Analysis of Reservoir Performance for Shale Gas Systems — RPSEA/GTI Project

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Introduction to Production Analysis for Tight Gas Systems

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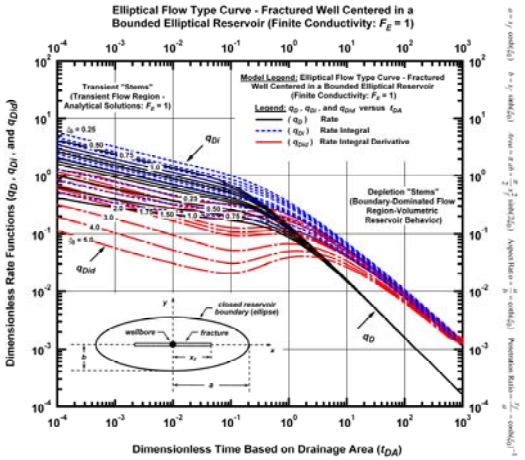
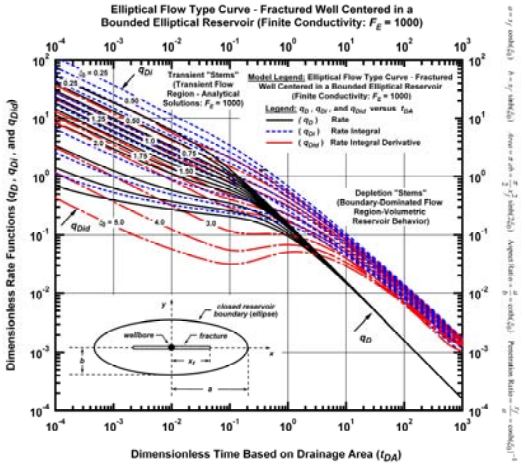
Vertical *TG/SG* Wells: *Elliptical Flow Domination*



a. Elliptical flow type curve solution — *low* fracture conductivity case.

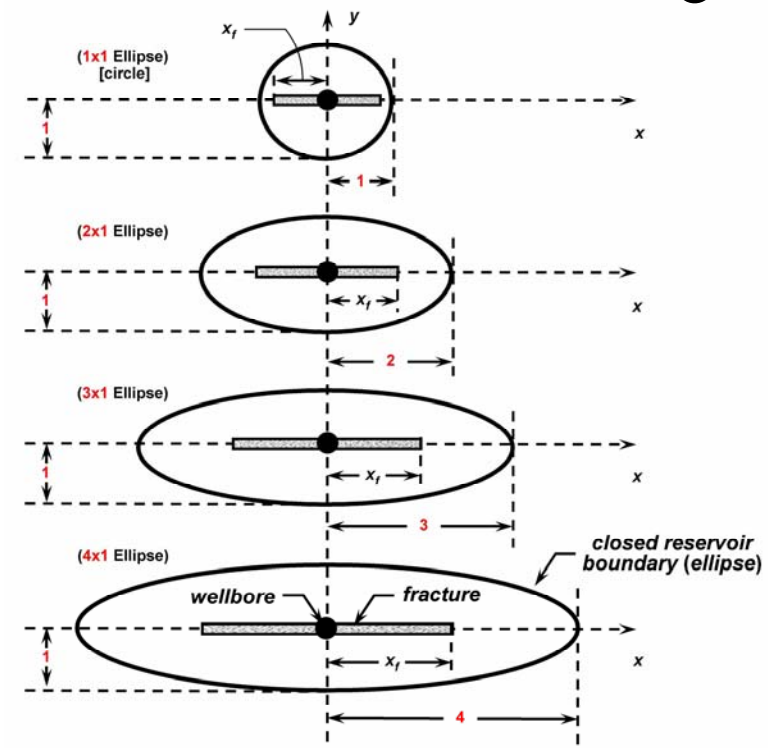


b. Elliptical flow type curve solution — *high* fracture conductivity case.

SPE 106308 (2007)

Evaluation of the Elliptical Flow Period for Hydraulically-Fractured Wells in Tight Gas Sands — Theoretical Aspects and Practical Considerations

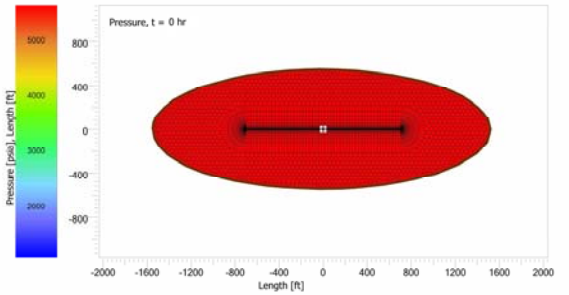
S. Amini, D. Ilk, and T. A. Blasingame, SPE, Texas A&M U.



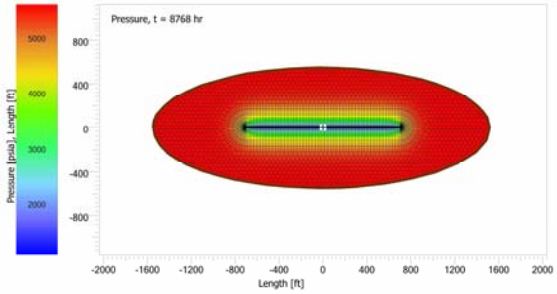
c. Elliptical boundary configurations (finite conductivity fracture case [Amini, *et al* (2007)].

Vertical *TG/SG* Wells: *Elliptical Flow Domination*

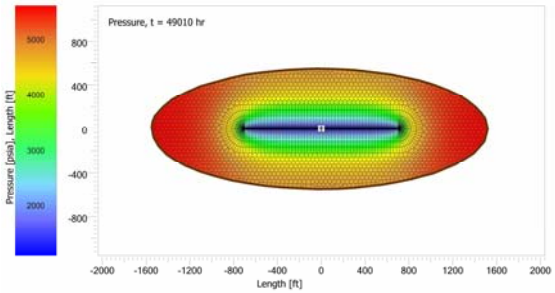
Results Generated Using:
Ecrin Product Suite, Kappa Engineering, Sophia-Antipolis, France (2008).



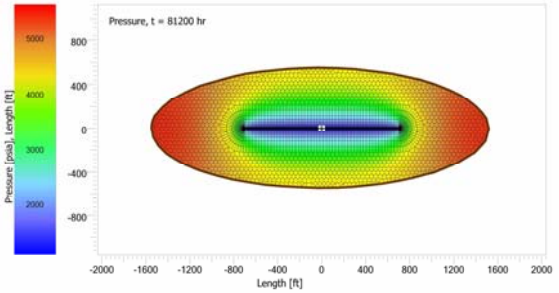
a. Pressure profile at 0 year (0 hr).



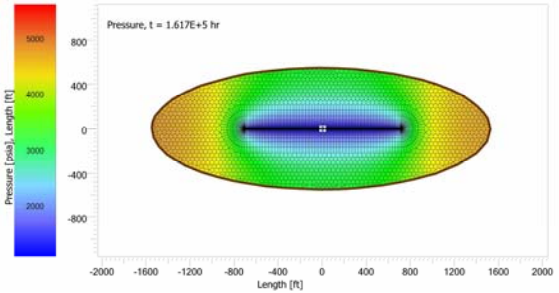
b. Pressure profile at 1 year (8768 hr).



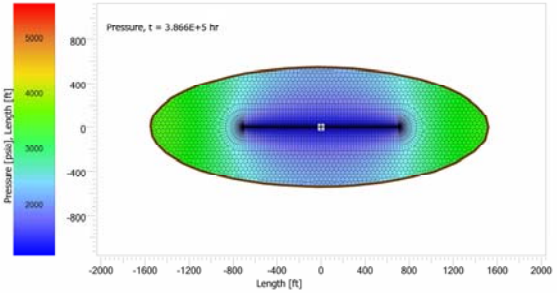
c. Pressure profile at 5.59 years (49,010 hr).



d. Pressure profile at 9.26 years (81,200 hr).



e. Pressure profile at 18.44 years (161,700 hr).



f. Pressure profile at 44.10 years (386,600 hr).

Issues Related to Horizontal Fractured Wells — Production Analysis for Shale Gas Systems

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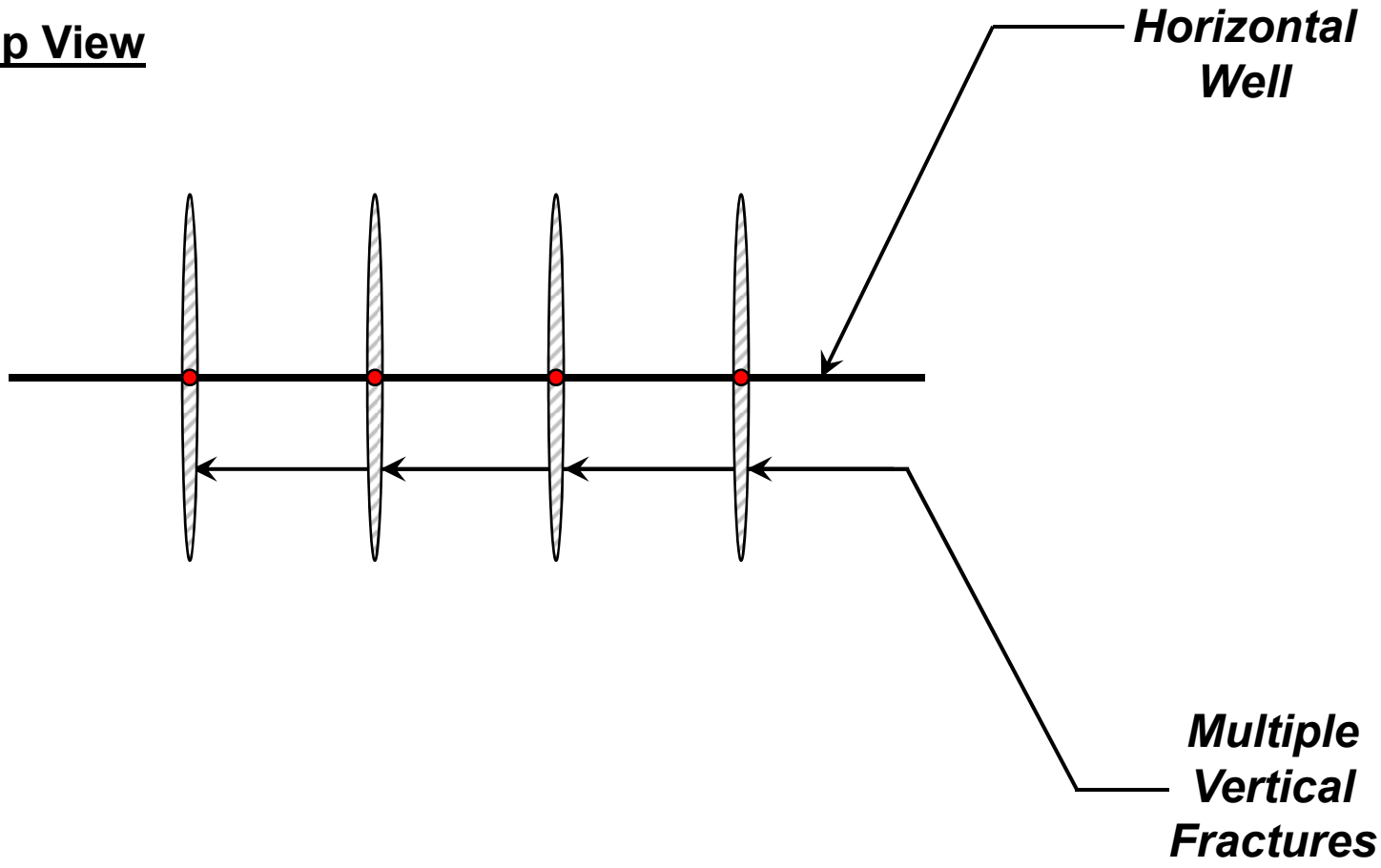
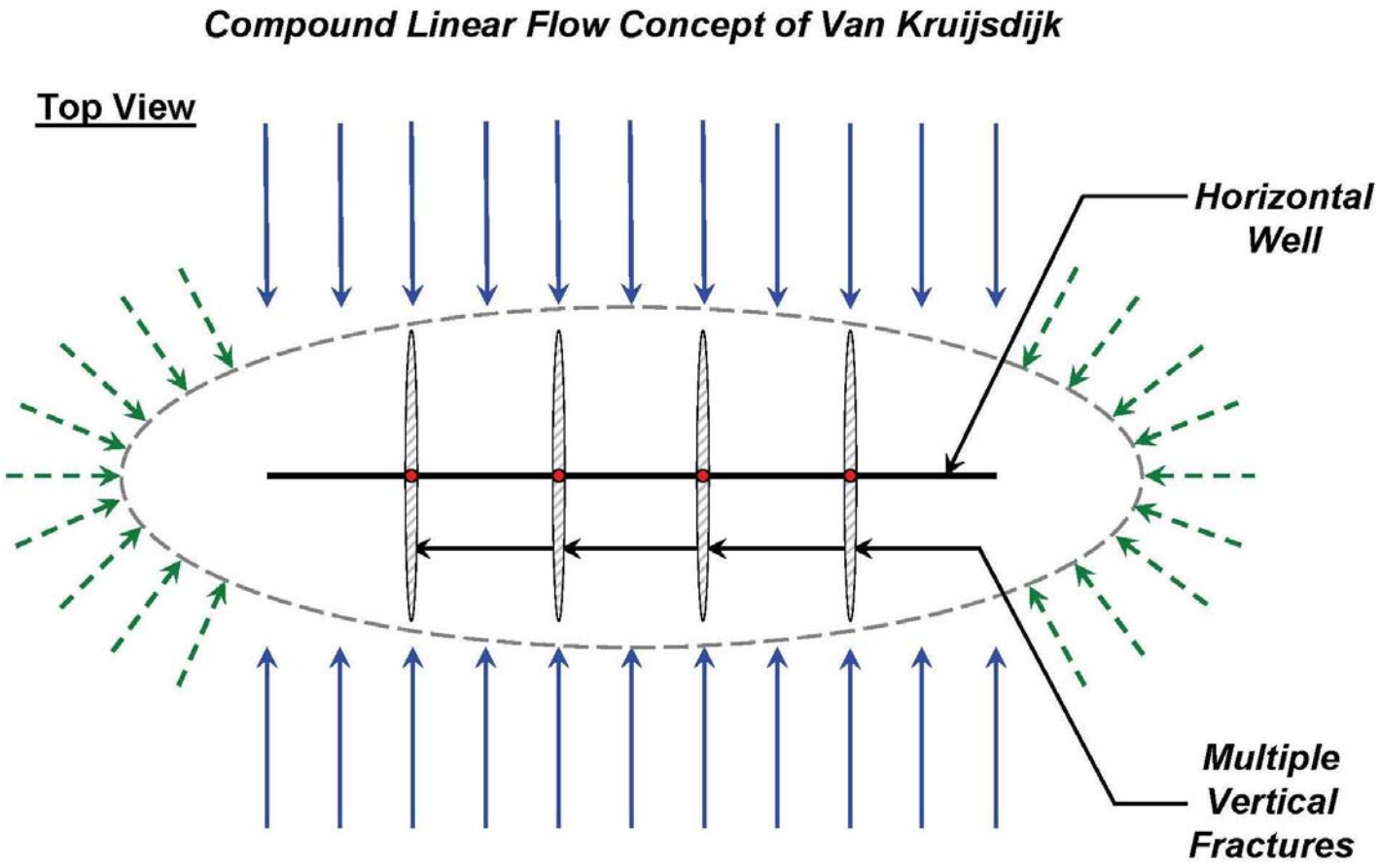
Horizontal Fractured Wells: Base *Simulation Model*

Base Simulation Model
for Horizontal Well with Multiple Hydraulic Fractures

Top View



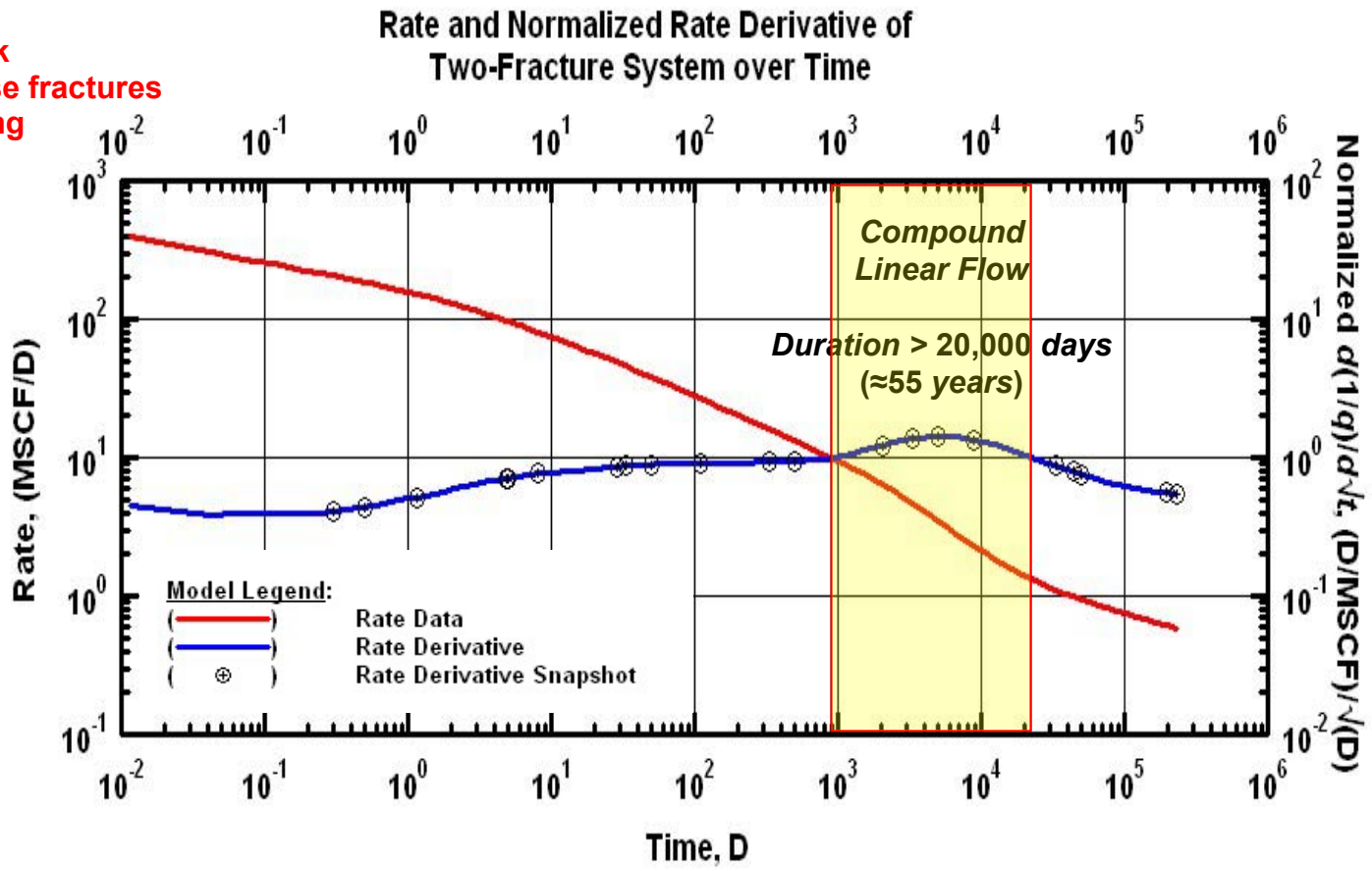
Horizontal Fractured Wells: *Compound Linear Flow*



- **Discussion**: ***Compound Linear Flow — Schematic Behavior***
  - van Kruysdijk and Dullaert schematic diagram (1989).
  - "Compound linear flow" = interference of fractures/horizontal well.
  - Flow regime can last DECADES.

Horizontal Fractured Wells: *Compound Linear Flow*

System:
— 100 nd rock
— 3 transverse fractures
— 25m spacing



- **Discussion**: *Compound Linear Flow — Interpretation Issues*
  - van Kruysdijk and Dullaert plot (1989).
  - Performance is DOMINATED by "compound linear flow."
  - INFINITE-ACTING condition for entire duration (≈200,000 days).

Horizontal Fractured Wells: *Issues, Realities, etc.*

Q1. Compound Linear Flow Domination? (transient flow)

A1. *Possibilities for estimating reservoir properties*:

- *a. Just give up — impossible to resolve anything.* (*default*)
- *b. "Lump" k, x_f, and L_{well} into a "parameter."* (*"mechanistic model"*)
- *c. Develop testing practices to estimate properties.* (*maybe…*)
- *d. Other model concepts* (*e.g., propagating ellipse*). (*very tedious*)

Q2. Estimating Reserves?

A2. *Issues*:

- *a. Extremely long transition to boundary-dominated flow.* (*reality*)
- *b. Hyperbolic rate relation will overestimate reserves.* (*as always*)
- *c. Power-law/exponential rate relation?* (*more validation*)

Q3. Role of simulation/modeling?

A3. *In the short-term, simulation/modeling is the primary tool at our disposal — we need diagnostic relations* (*i.e., analytical/semi-analytical solutions*); *BUT numerical solutions will dominate the "modeling" effort.*

Production Decline Analysis — A (Very) Brief Review

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SPE 116731: *Definitions of Rate Functions*

- **Rate Function Definitions:**
  - ***Loss Ratio*:**

$$\frac{1}{D} \equiv -\frac{q}{dq/dt} \qquad \left[\text{or } D \equiv -\frac{dq}{dQ} \right]$$

  - ***Derivative of Loss Ratio*:**

$$b \equiv \frac{d}{dt}\left[\frac{1}{D}\right] \equiv -\frac{d}{dt}\left[\frac{q}{dq/dt}\right] \qquad \left[\text{or } \; b \equiv q\frac{d}{dQ}\left[\frac{1}{D}\right] \right]$$

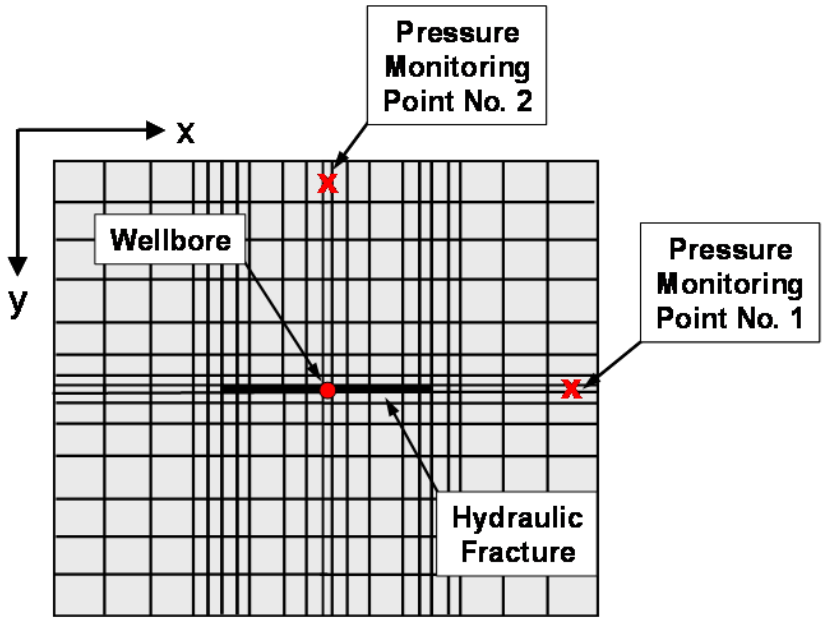
  - ***Exponential and Hyperbolic Rate Relations*:**

(Exponential Decline) (Hyperbolic Decline)

$$D = \text{con} \rightarrow q = q_i \exp[-D_i t]; \text{or } b = \text{con} \rightarrow q = \frac{q_i}{[1 + bD_i t]^{(1/b)}}$$

- **Cause and Effect:**
  - **Hyperbolic relation is mis-applied to transient data.**
  - **What is the "characteristic behavior" of the *D* and *b*-parameters? *Evaluate continuously using data*.**

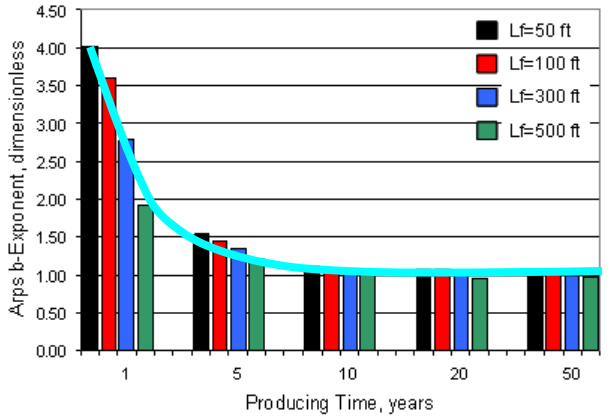
Decline Analysis: *Tight Gas Systems*

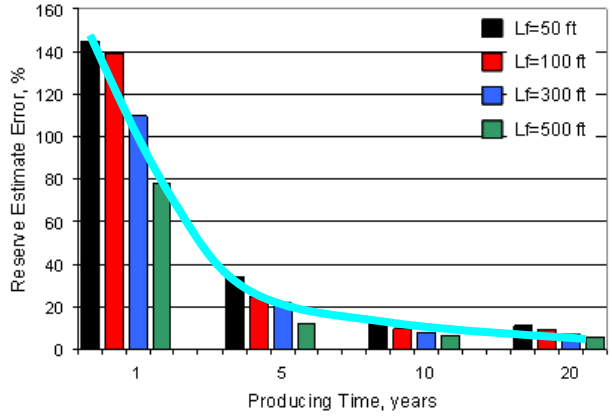


SPE 109625 (2007)

Estimating Reserves in Tight Gas Sands at HP/HT Reservoir Conditions: Use and Misuse of an Arps Decline Curve Methodology

J.A. Rushing, A.D. Perego, R.B. Sullivan, Anadarko Petroleum, and T.A. Blasingame, Texas A&M U.





Numerical Model Considers:

- ***Reservoir Layering.***
- ***k_v/k_h ratio.***
- ***Fracture Length, x_f.***
- ***Fracture Conductivity, F_{cD}.***

Analysis/Validation Approach:

- ***Fit q(t) with Arps' hyperbolic relation.***
- ***Compare reserves to model at 30 years.***

SPE 116731: *"Power-Law Exponential" Rate Result*

- ***Observed Behavior of the "Decline" Parameter [D(t)]:***

$$D \equiv -\frac{1}{q}\frac{dq}{dt} \approx D_\infty + n\hat{D}_i t^{-(1-n)} \quad \left[\approx D_\infty + At^{-B}\right]$$

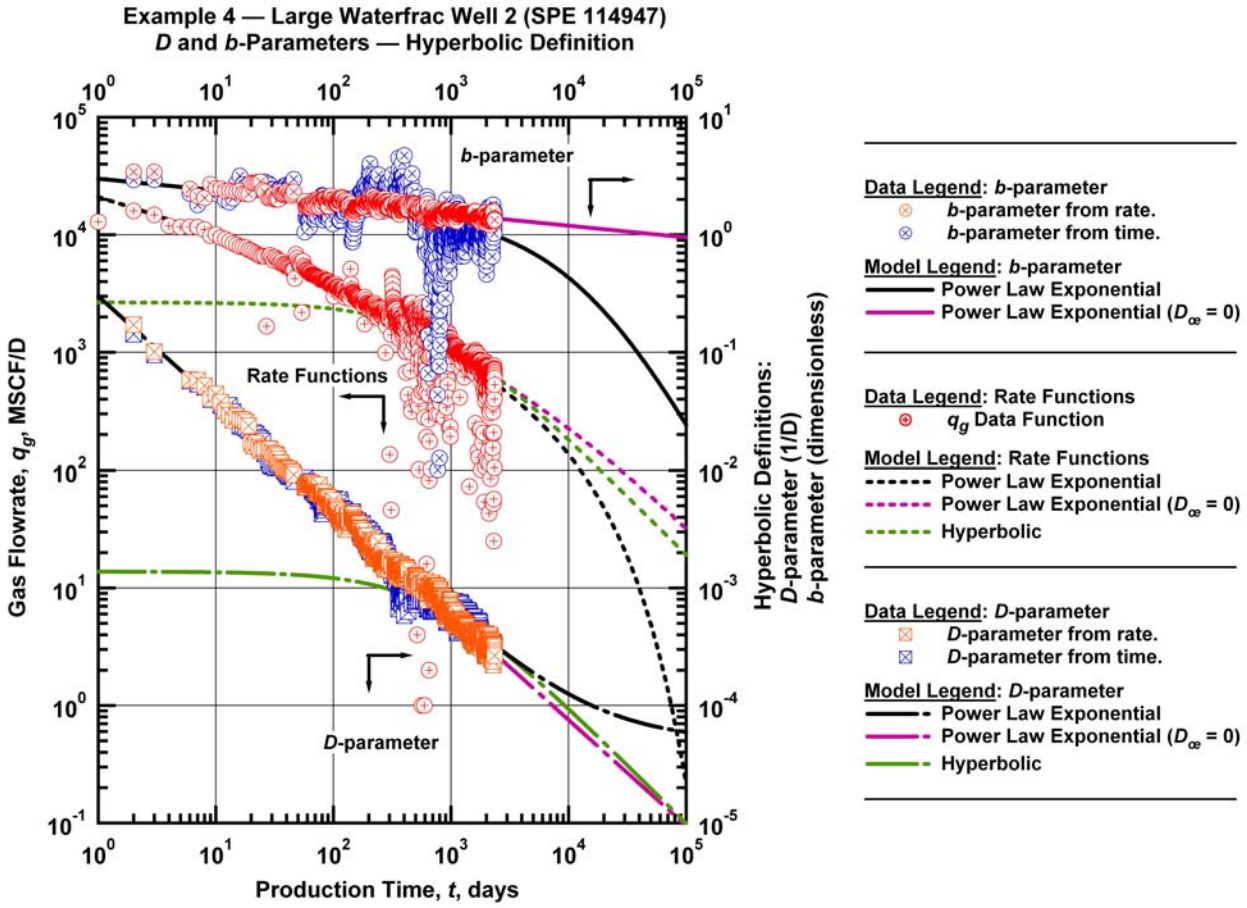
- ***Solving for Flowrate [q(t)] Using the D(t) Relation:***

$$q = \hat{q}_i \exp[-D_\infty t - \hat{D}_i t^n]$$

- ***Solving for the "Hyperbolic" Parameter [b(t)]:***

$$b = \frac{n\hat{D}_i(1-n)}{[n\hat{D}_i + D_\infty t^{(1-n)}]^2} t^{-n}$$

SPE 116731: *q-D-b Plot — Large WF Tight Gas Well*



- **Discussion**: ***Large "Waterfrac" Gas Well***
  - Erratic rate behavior caused by liquid loading is seen at late times.
  - Outstanding matches of the computed *D*- and *b*-parameters with the power-law exponential model are observed.

Data Needs/Issues — Well Performance Analysis NAS Cases

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Data/Task List for New Albany Shale: (*Blasingame*)

- **Data Requirements:** — **Status**
  - Production Rates (and Pressures) — TAMU/GTI/Operator(s)
  - Pressure Transient Test Data — Operator(s)
  - Reservoir/Fluid Properties — TAMU/GTI/Operator(s)
  - Well Completion Reports — TAMU/GTI/Operator(s)

- **Deliverables:** — **Status**
  - Production Data Analysis [$q(t)$ or $p_{wf}(t)$ & $q(t)$] — select cases only
  - Pressure Transient Test Analysis — select cases only
  - Integrated Reservoir Description* — final deliverable

- **Tasks** — **Priority**
  - Assemble Data (production/reservoir/fluid) — very high
  - Analysis of production and pressure transient data — high
  - Correlation with other data types (logs, seismic, etc.) — medium
  - Correlation with well completion information — high

**In the context of this project, an "Integrated Reservoir Description" is a correlation product — a map or correlation view of the reservoir with results and different data types.*

Rate-Time Analysis for Joe HOBBS Well (Meade Co KY)
(*Example Case: New Albany Shale*)

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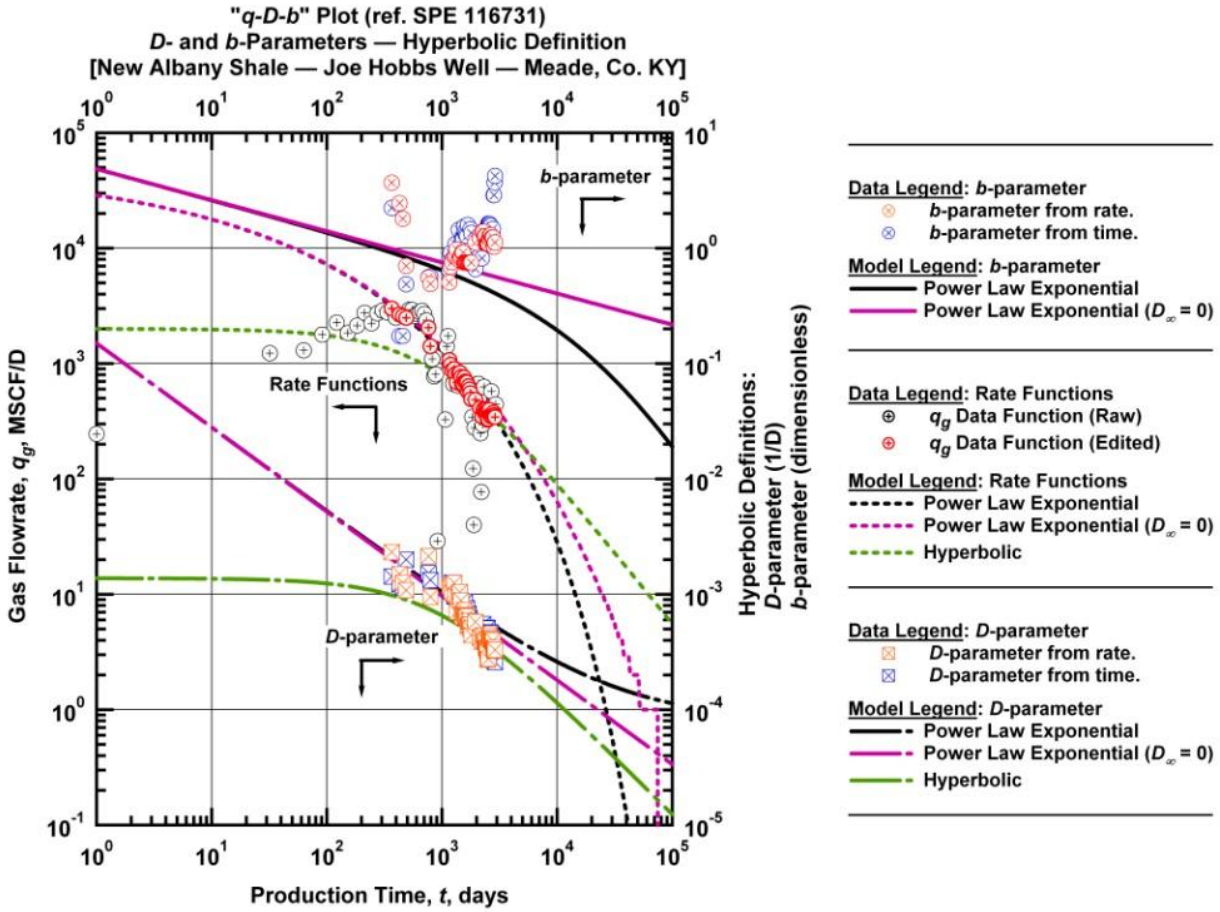
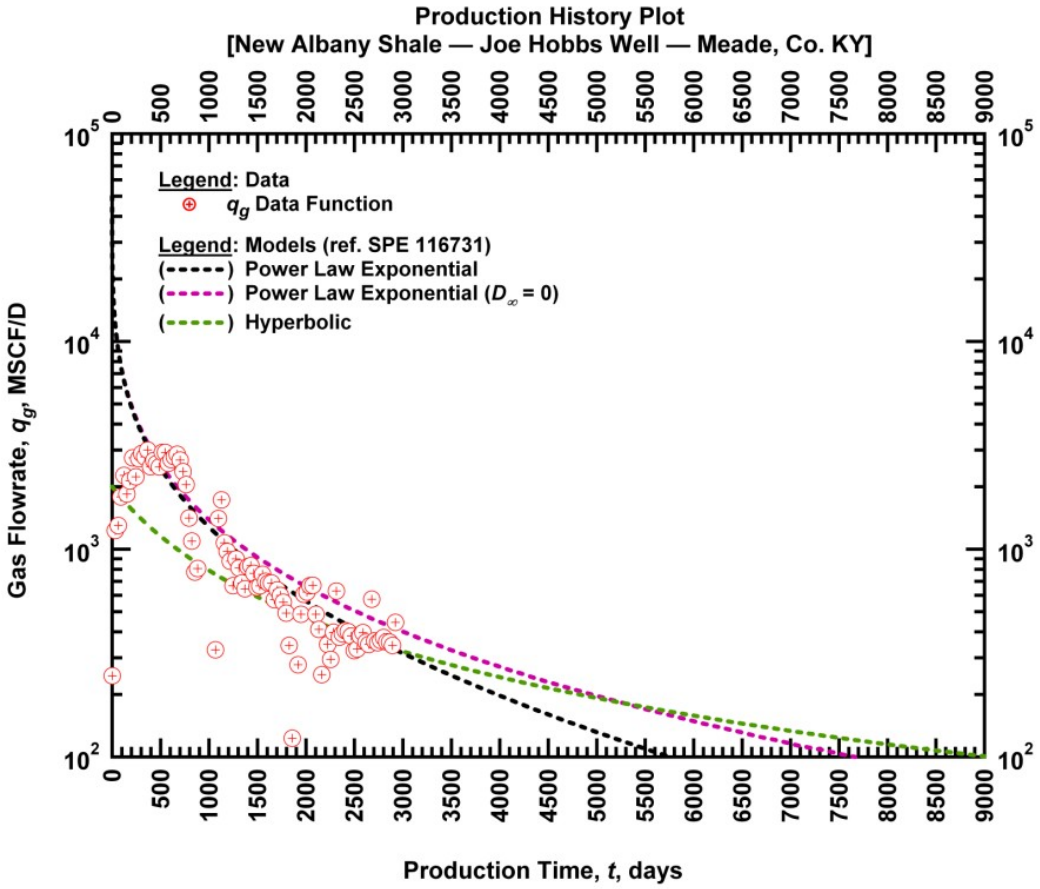
Joe HOBBS Well (Meade Co KY): *q-D-b Plot*



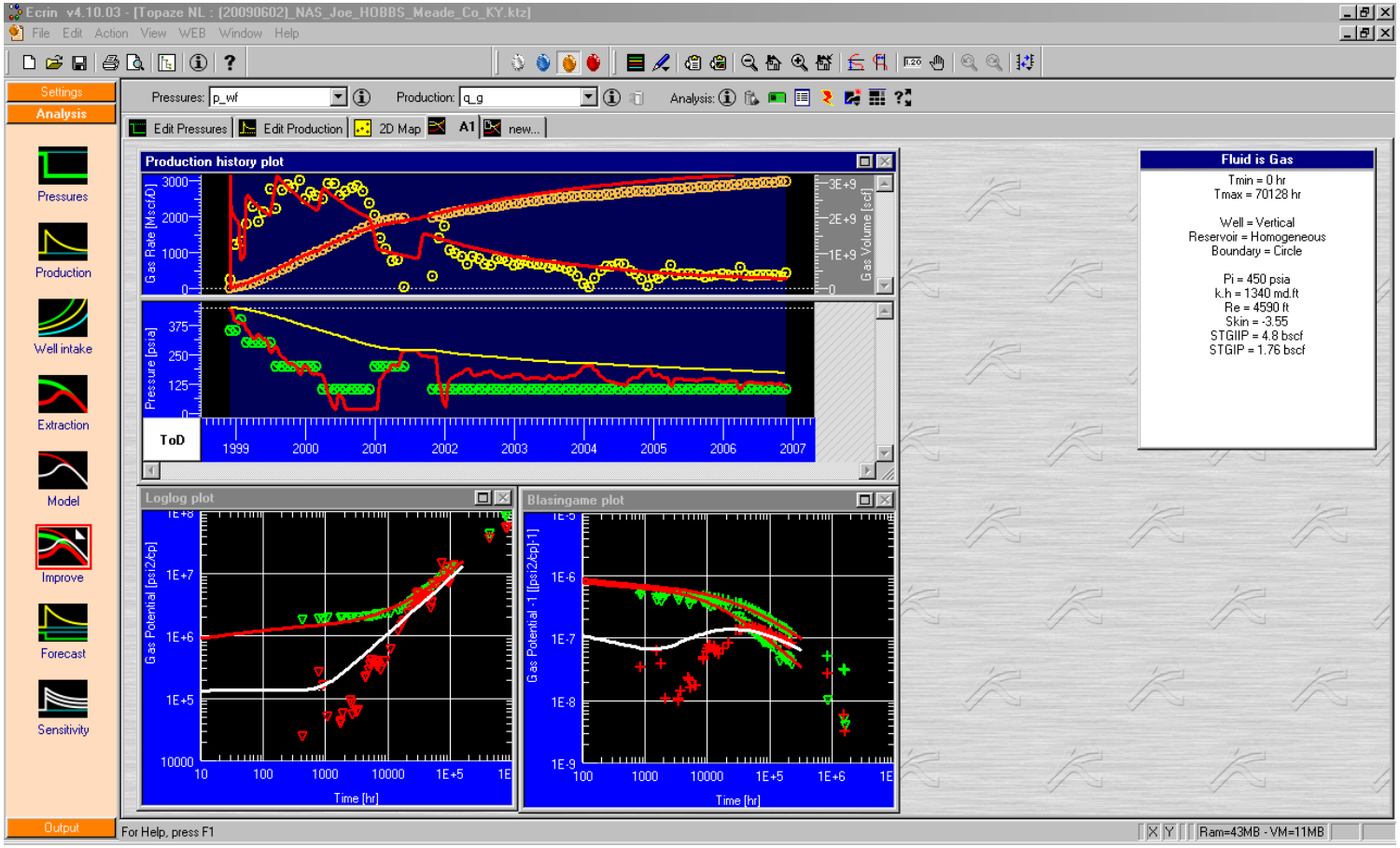
- **Discussion**: ***q-D-b Plot for Joe HOBBS Well (Meade Co KY)***
  - Monthly data from PUBLIC records.
  - Fair *D*-parameter and weak *b*-parameter computed from data.
  - Reasonable match of rate data (BDF) — poor transient data.

Joe HOBBS Well (Meade Co KY): *Rate-Time Plot*



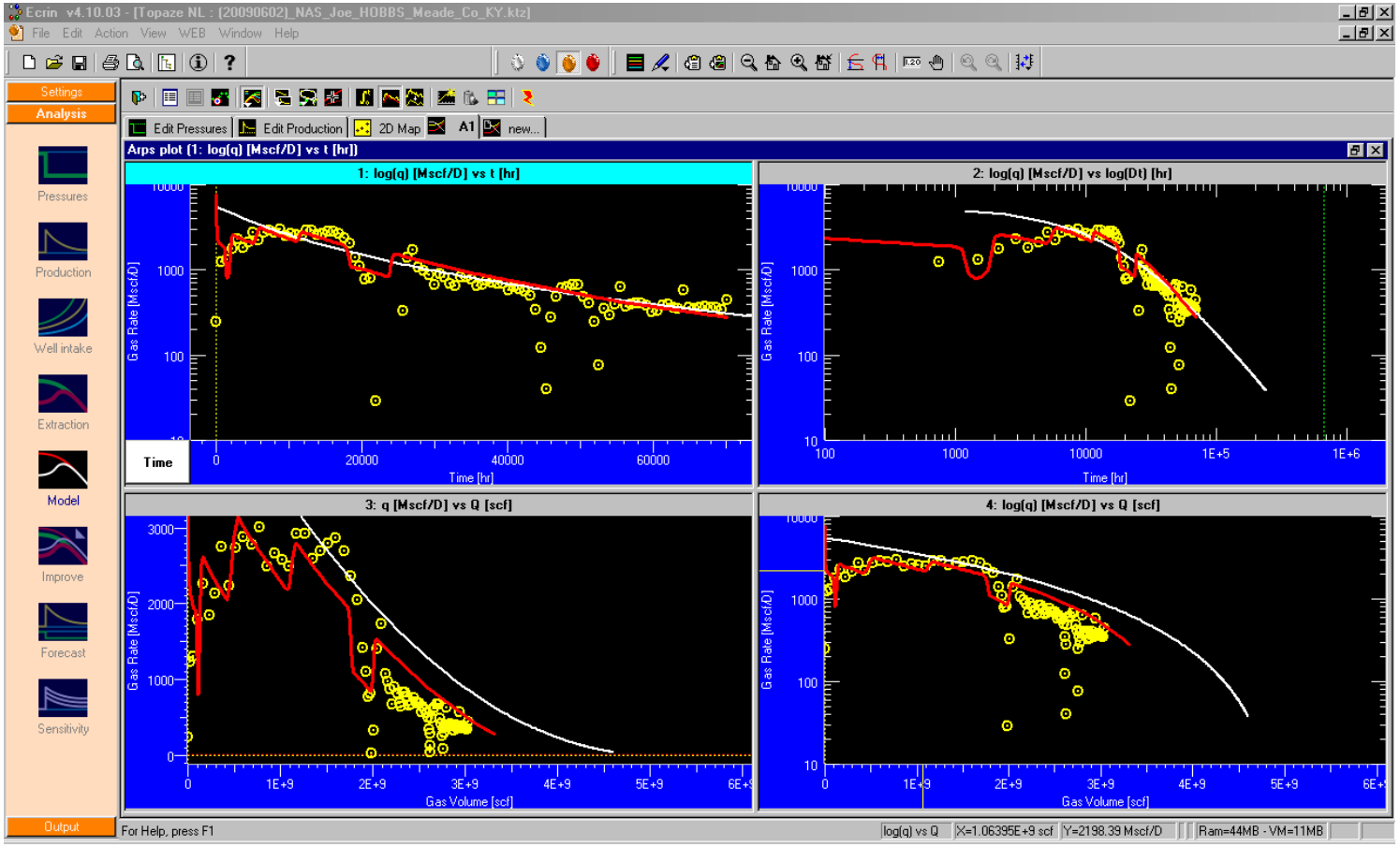
- **Discussion**: ***Rate-Time Plot for Joe HOBBS Well (Meade Co KY)***
  - Monthly data from PUBLIC records.
  - Model matches are problematic — poor transient data, no pressure.
  - Power Law Exponential ($D_\infty \neq 0$) yields a reasonable (conservative) match.

Joe HOBBS Well (Meade Co KY): *Topaze Analysis*



- **Discussion**: *Topaze Analysis for Joe HOBBS Well (Meade Co KY)*
  - No pressure data — profile ASSUMED.
  - Match is obviously influence by the lack of pressure data.
  - This work is provided as a "what we should be doing case…"

Joe HOBBS Well (Meade Co KY): *Topaze Analysis*



- **Discussion**: *Topaze/Arps Analysis for Joe HOBBS Well (Meade Co KY)*
  - Workable, but hyperbolic is probably an "overestimator."
  - Reservoir model match (red trend) is a guess, but match is consistent.
  - Poor correlation of Arps line (white trend) is due to lack of early decline.

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End of Presentation

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RPSEA/GTI Meeting — New Albany Shale Project Group
Chicago, IL (USA) — 04 June 2009

A Numerical Study of Performance for Tight Gas and Shale Gas Reservoir Systems (Selected Slides)

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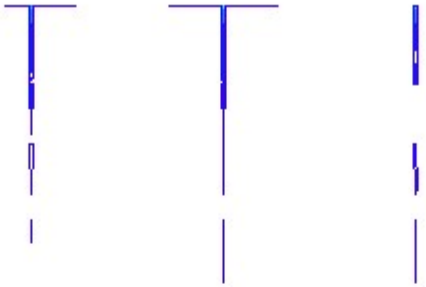
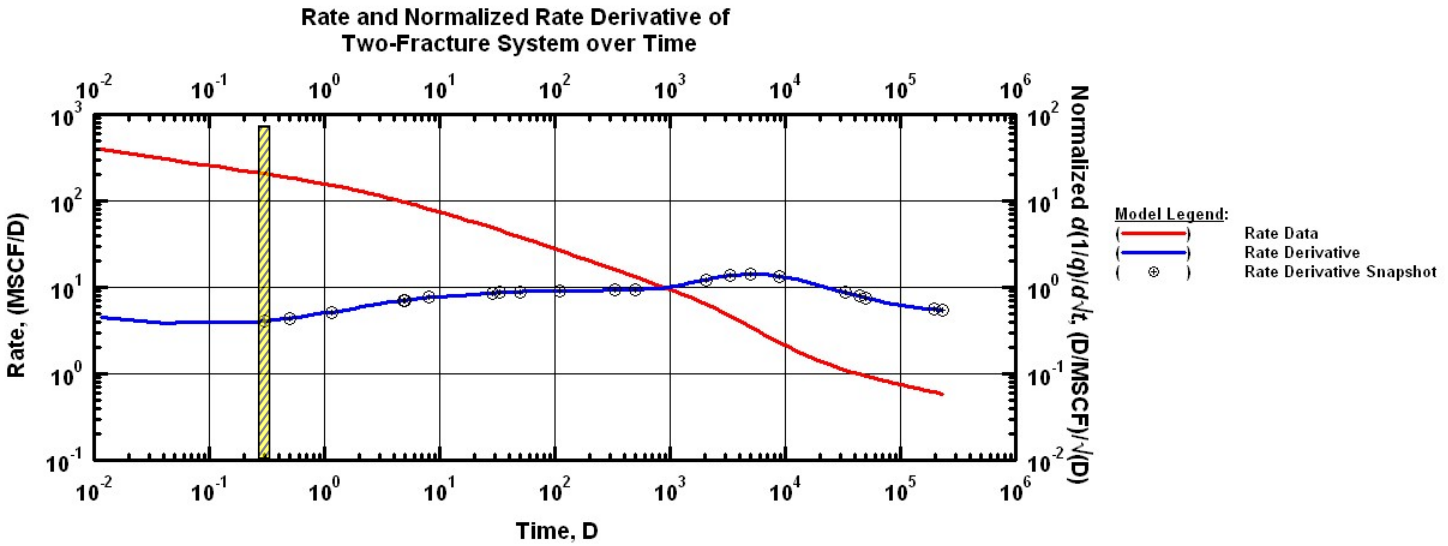
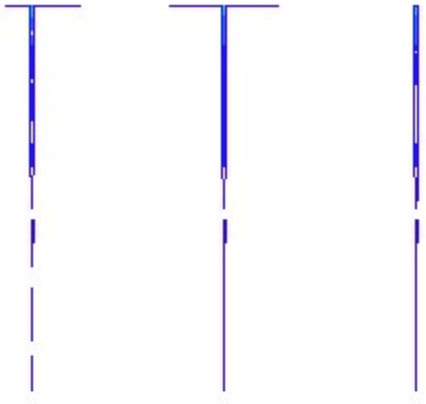
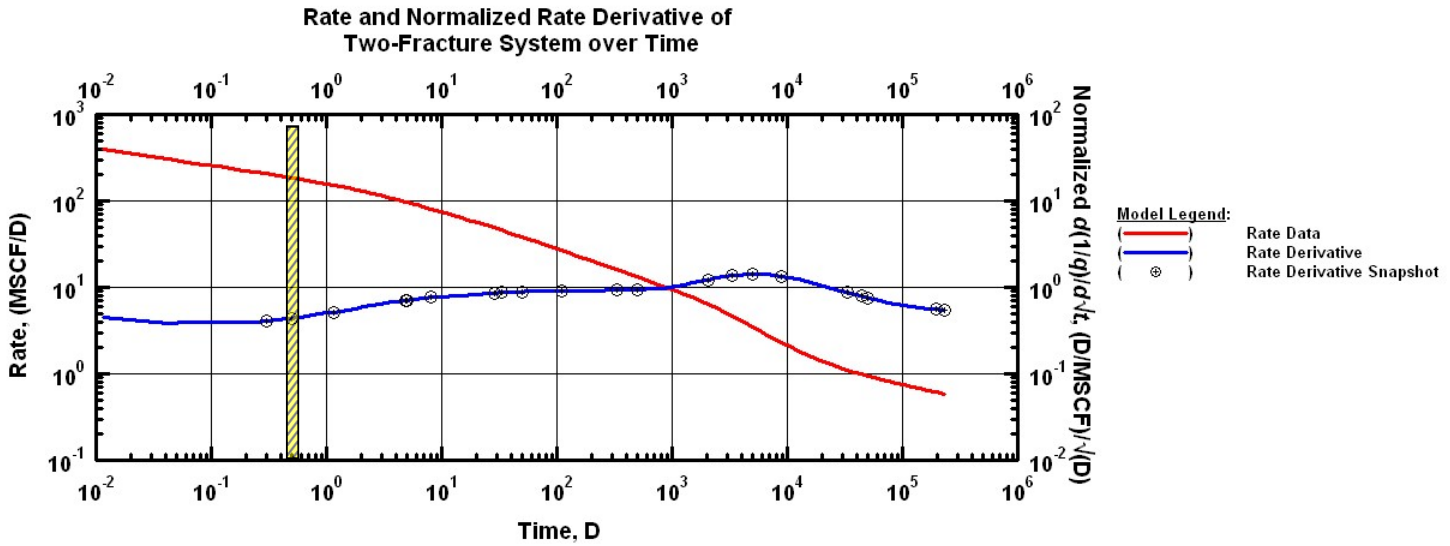
System:
— 100 nd rock
— 25m spacing
— 0.3 days



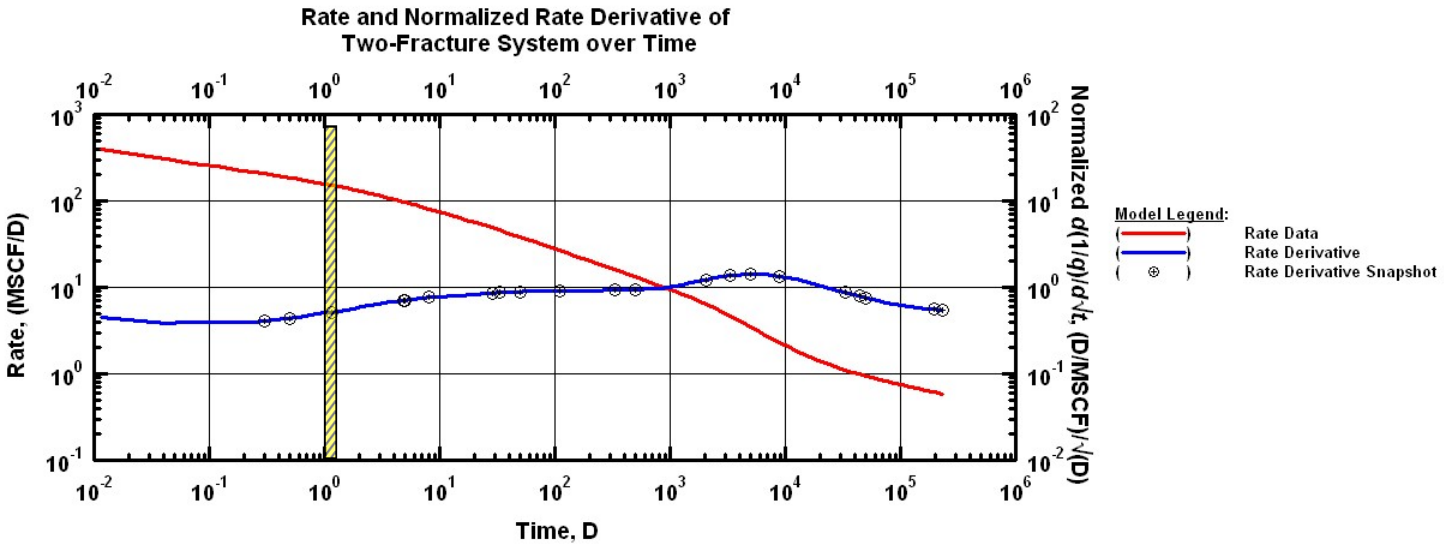


System:
— 100 nd rock
— 25m spacing
— 0.5 days

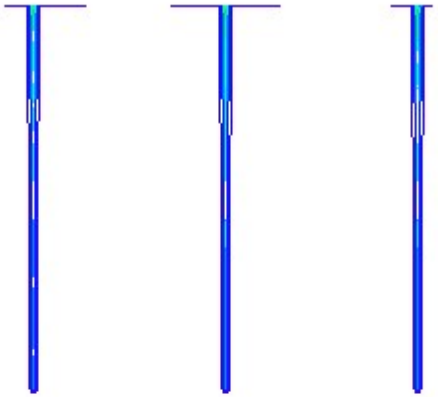


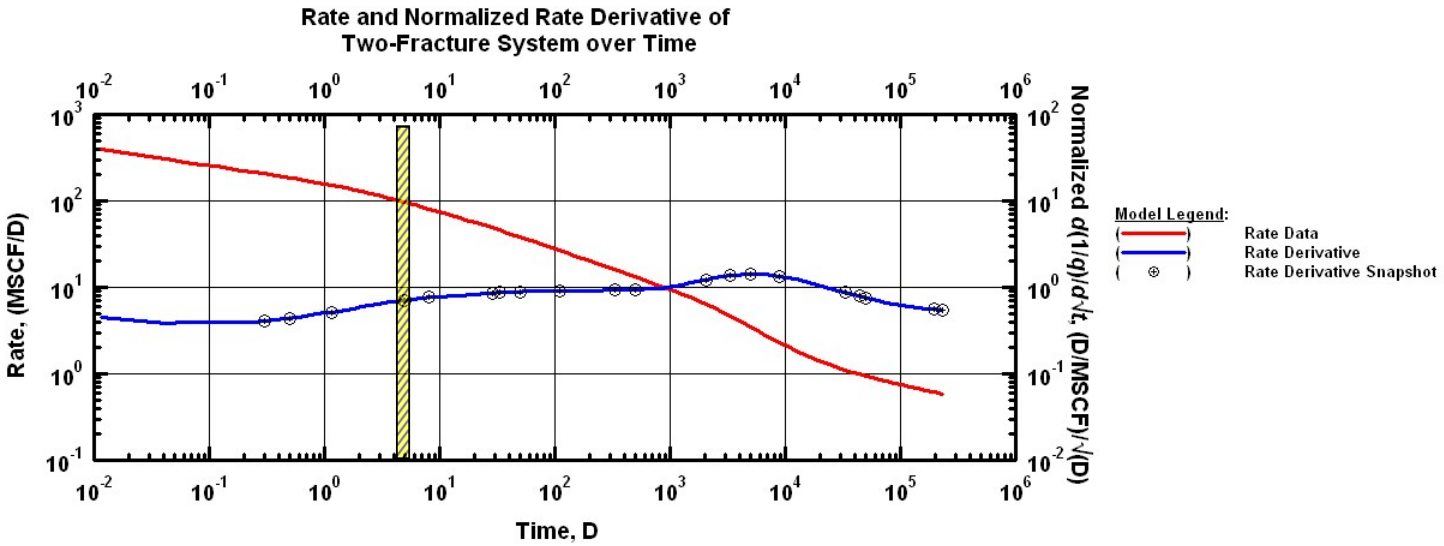


System:
— 100 nd rock
— 25m spacing
— 1 day

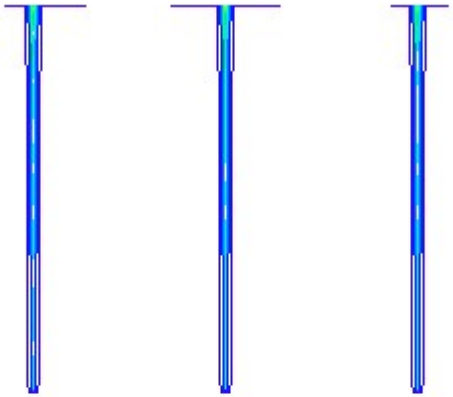


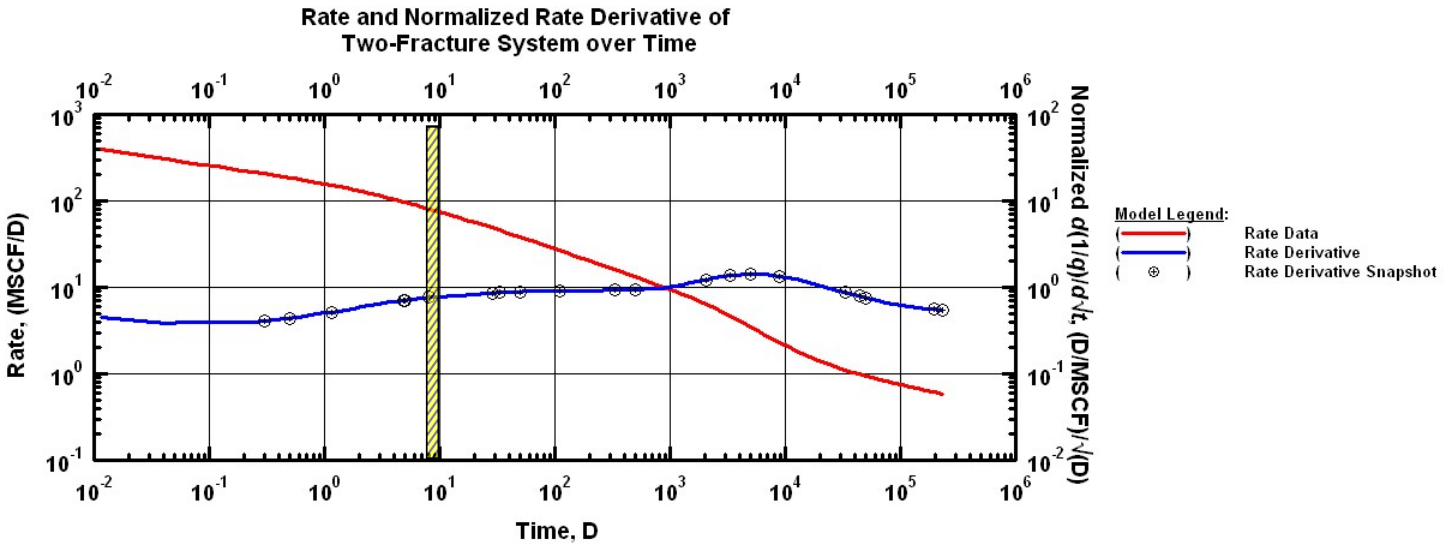
System:
— 100 nd rock
— 25m spacing
— 5 days



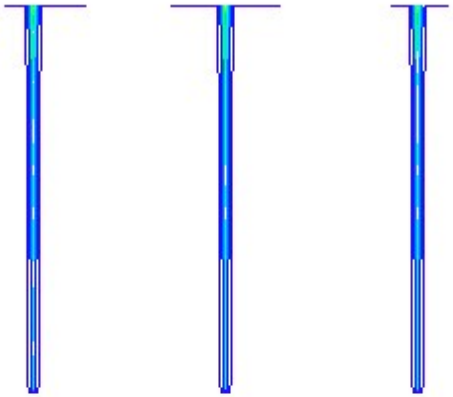


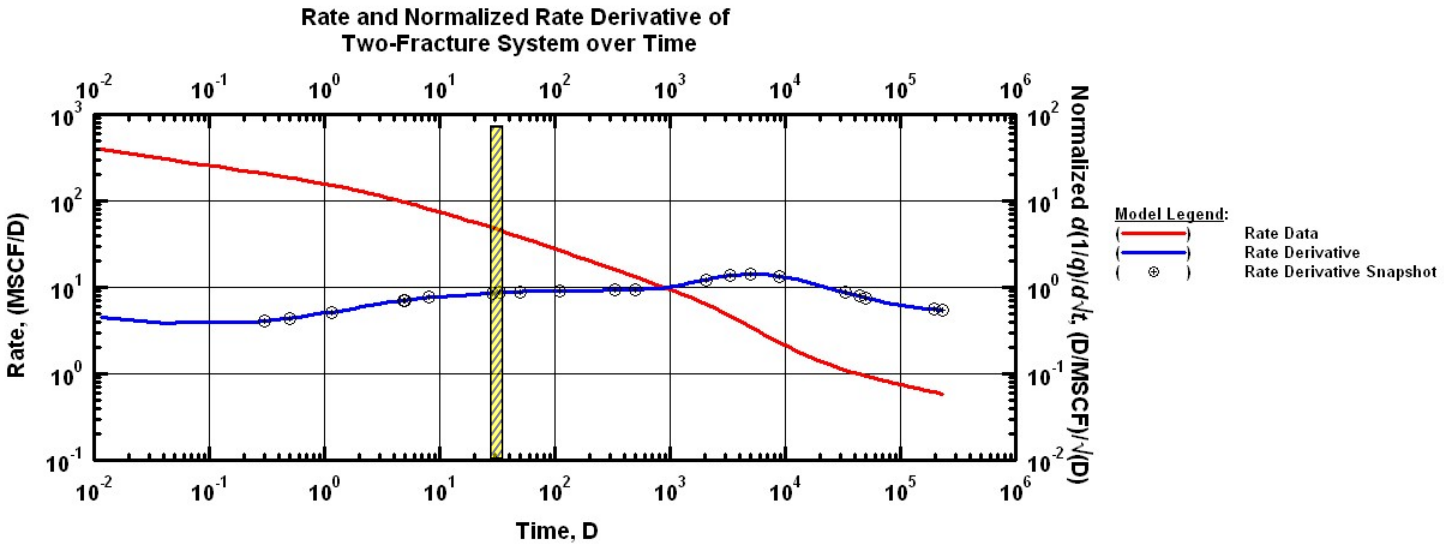
System:
— 100 nd rock
— 25m spacing
— 8 days



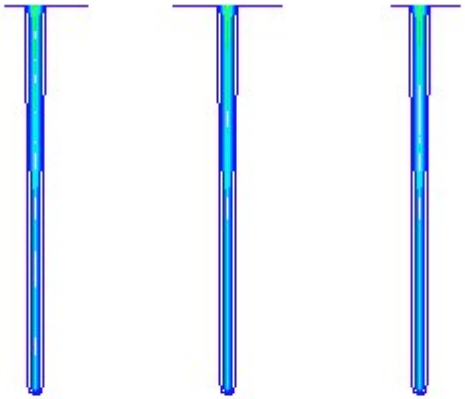


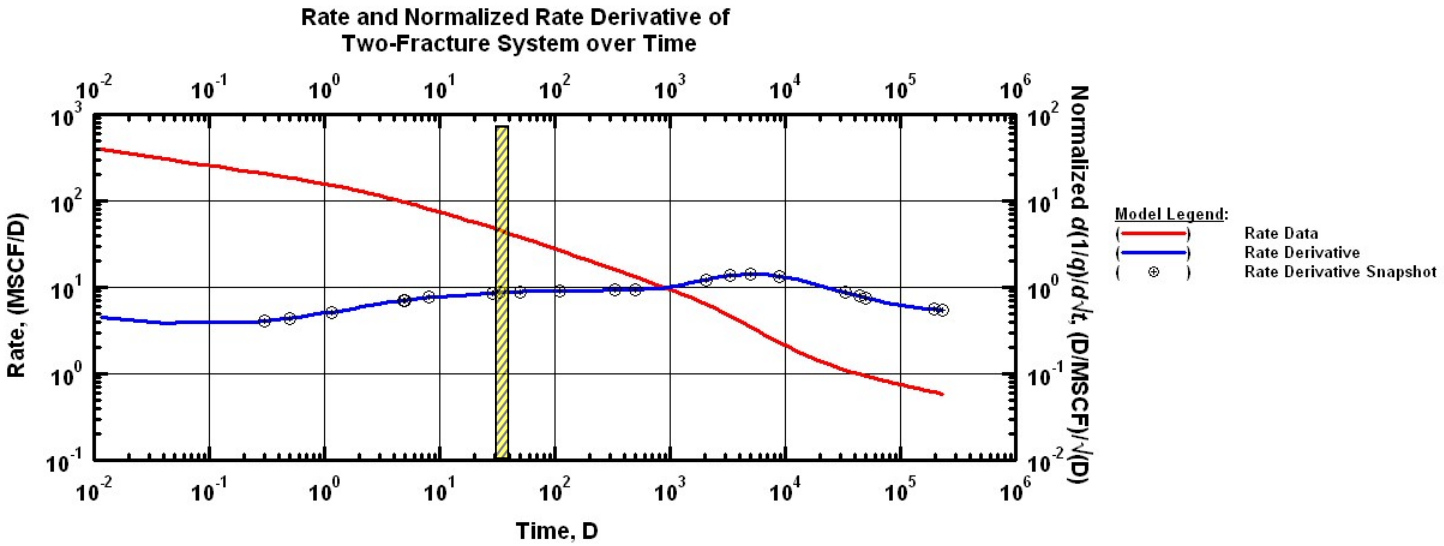
System:
— 100 nd rock
— 25m spacing
— 28 days



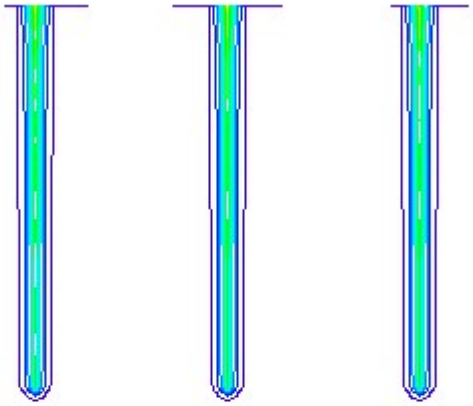


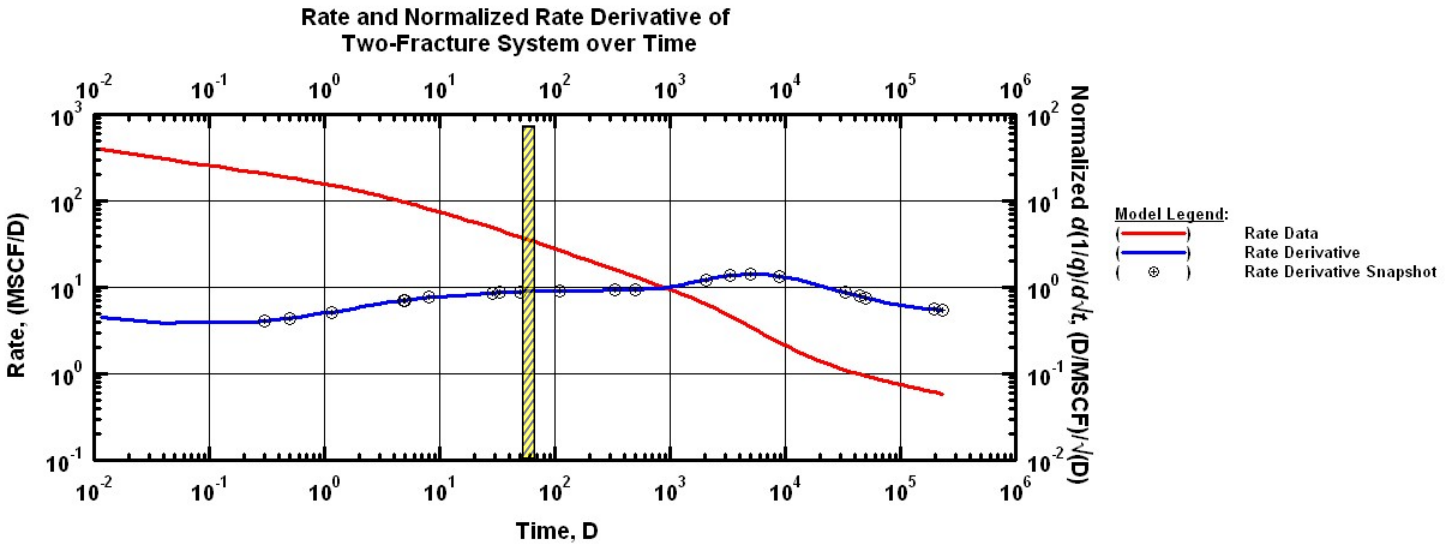
System:
— 100 nd rock
— 25m spacing
— 33 days



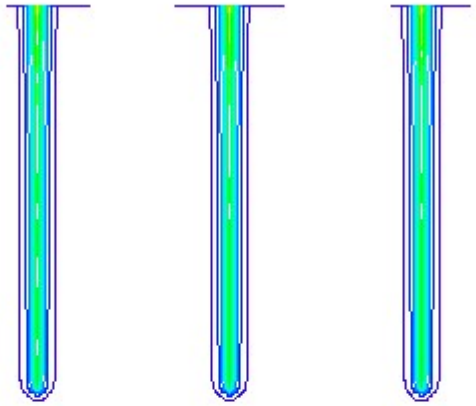


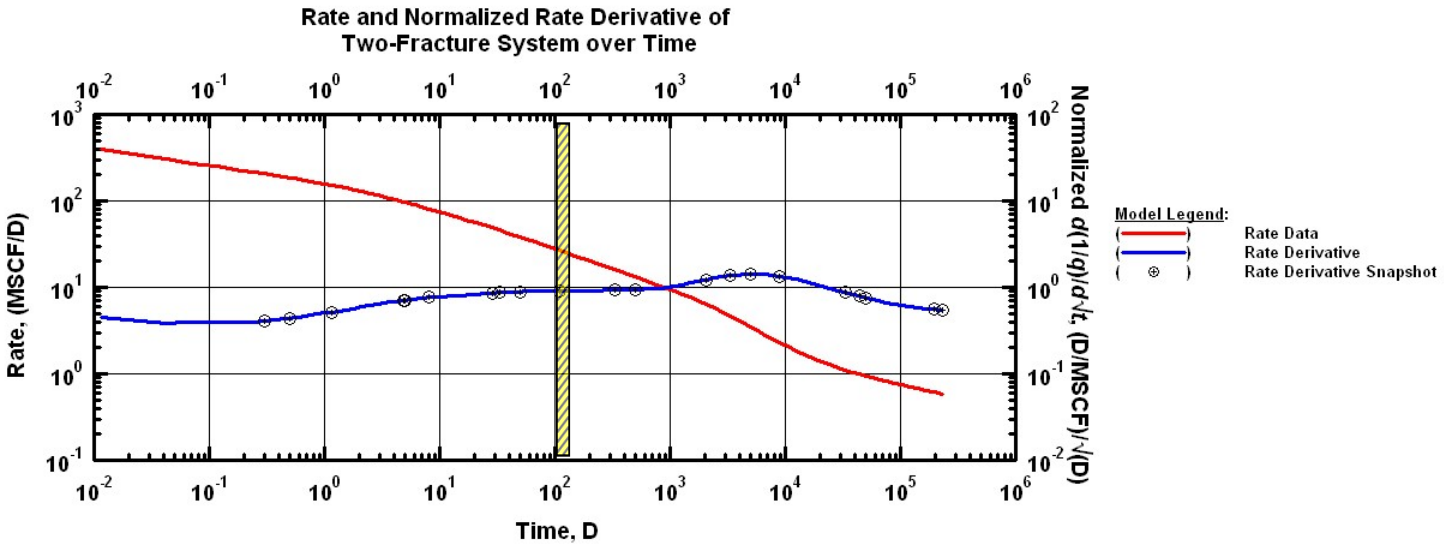
System:
— 100 nd rock
— 25m spacing
— 50 days



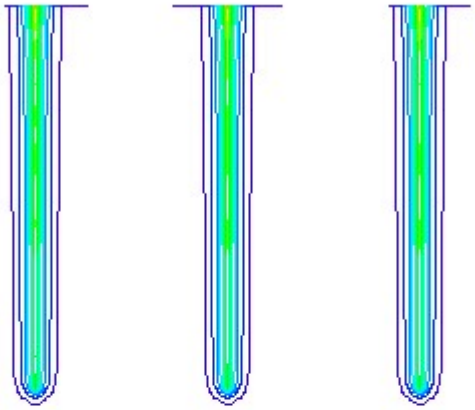


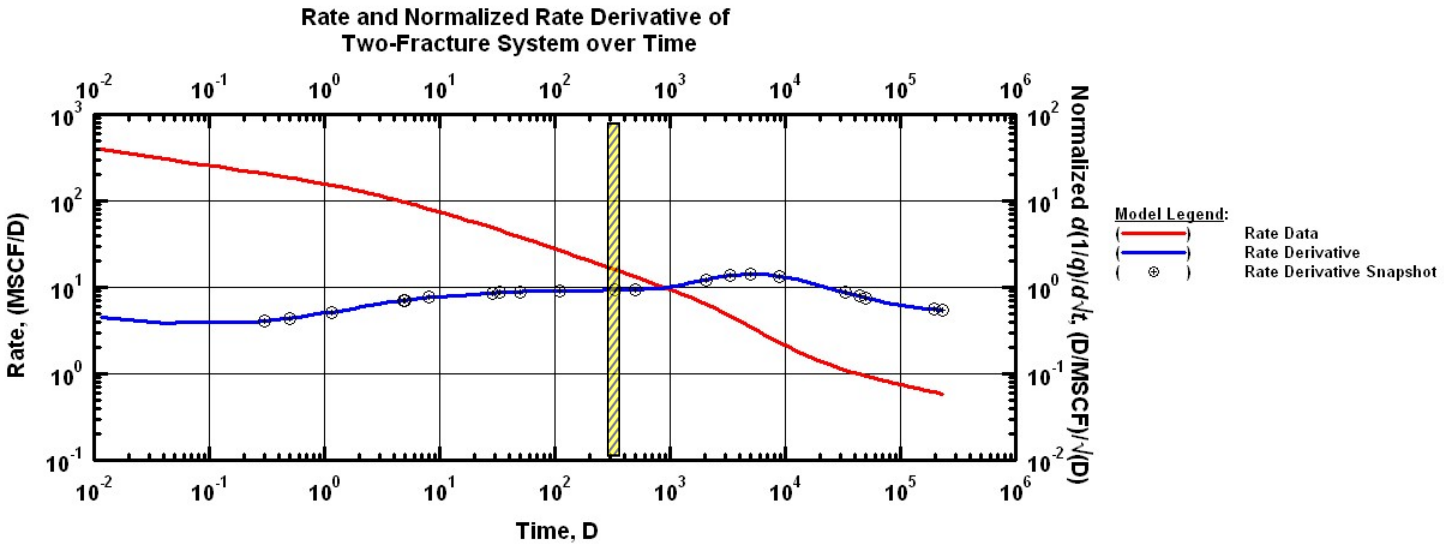
System:
— 100 nd rock
— 25m spacing
— 109 days



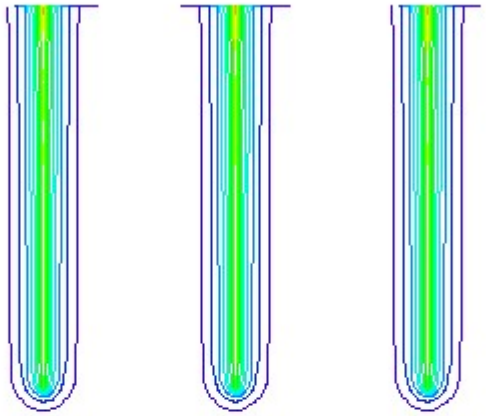


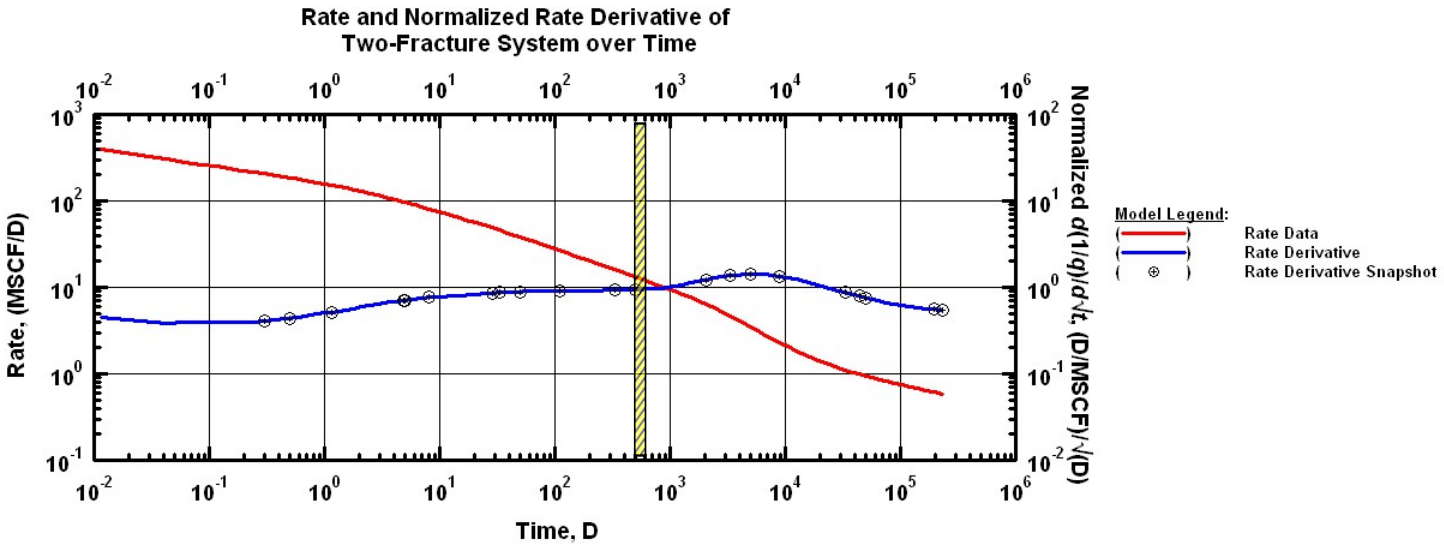
System:
— 100 nd rock
— 25m spacing
— 330 days



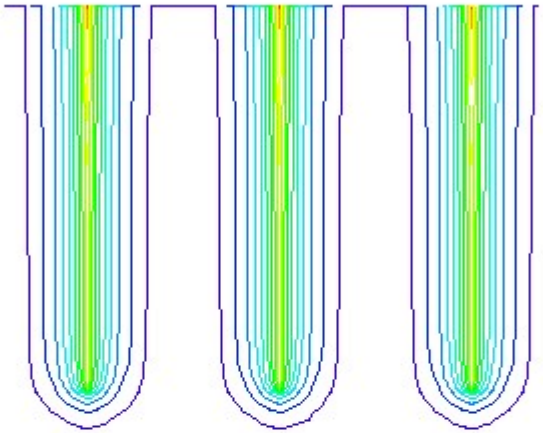


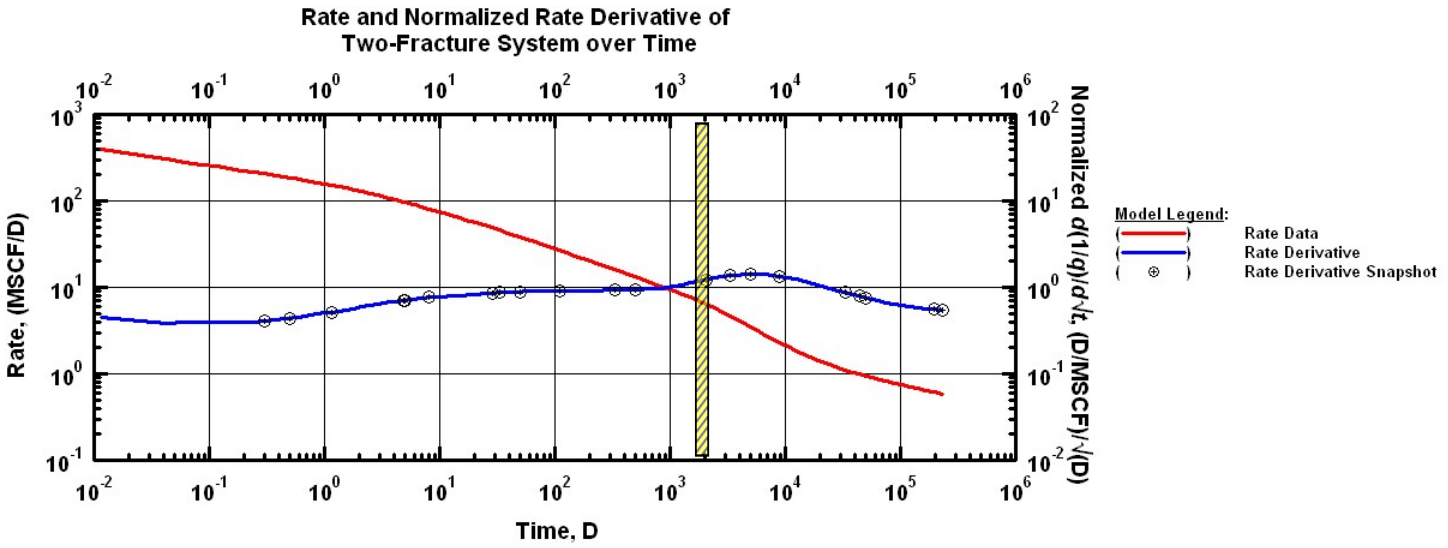
System:
— 100 nd rock
— 25m spacing
— 500 days



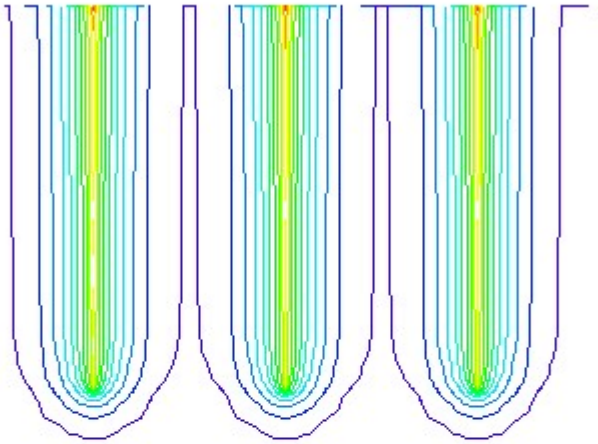


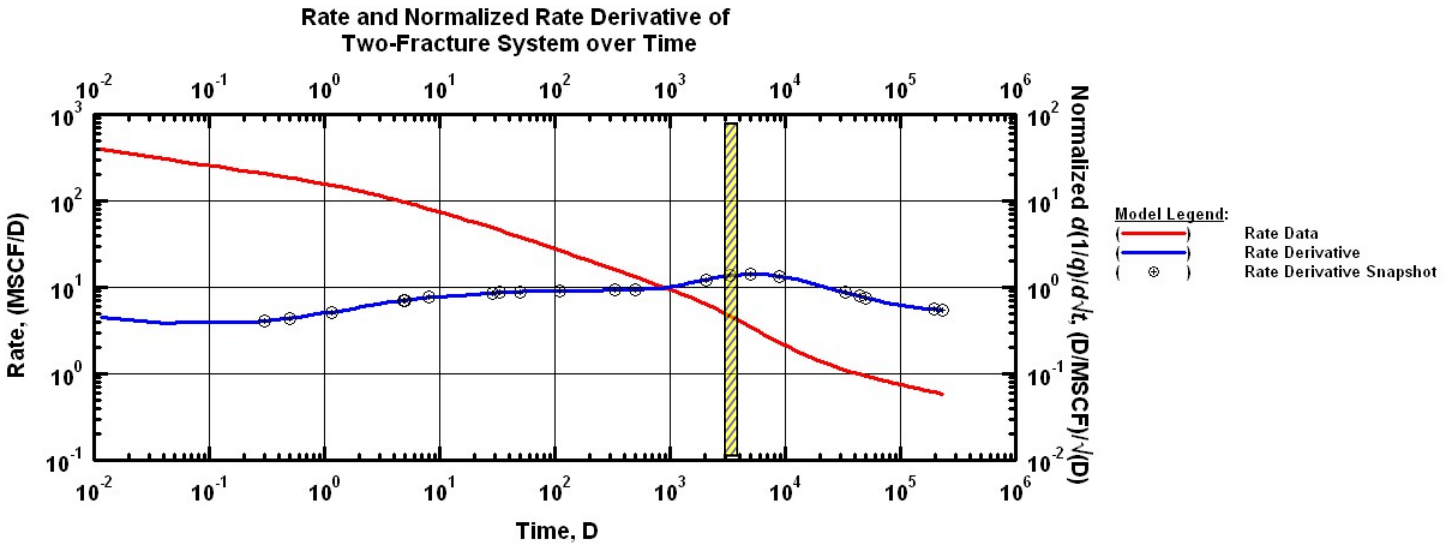
System:
— 100 nd rock
— 25m spacing
— 5.7 years



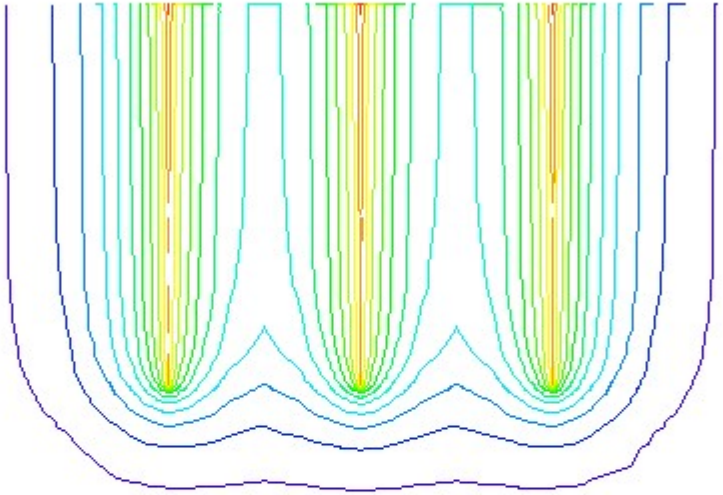


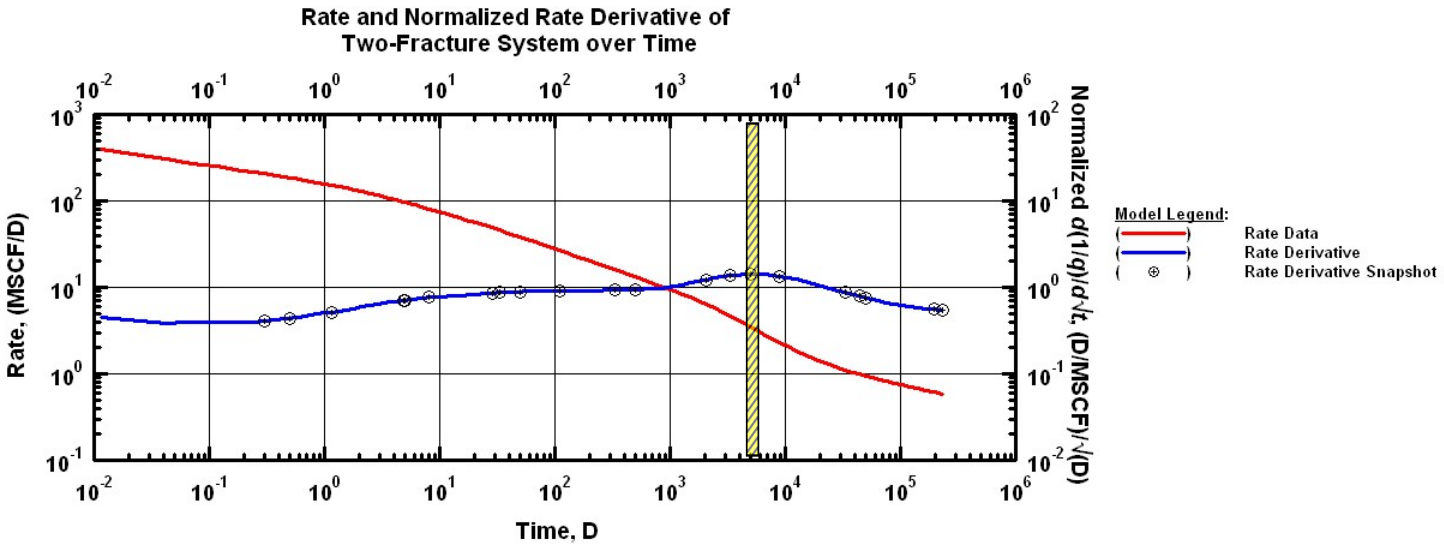
System:
— 100 nd rock
— 25m spacing
— 9 years



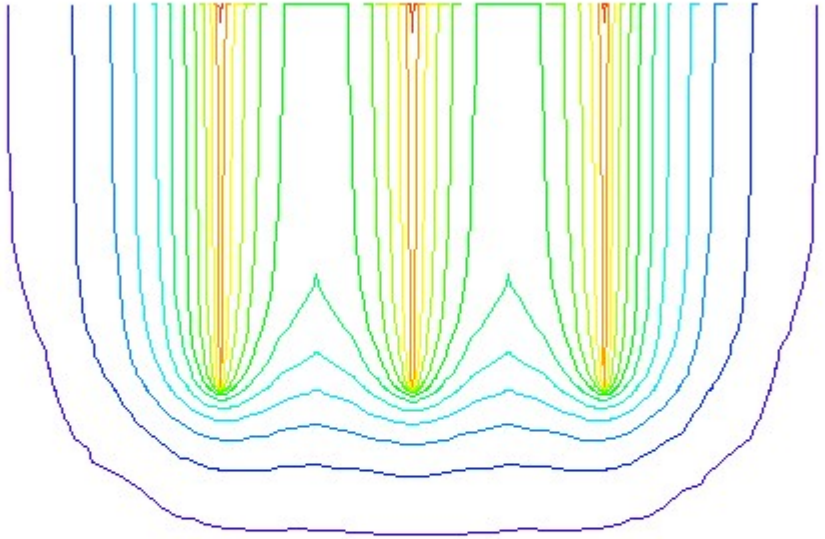


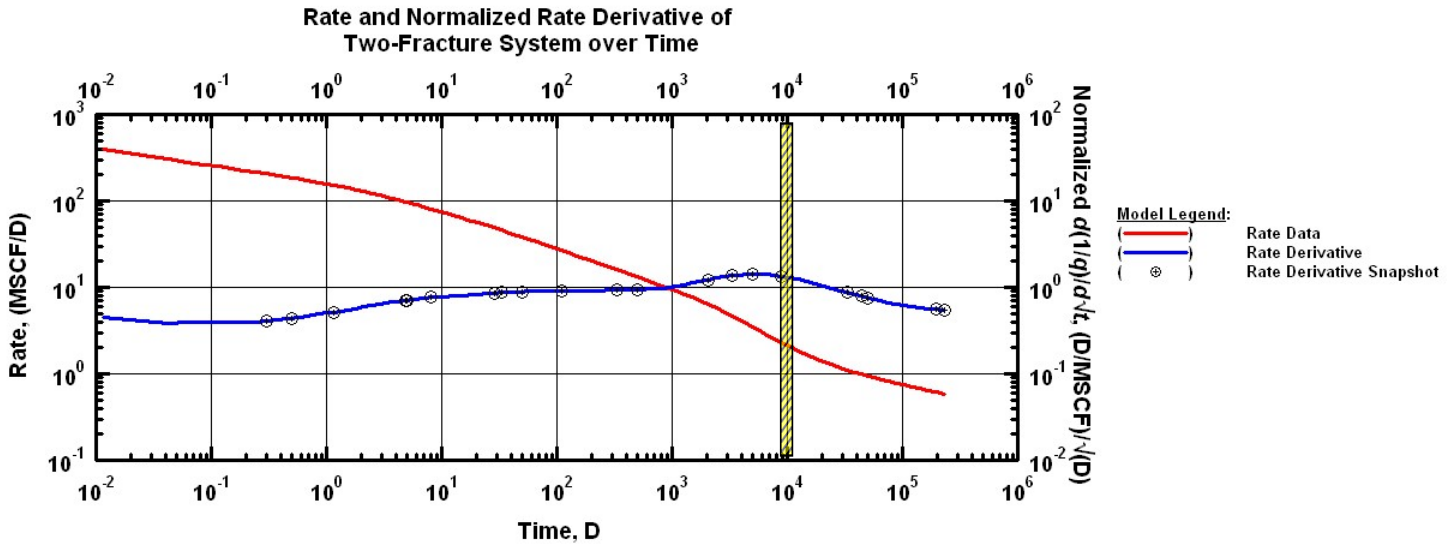
System:
— 100 nd rock
— 25m spacing
— 14 years



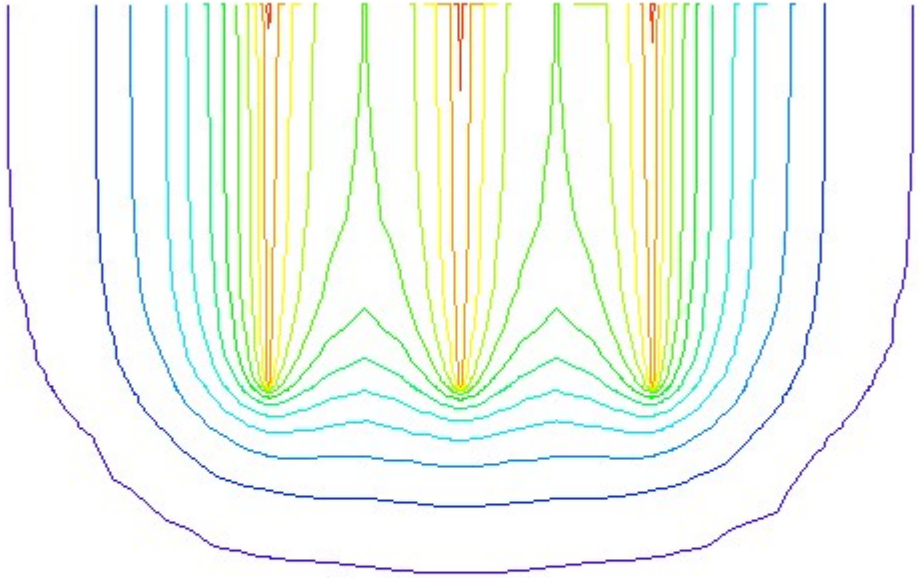


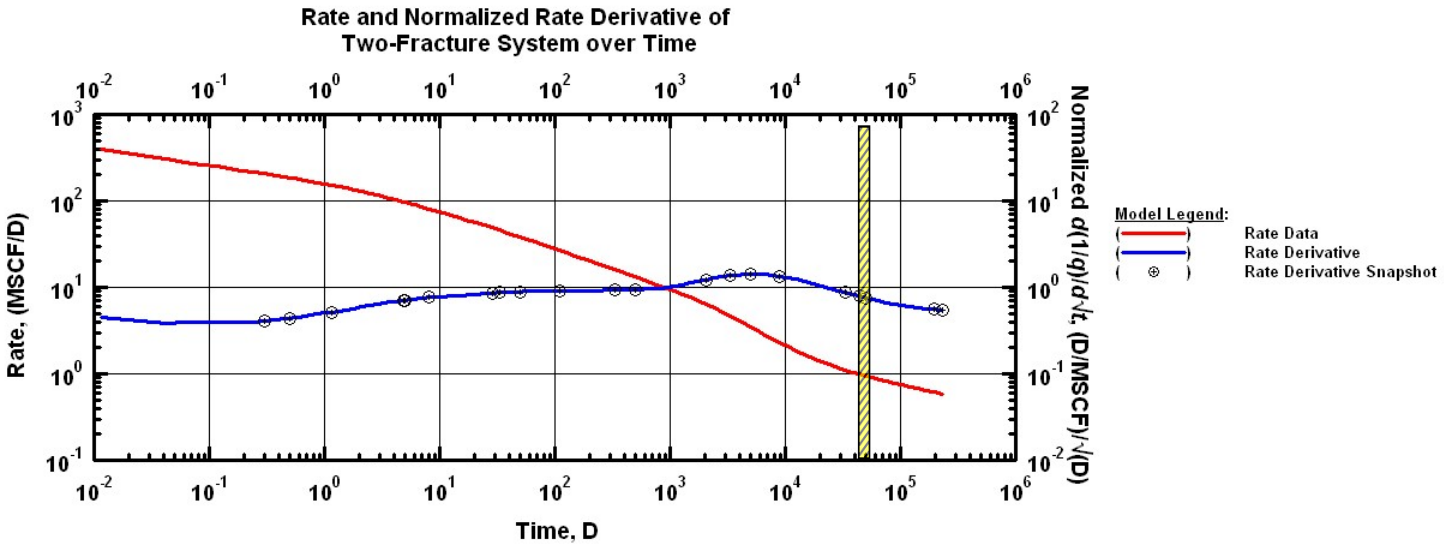
System:
— 100 nd rock
— 25m spacing
— 25 years



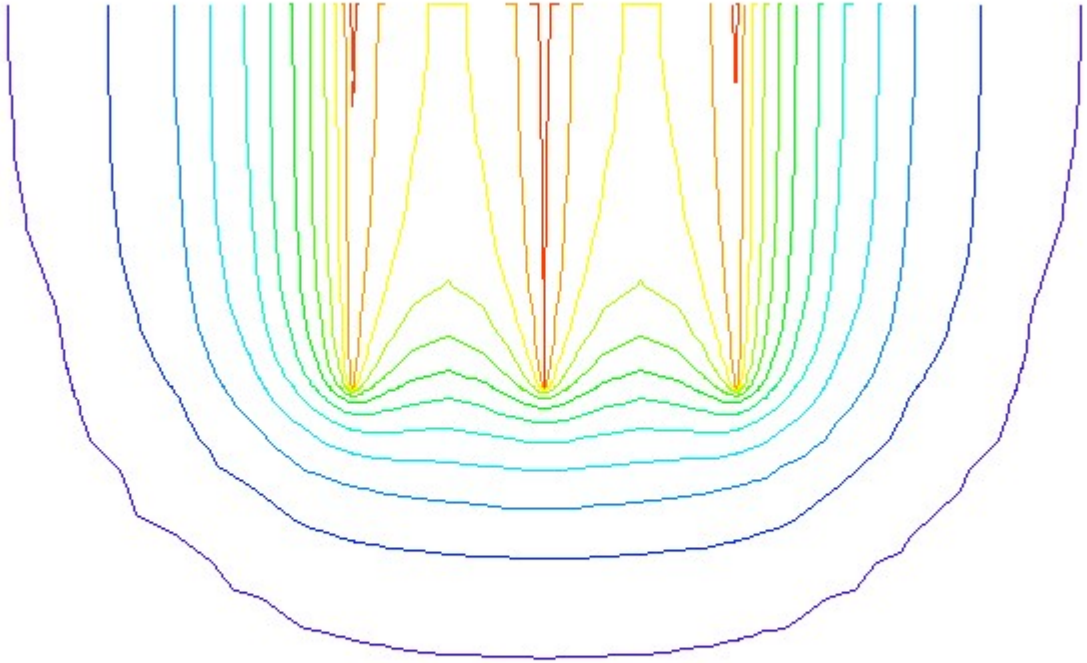


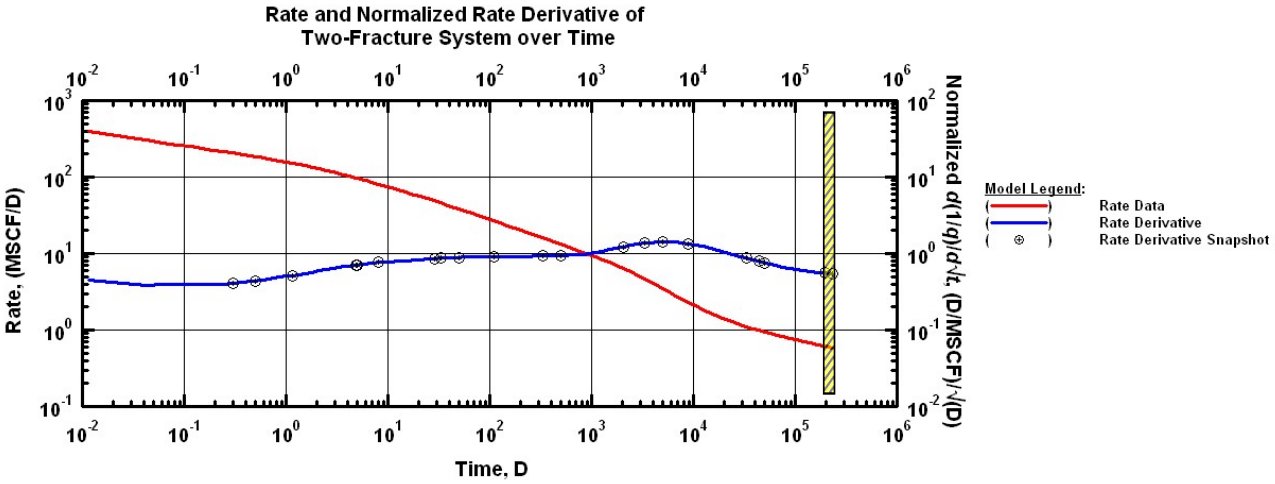
System:
— 100 nd rock
— 25m spacing
— 90 years





System:
— 100 nd rock
— 25m spacing
— 120 years





RPSEA/GTI Meeting — New Albany Shale Project Group
Chicago, IL (USA) — 04 June 2009

q-D-b Plots — Barnett Shale Gas Cases (Selected Slides)

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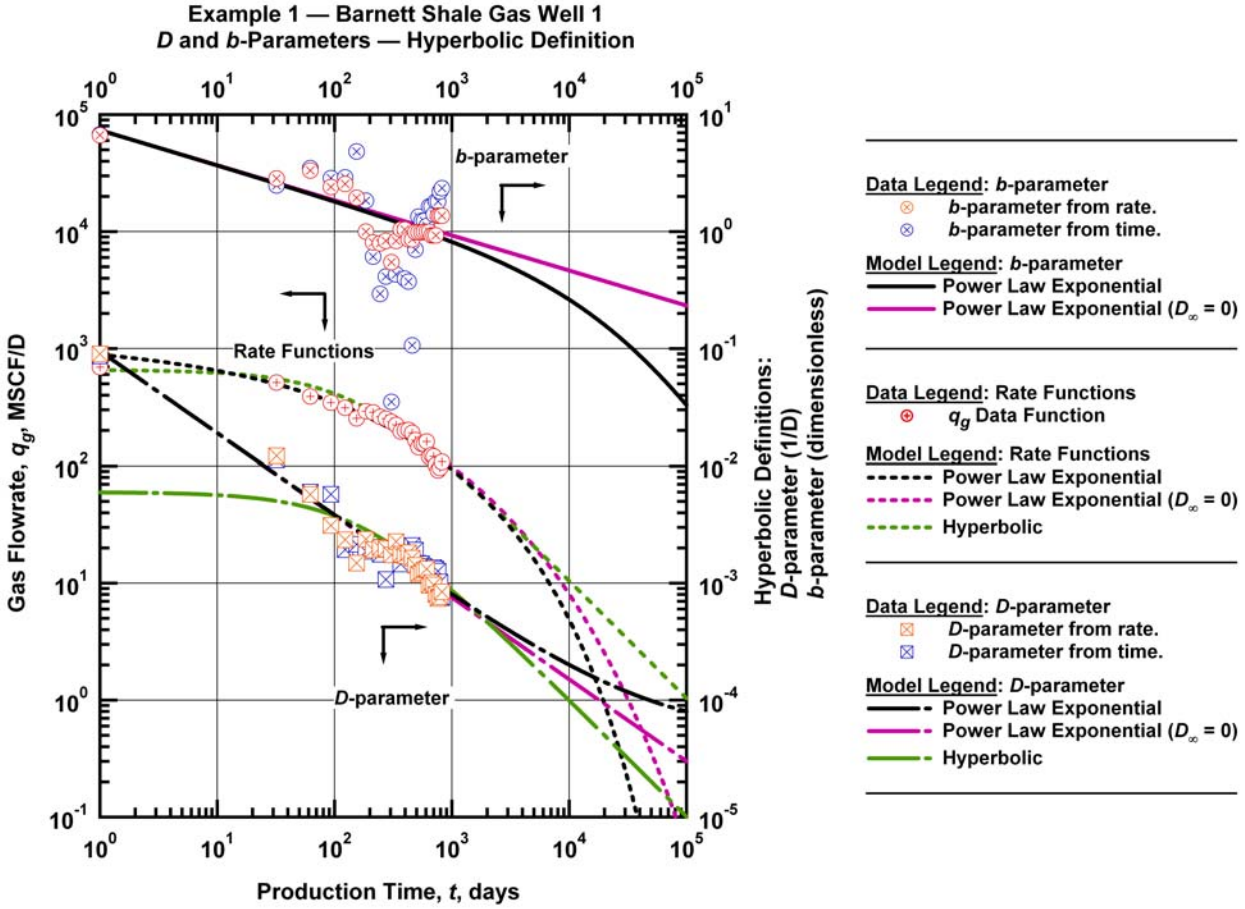
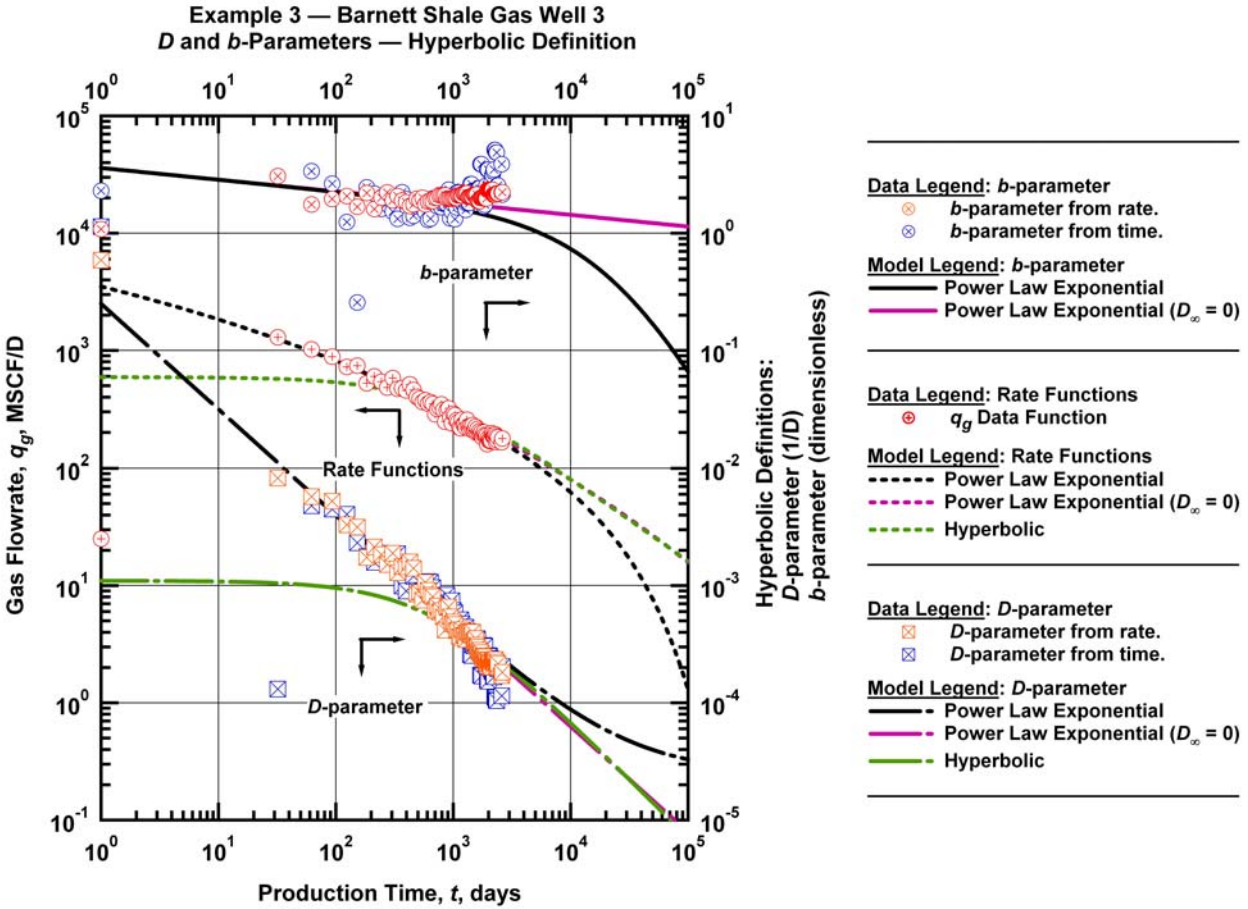
SPE 119897: *q-D-b Plot — Barnett Shale Gas Well* 1



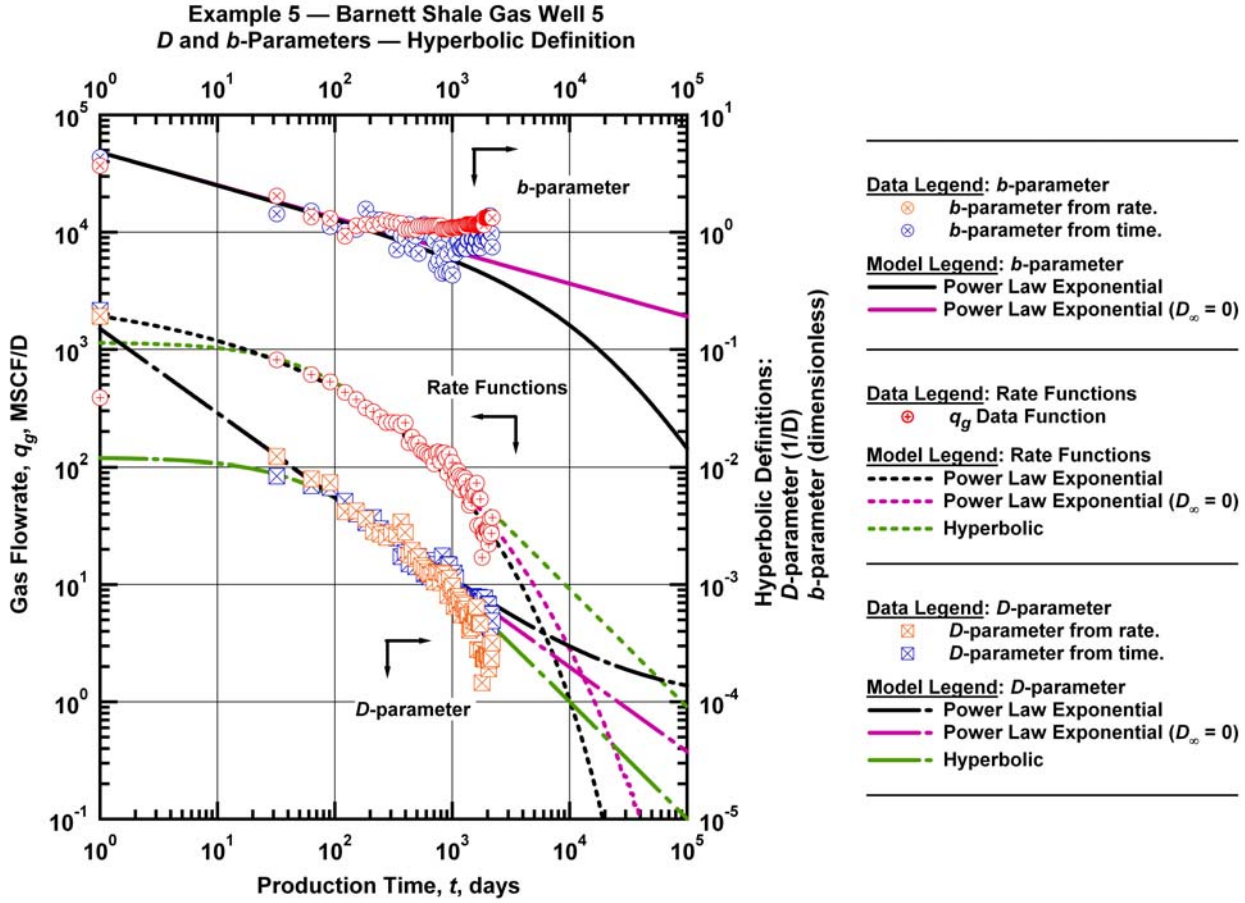
- **Discussion**: ***Barnett Shale Gas Well* 1**
  - Monthly data from PUBLIC records.
  - Fair *D*-parameter and fair/weak *b*-parameter computed from data.
  - Excellent rate match using the new model (transient and BDF).

SPE 119897: *q-D-b Plot — Barnett Shale Gas Well 3*



- **Discussion**: ***Barnett Shale Gas Well 3***
  - Monthly data from PUBLIC records.
  - Good *D*-parameter and good/fair *b*-parameter computed from data.
  - Excellent overall rate match with the new model (all transient flow?).

SPE 119897: *q-D-b Plot — Barnett Shale Gas Well 5*



- **Discussion**: ***Barnett Shale Gas Well 5***
  - Monthly data from PUBLIC records.
  - Good *D*-parameter and good *b*-parameter computed from data.
  - Excellent rate match using the new model (transient and BDF).