\Downarrow$$

$$\beta \equiv \frac{1}{b}$$

Time-Rate Analysis — *Continuous Evaluation of Effective Decline*

Data-driven methodology to identify long-term decline behavior

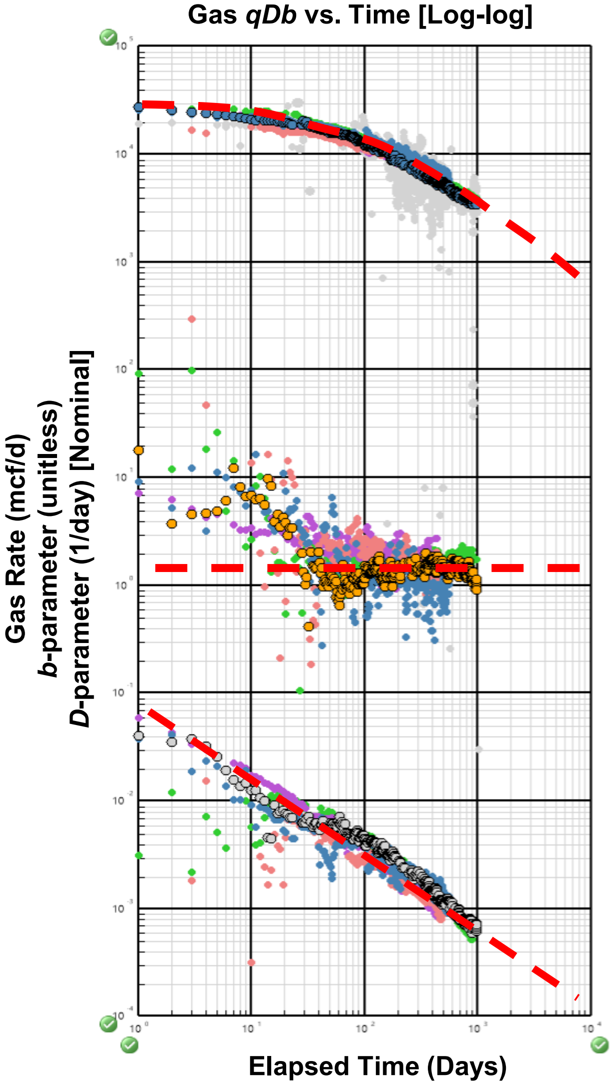


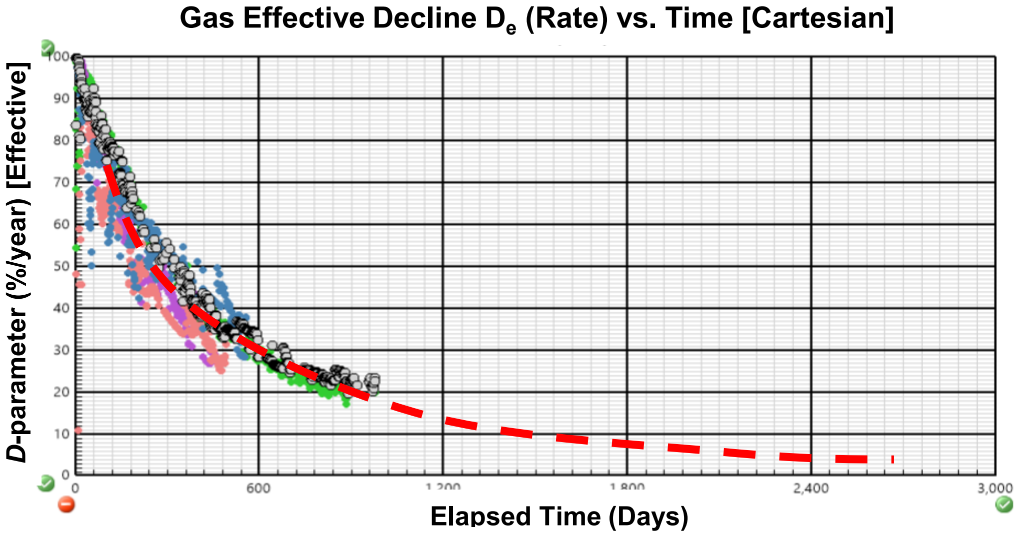


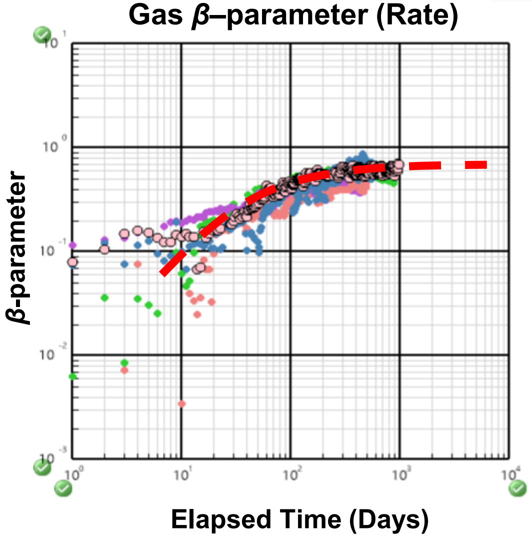
- Extrapolation of effective decline trend implies terminal decline rate values below 10 percent/year.
- Value of "terminal" decline rate may be estimated based on projected trends (and comparisons).
- Trends can be compared against "long-term" behavior (e.g. older vintage wells).

Time-Rate Analysis — *Characteristic Response based on Groupings*

Diagnostic plots allows for extracting type curve shape/decline parameters





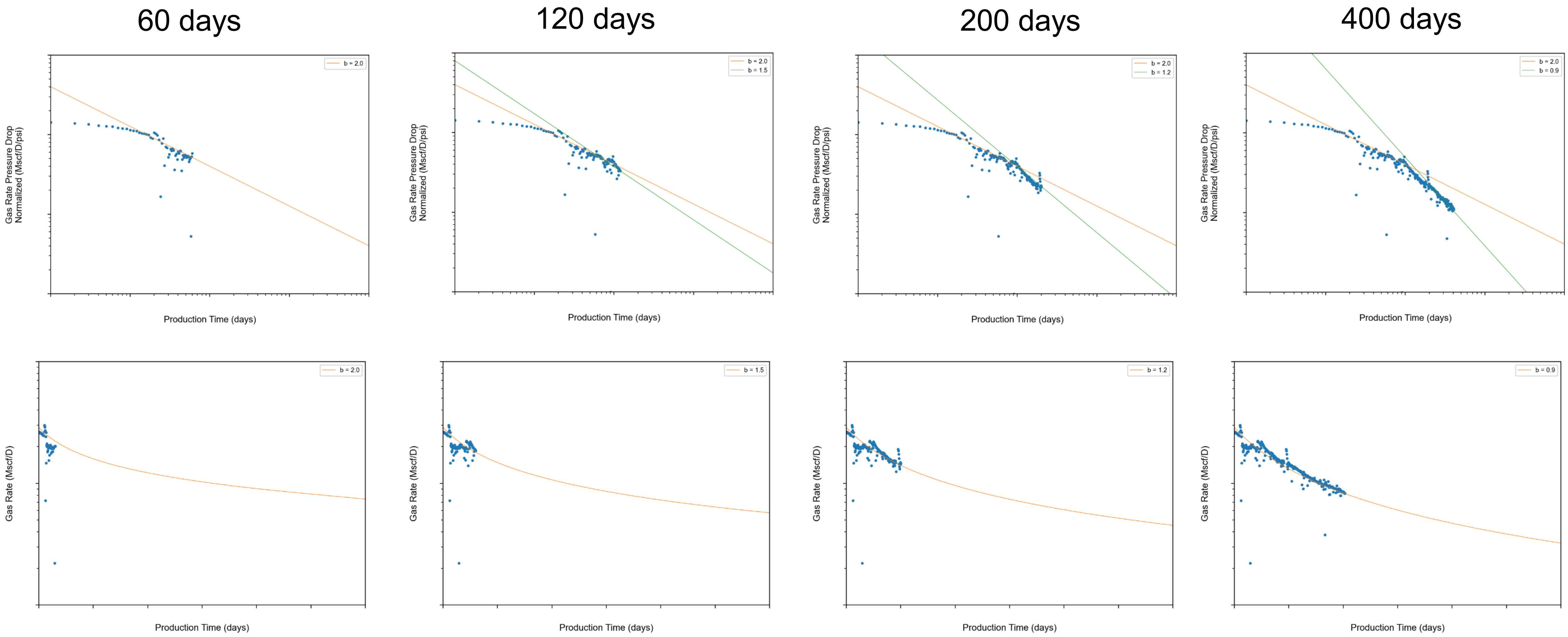


Characteristic response

- Groupings of wells based on distinct characteristics
  - Geology
  - PVT properties
  - Completion design
  - Well spacing
- Representative decline parameters can be used for constructing type well profiles.

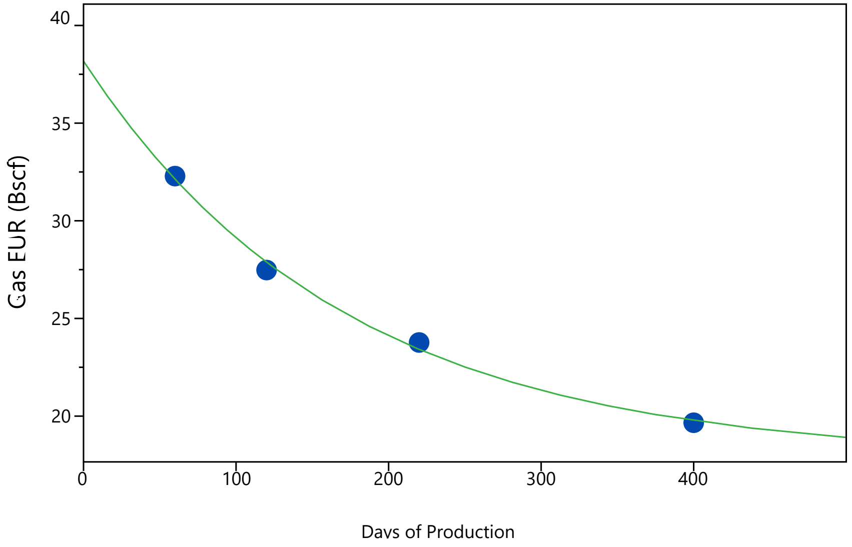
Time-Rate Analysis — Continuous Evaluation of b-factor

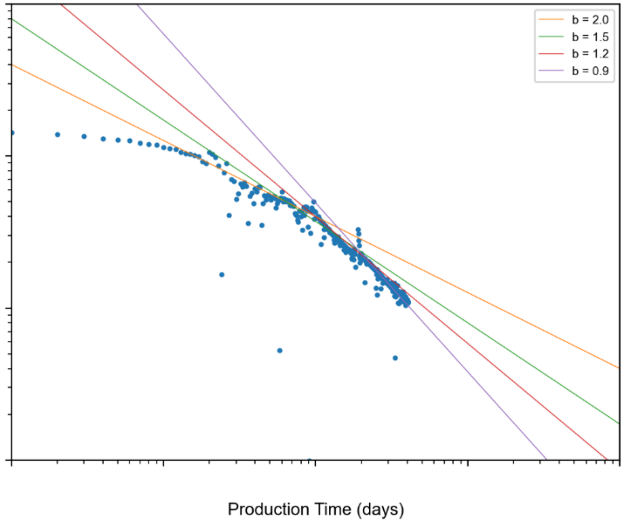
As more days of production are available for analysis, uncertainty on production forecasts may decrease

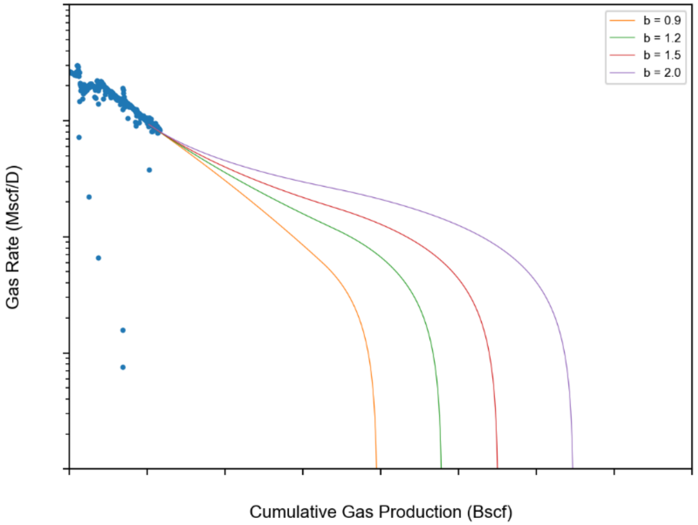


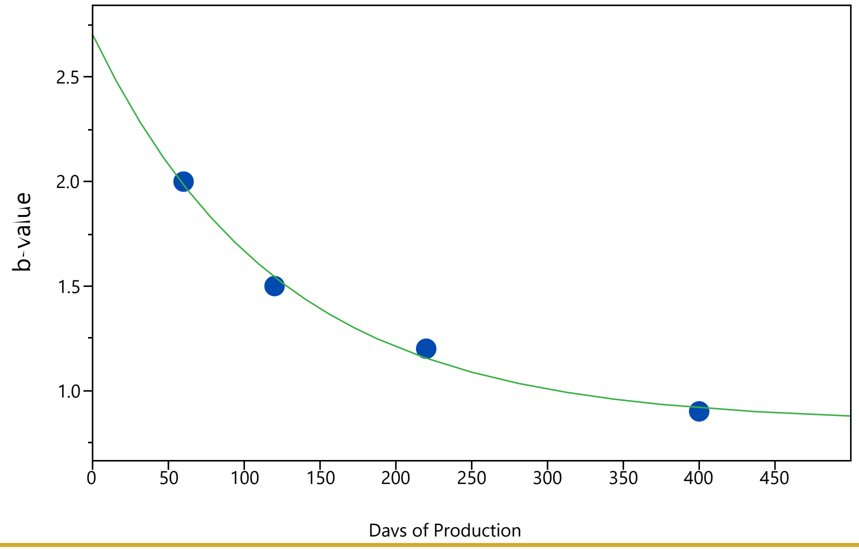
Time-Rate Analysis — Continuous Evaluation of b-factor

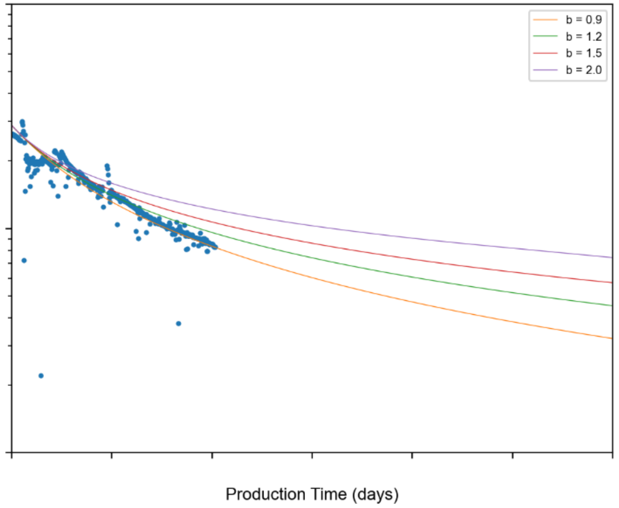
Flow regime diagnostics help identifying potential changes in EUR and decline parameters over time.











- At early production times, diagnostic signature shows linear-flow which translates to high b-factors.
- As production time increases, late time decline behavior develops and b-value interpretation shows increasing slope.
- Due to change in flow regimes, higher uncertainty should be expected at early times.
- For this example, b-value appears to stabilize at 400 days.

Variable Pressure Drop Cases

Theoretically variable rate/pressure responses are obtained through convolution/superposition

- Variable pressure decline curve analysis uses time-rate production data normalized by discrete pressure drop changes ($p_i - p_{wf}$) as the constant pressure relation for analysis.
- It is worth to note that the pressure drop normalization serves only for an approximation, and it is not exact.

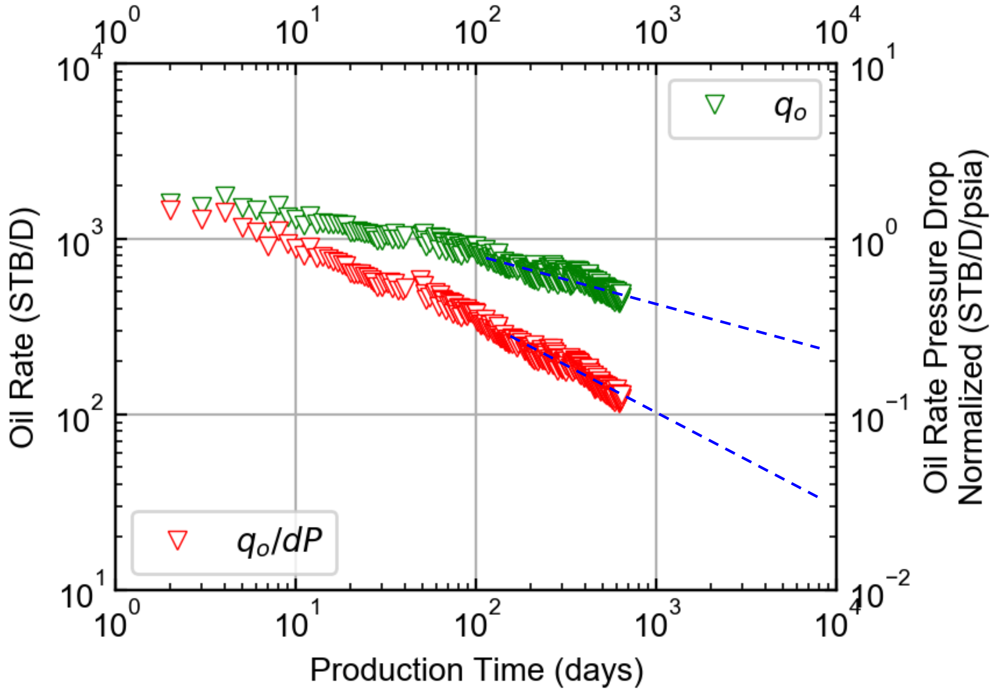
Measured flowrate data

$$q(t)_{normalized} = \frac{q(t)}{\Delta p} = \frac{q(t)}{(p_i - p_{wf})}$$

Rate pressure drop normalized

Initial reservoir pressure

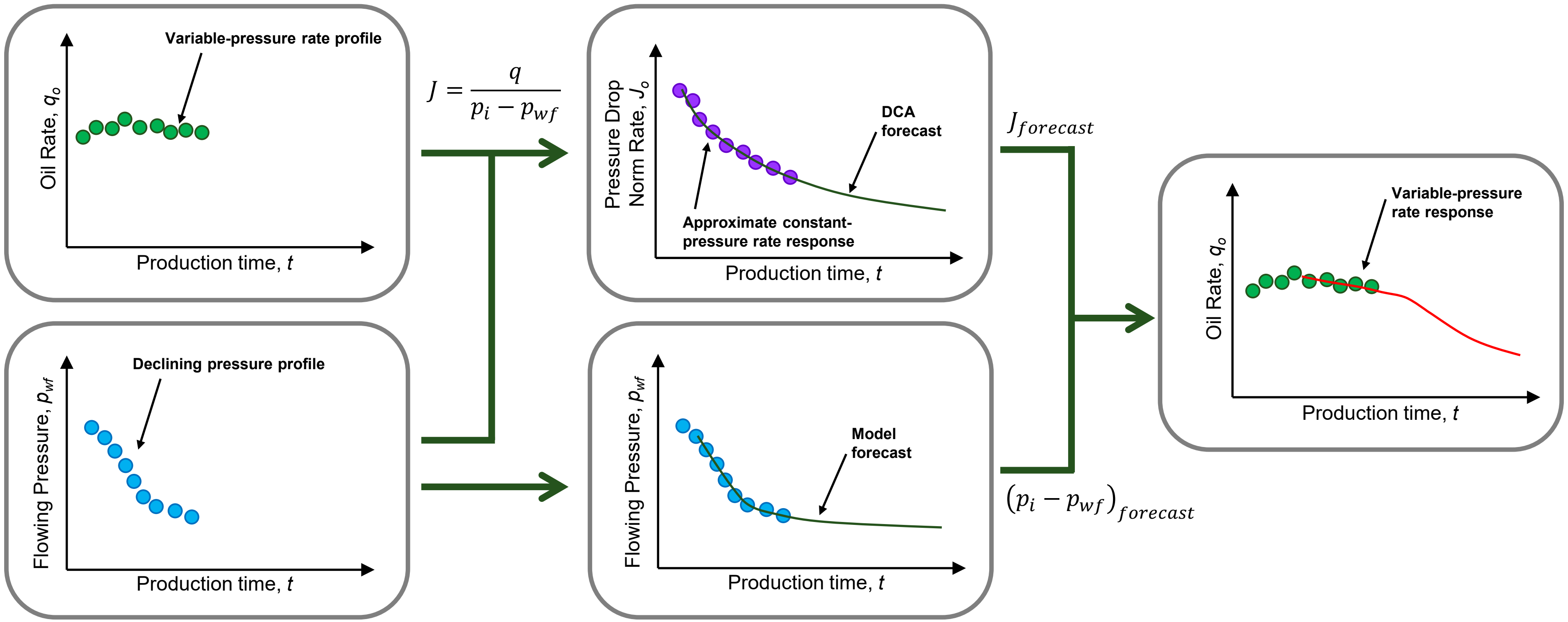
Measured bottomhole pressure data



Forecasting Production Rates using Time-Rate-Pressure Data

Pressure drop normalized rate data are used for forecasting well performance

- Flowing pressure profiles have a declining behavior during the production life of the well. The use of pressure drop normalized rate data attempt to provide a “constant-pressure” rate response to be forecasted with decline curve analysis.
- Normalized rate and flowing pressure are both forecasted. Resulting profiles are used to obtain the “variable-pressure” response of oil rate in time.



Rate-Integral Function

The rate-integral function assist decline curve analysis by smoothing the data

- Why use the rate-integral function?

  The rate-integral smooths the data to allow for more unique analysis.

- Rate integral function:

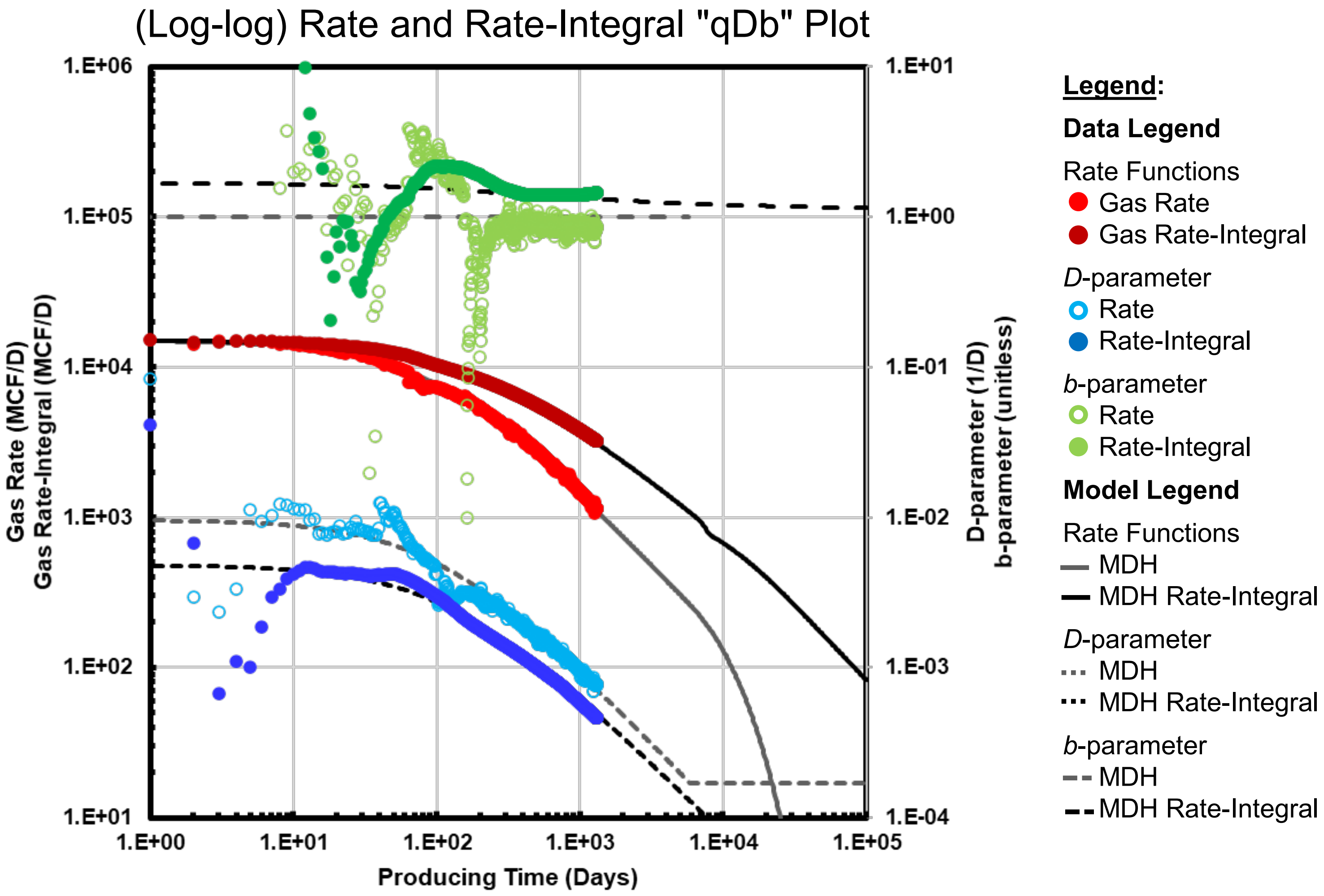
$$q_{int}(t) = \frac{1}{t}\int_0^t q(t)dt$$

- Rate integral-derivative function:

$$q_{int,d}(t) = t\,\frac{dq_{int}(t)}{dt}$$

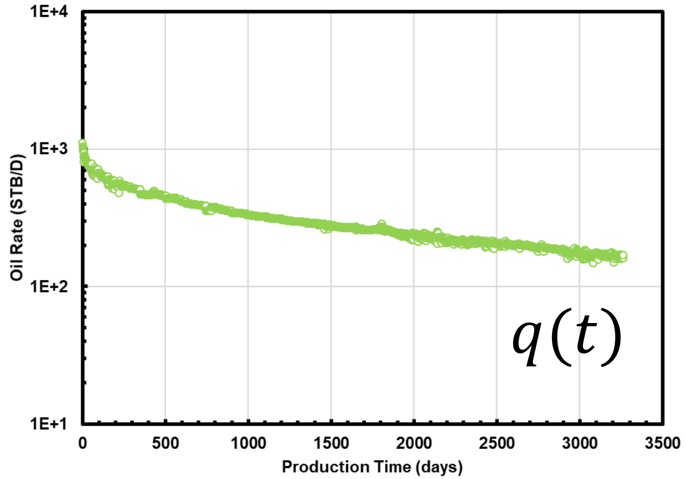
- Re-calculated rate from rate integral and rate integral-derivative functions:

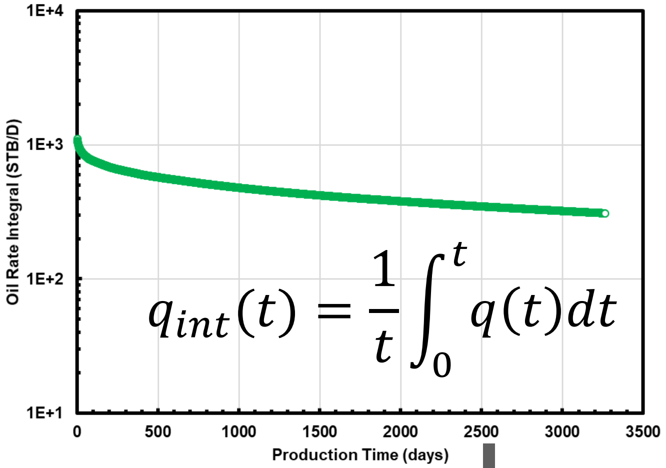
$$q_{recalc}(t) = q_{int}(t) - q_{int,d}(t)$$

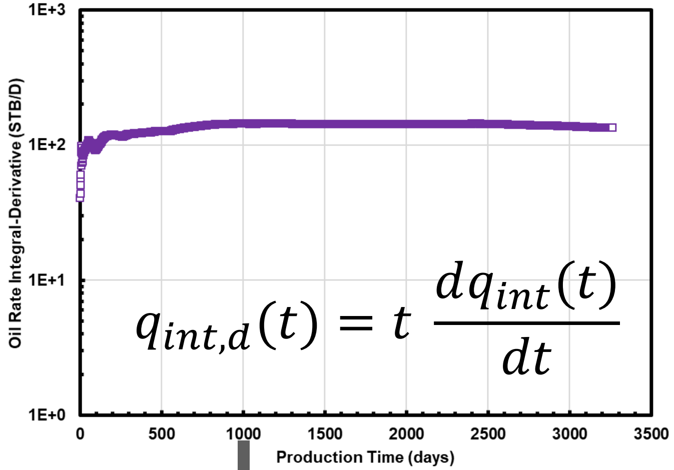


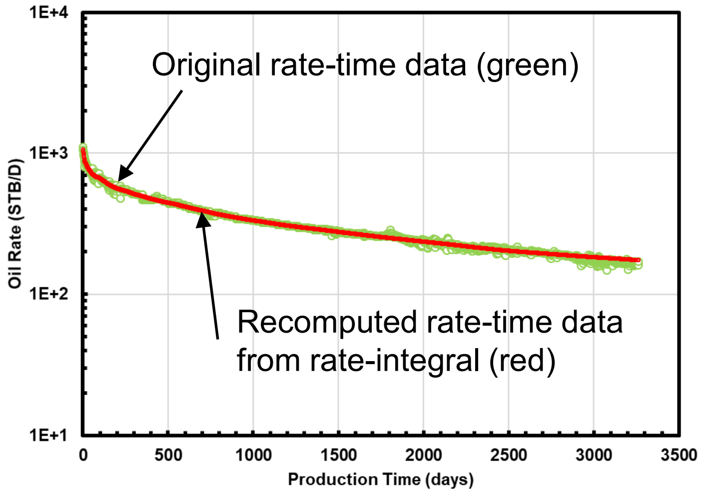
Rate-Integral Function

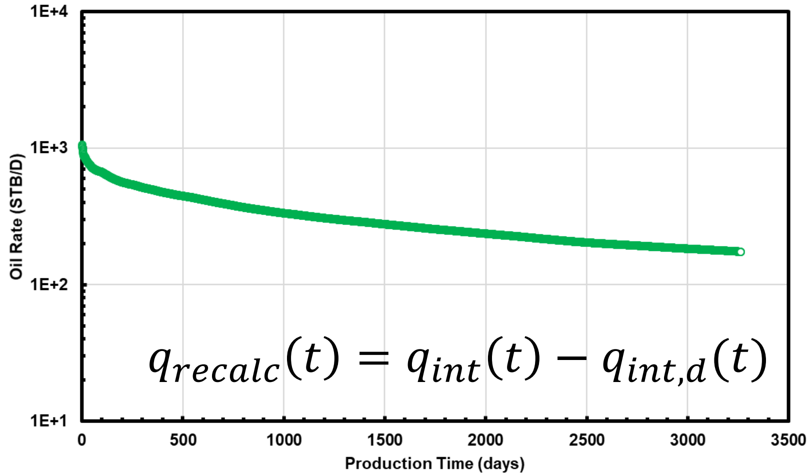
Recomputed rates from using rate-integral function may provide better resolution to identify certain decline curve parameters





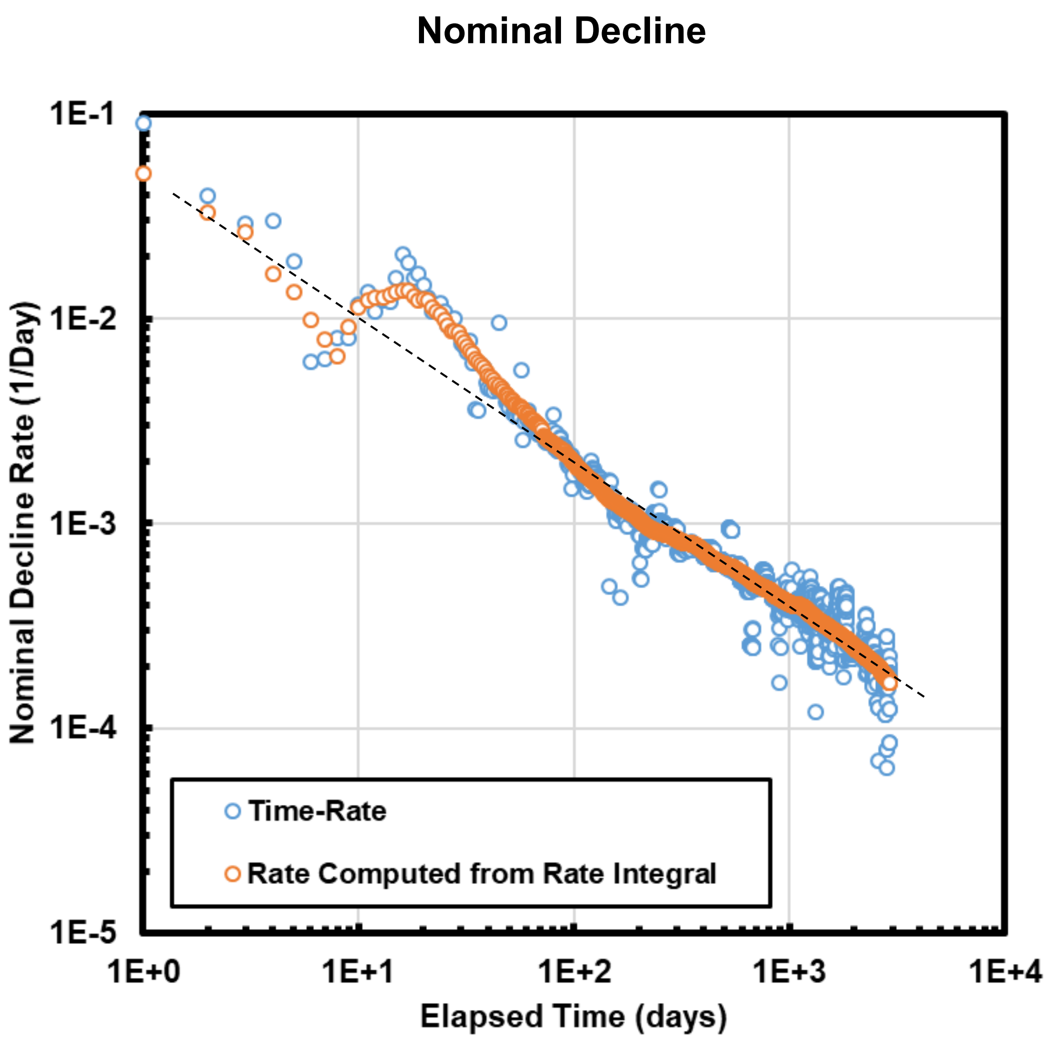


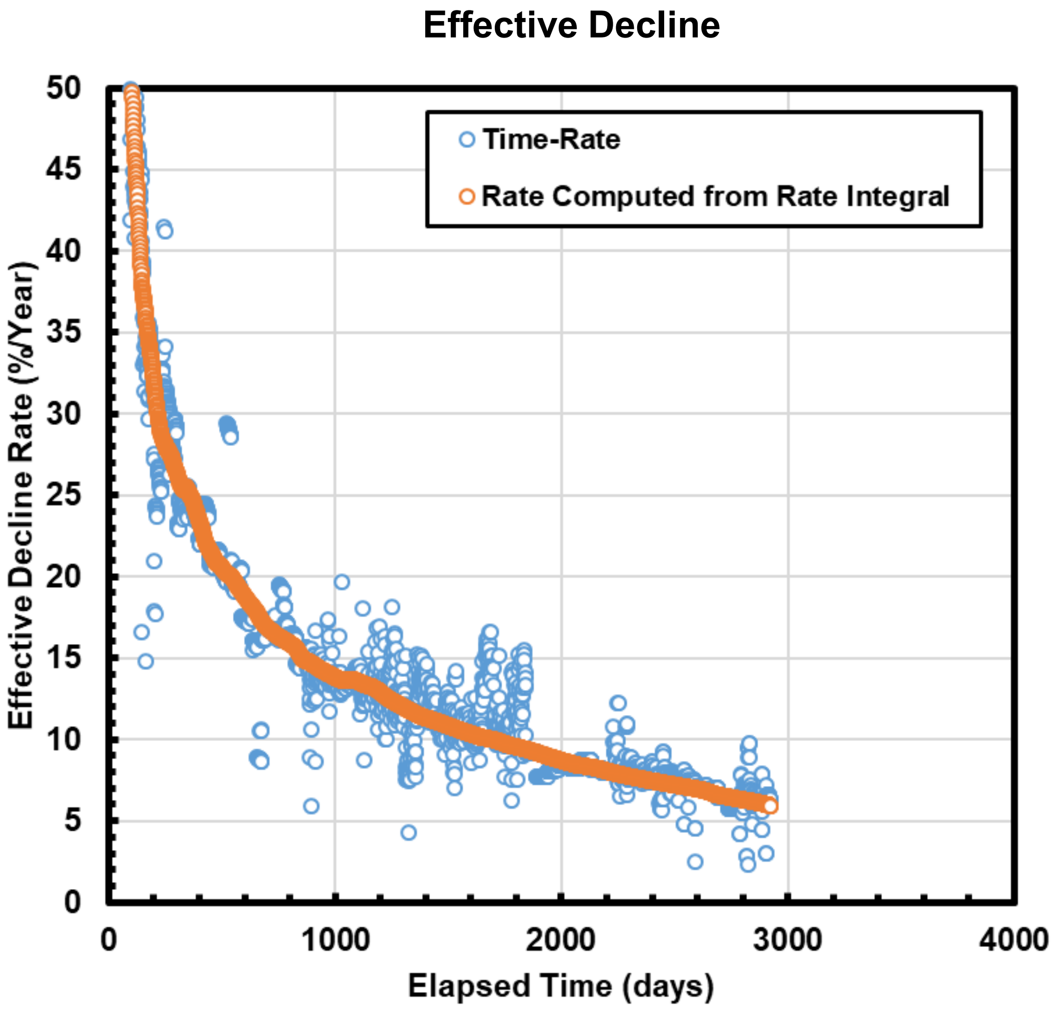




Rate-Integral Function

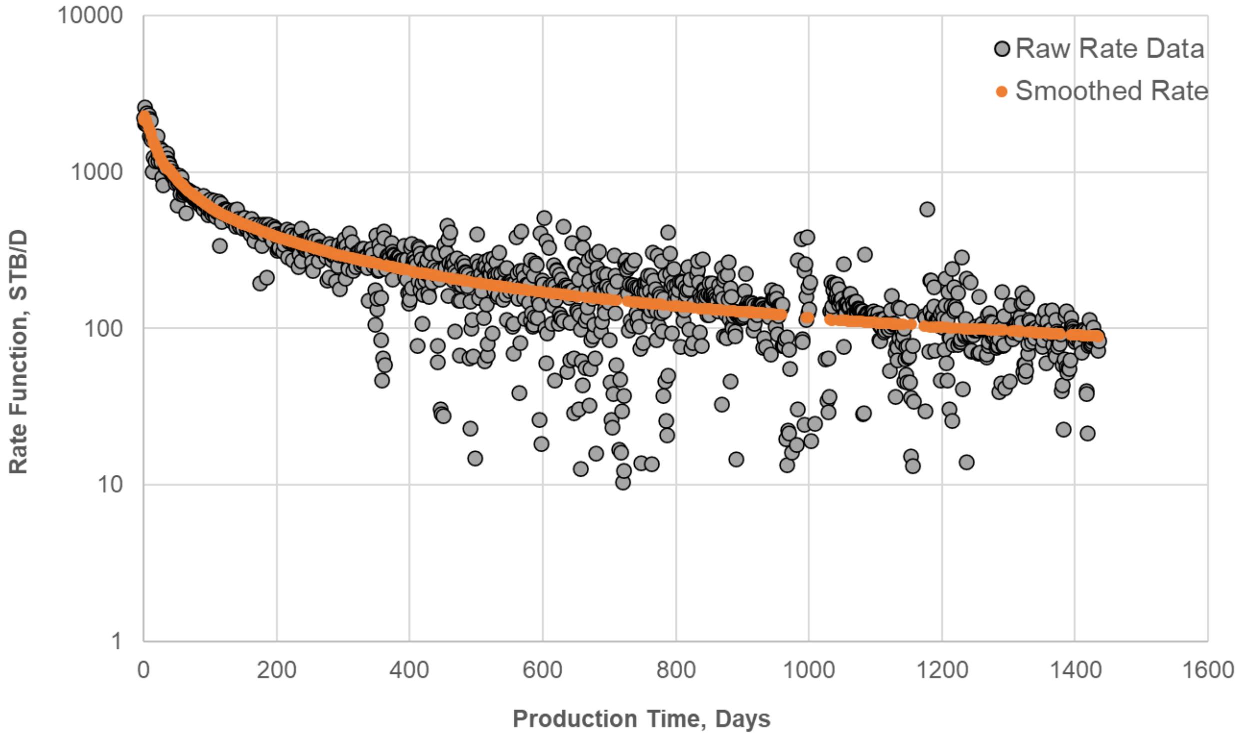
Rate-time functions are computed to compare the resolution between rate and rate-integral

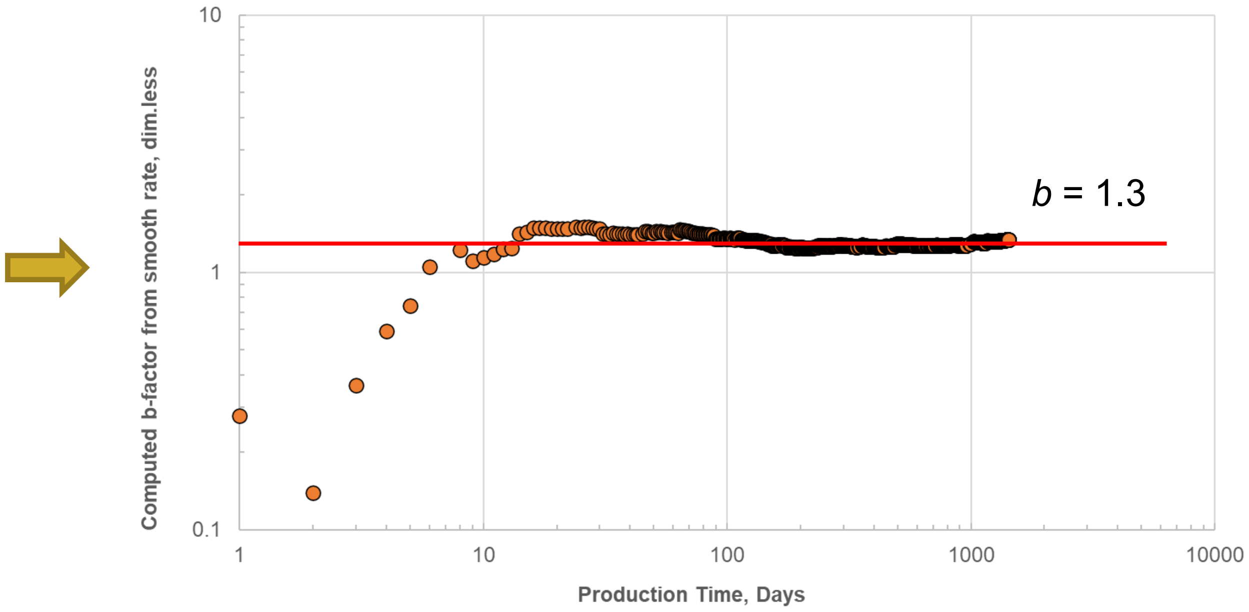




Rate-Integral Function

Higher resolution of recomputed rate data allows for better identification of decline parameters

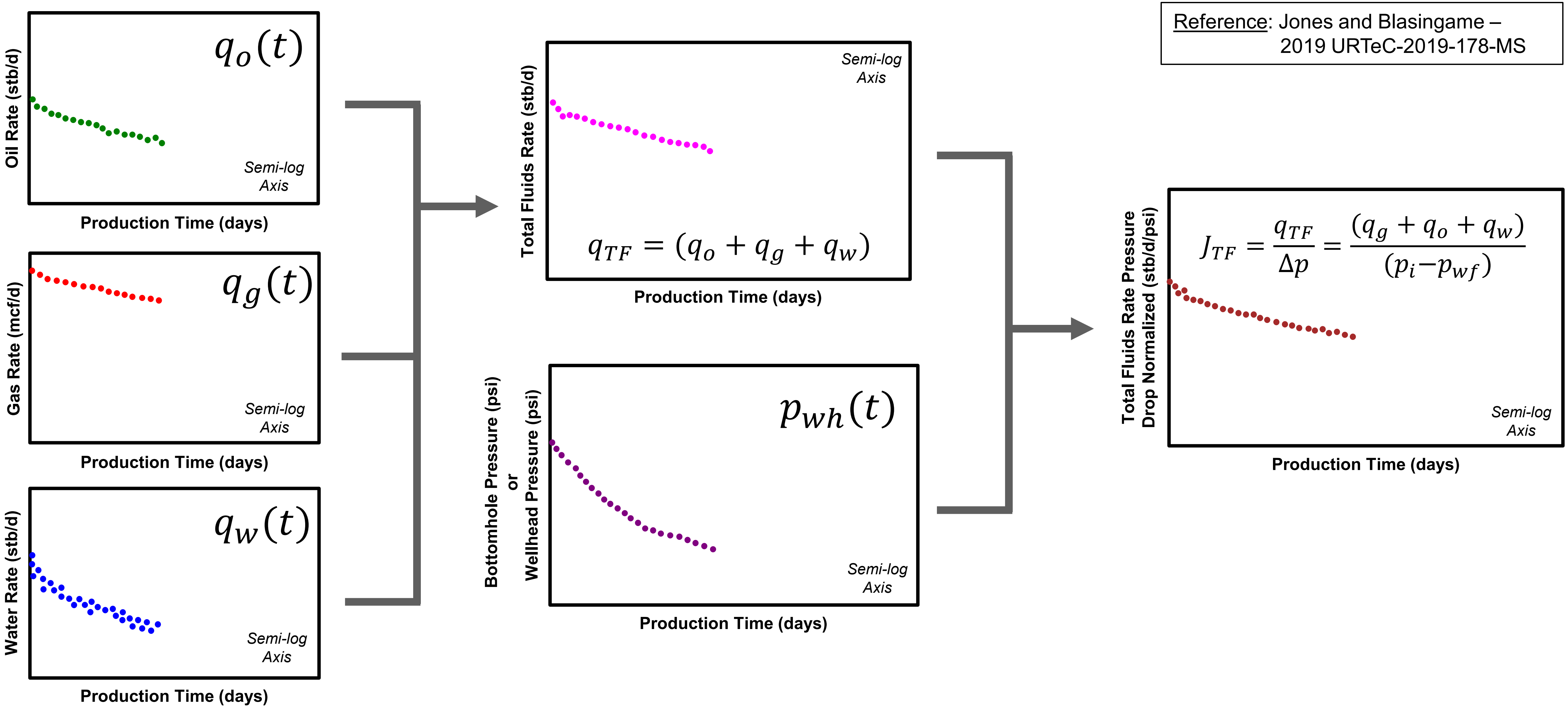




Multiphase Decline Curve Analysis

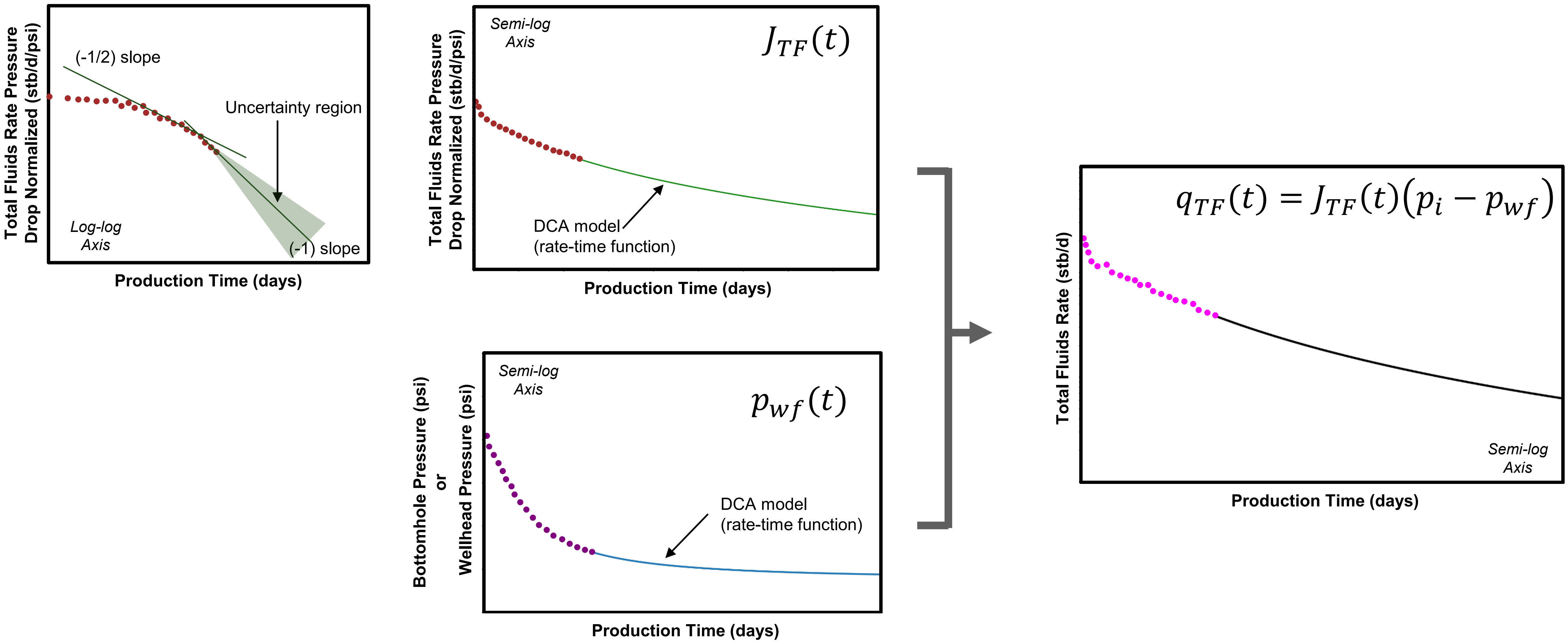
Originally presented to predict multiphase flowrates using early-time flowback data with flowing measured bottomhole pressures

Reference: Jones and Blasingame – 2019 URTeC-2019-178-MS



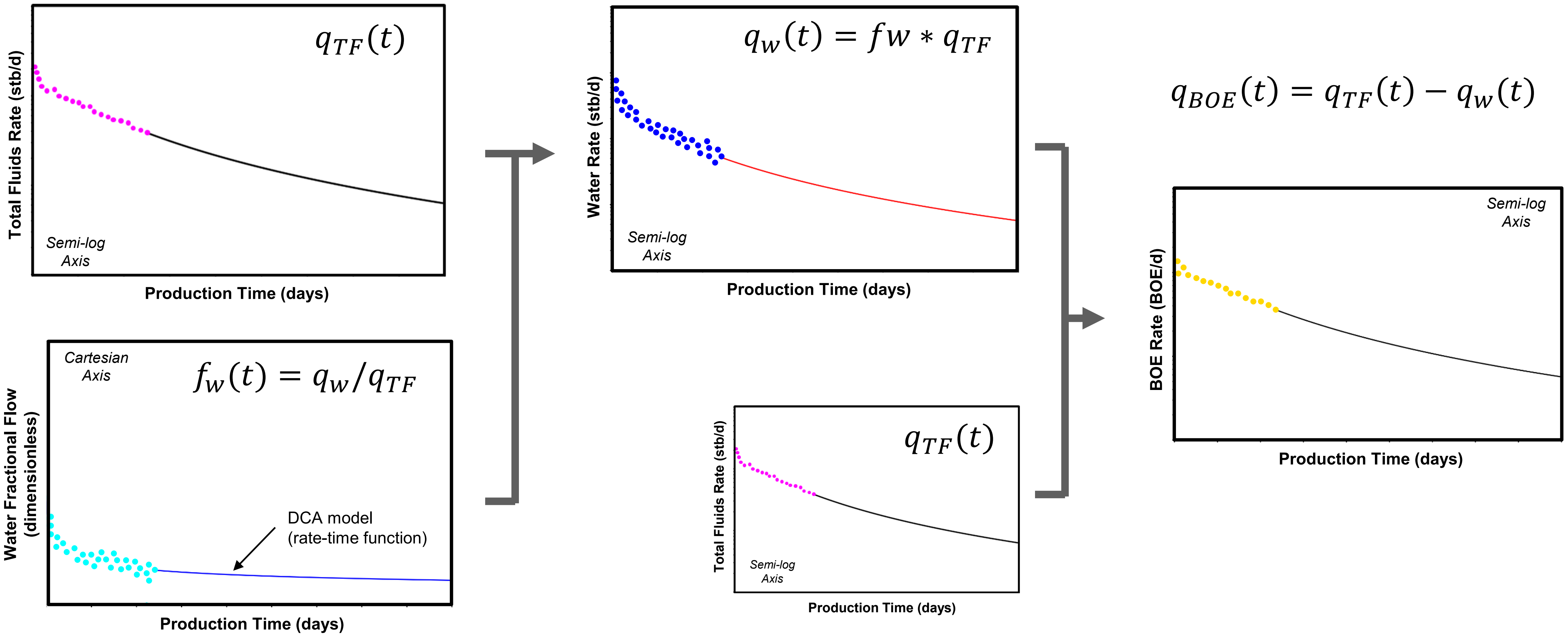
Multiphase Decline Curve Analysis

Diagnostics are performed using “pressure drop normalized total fluid” rate data



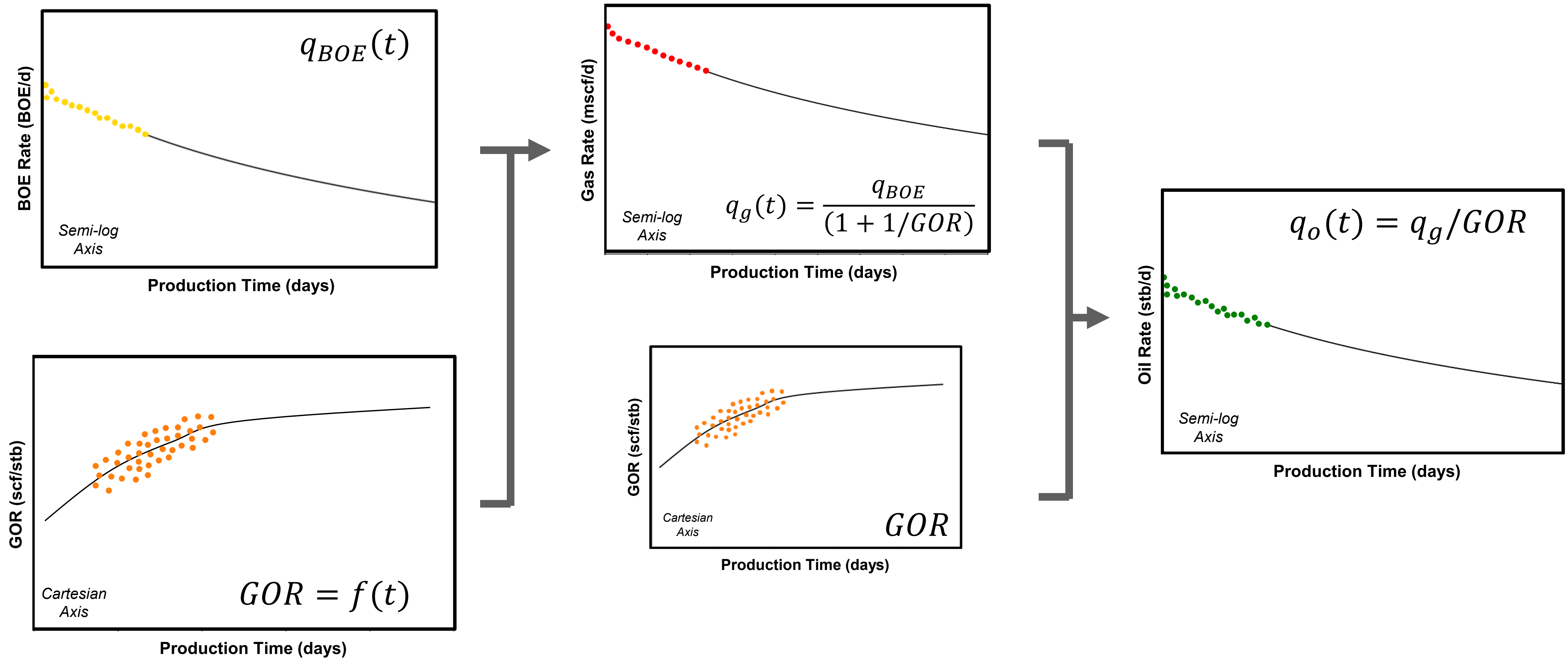
Multiphase Decline Curve Analysis

Modeling “water cut” or “fractional flow of water” is based on empirical methods



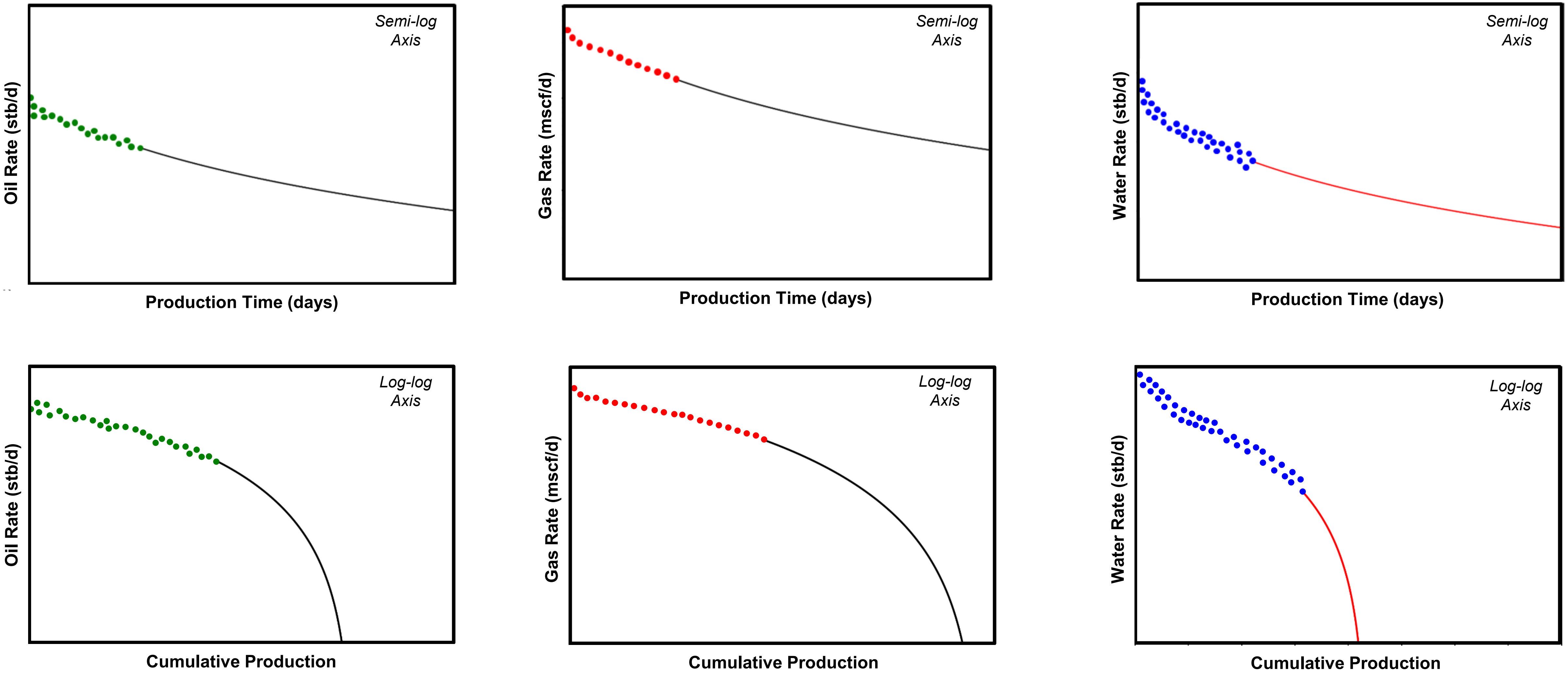
Multiphase Decline Curve Analysis

Methodology is not bound by any physical constraints – GOR/CGR modeling can be performed empirically



Multiphase Decline Curve Analysis

Oil, gas, and water forecasts are obtained as a result of the process

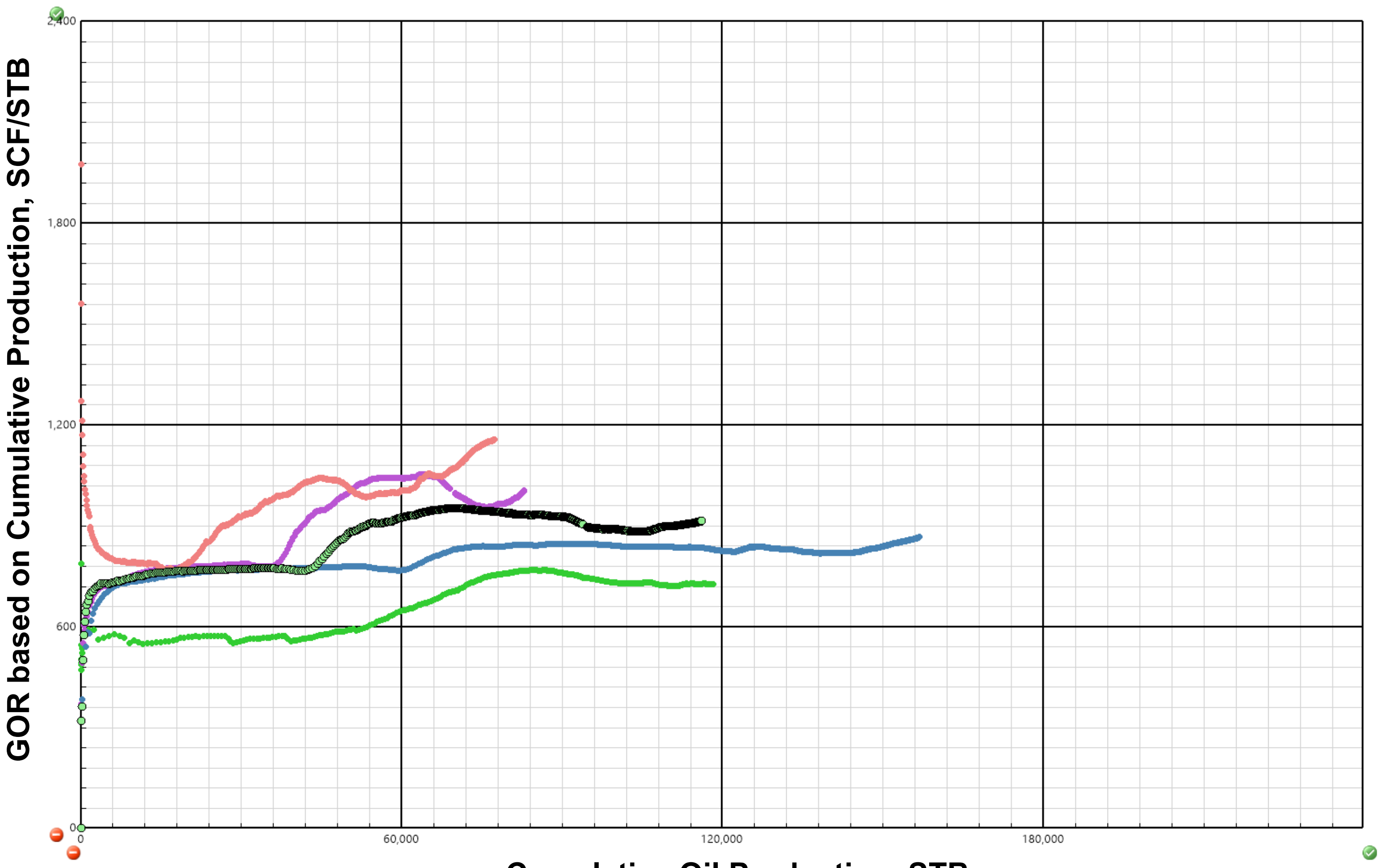


Multiphase Decline Curve Analysis

Estimation of gas-oil ratio profile methodology based on a data-driven approach

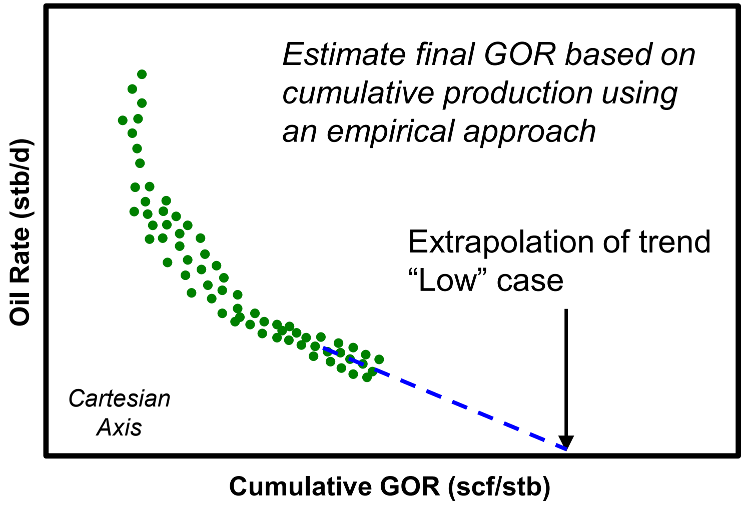
- Estimate oil (major phase) EUR.
- Prepare plots of “Oil Rate vs Cumulative GOR” and extrapolate trends.
  - Cumulative GOR is used for better resolution.
  - Cartesian plot and Semi-log plots of oil rate and cumulative GOR for investigating low case and high case estimates.
- Use Cumulative GOR and Cumulative oil production plot to “sense check” profiles and final “cumulative” GOR estimates.
- Plot “instantaneous” and “cumulative” GOR data to estimate “final” instantaneous GOR.
- Model GOR profile and estimate gas EUR.

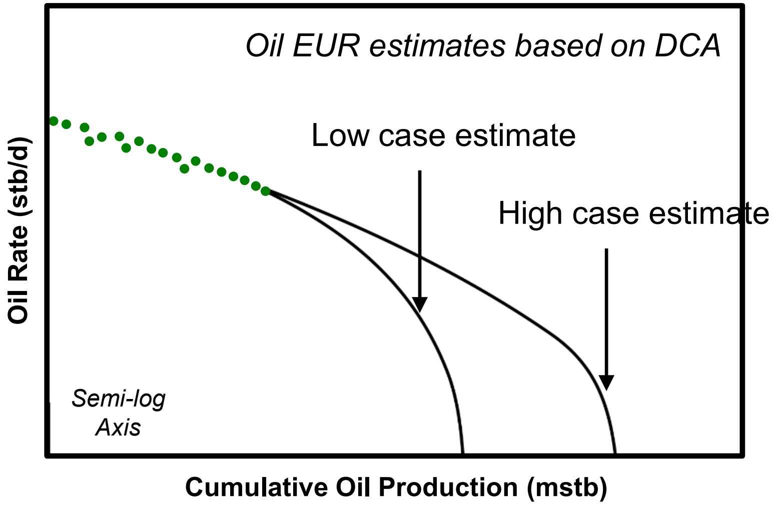
Cumulative GOR vs. Cumulative Oil

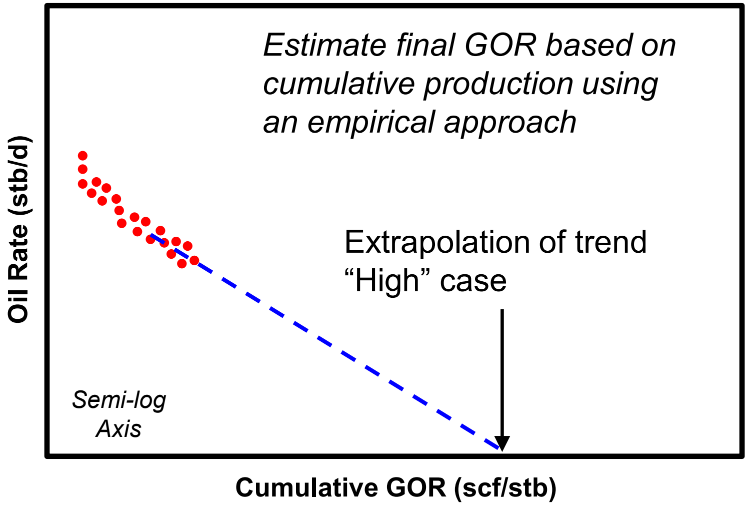


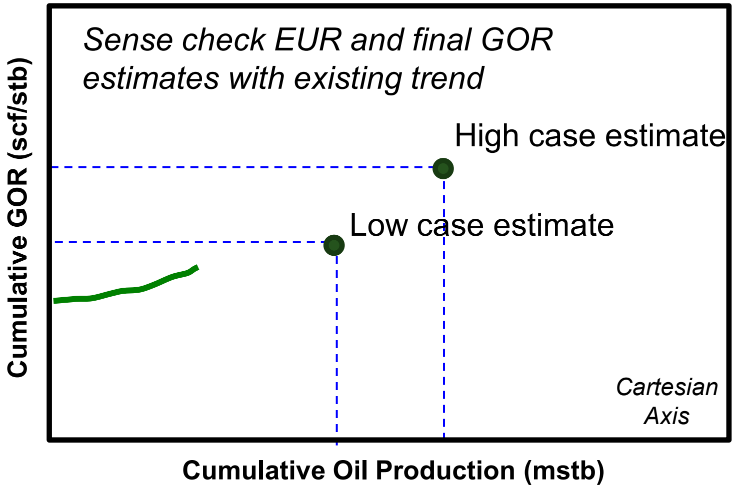
Multiphase Decline Curve Analysis

Underlying concept is based on “straight-line” extrapolation of rate and cumulative GOR with simple transformations



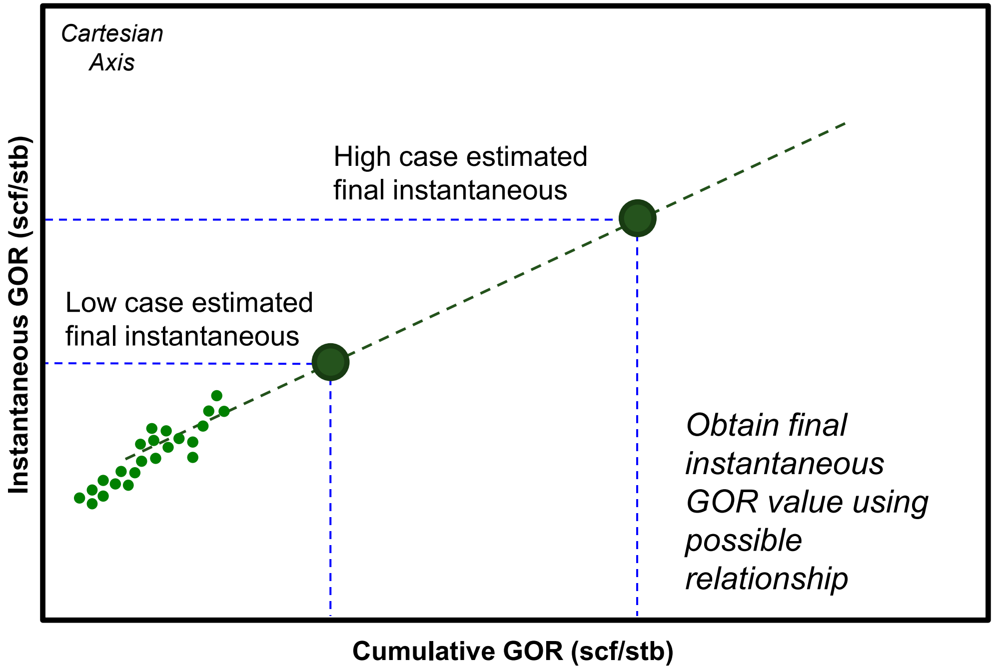


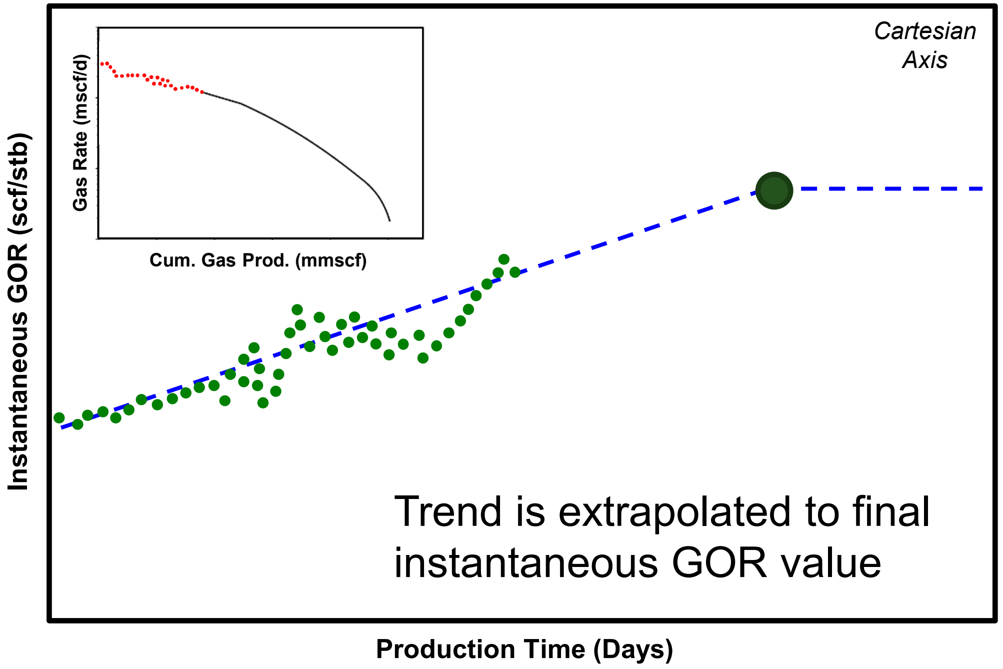




Multiphase Decline Curve Analysis

Final GOR profile is established using a potential relationship between cumulative and instantaneous GOR behavior





Summary of the Presentation

Diagnostic methods are powerful to identify trends, analyze and forecast production

- Key Discussion Points
  - Assumptions and limitations of the traditional Arps decline models.
  - Utilization of diagnostic methodologies to assess decline curve model parameters (e.g., Arps' hyperbolic b-factor, terminal decline rate, etc.).
  - Considerations for production forecasting using Arps and other decline models.
  - Incorporation of techniques which include incorporation of multi-phase flow, variable flowing pressures into decline curve analysis.
  - Impact of production data quality on decline curve analysis.
  - Considerations for characteristic solutions ("type well profiles").