Workflow for Applying Simple Decline Models to Forecast Production in Unconventional Reservoirs

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What Alternatives Do We Have in Forecasting?

- Comprehensive, “full-physics” models
  - Numerical reservoir simulators
  - Spatial variation in reservoir, stimulation properties
  - Multiphase flow
  - Physics, reservoir description complete, accurate?
- Analytical models
  - Simplifying assumptions, basic physics honored
  - Dominant flow mechanisms included (hopefully)
- Simple models
  - Basic physics often ignored – maybe all physics
  - Limiting assumptions often misunderstood

Why Simple Decline Models?

- Need: 100's or 1000's of wells to forecast in short time
  - Periodic reserves estimates
  - Economic analysis of operations
- Full physics models may take days for initial reservoir description, history matching, forecasting
- Analytical model studies usually take less time, but far more time than available for routine forecasting
- Practical conclusion: Use simple models for routine work – but need to
  - Recognize assumptions, possibly limiting
  - Identify appropriate model for given situation

So How Can We Proceed?

- Use full-physics models or analytical models to identify appropriate simple models and likely range of parameters in simple models
- Example: Use simulation, varying permeability, lateral length, fracture length, fracture spacing to estimate appropriate values of b, D_{min} in Arps model for rapid, routine data processing

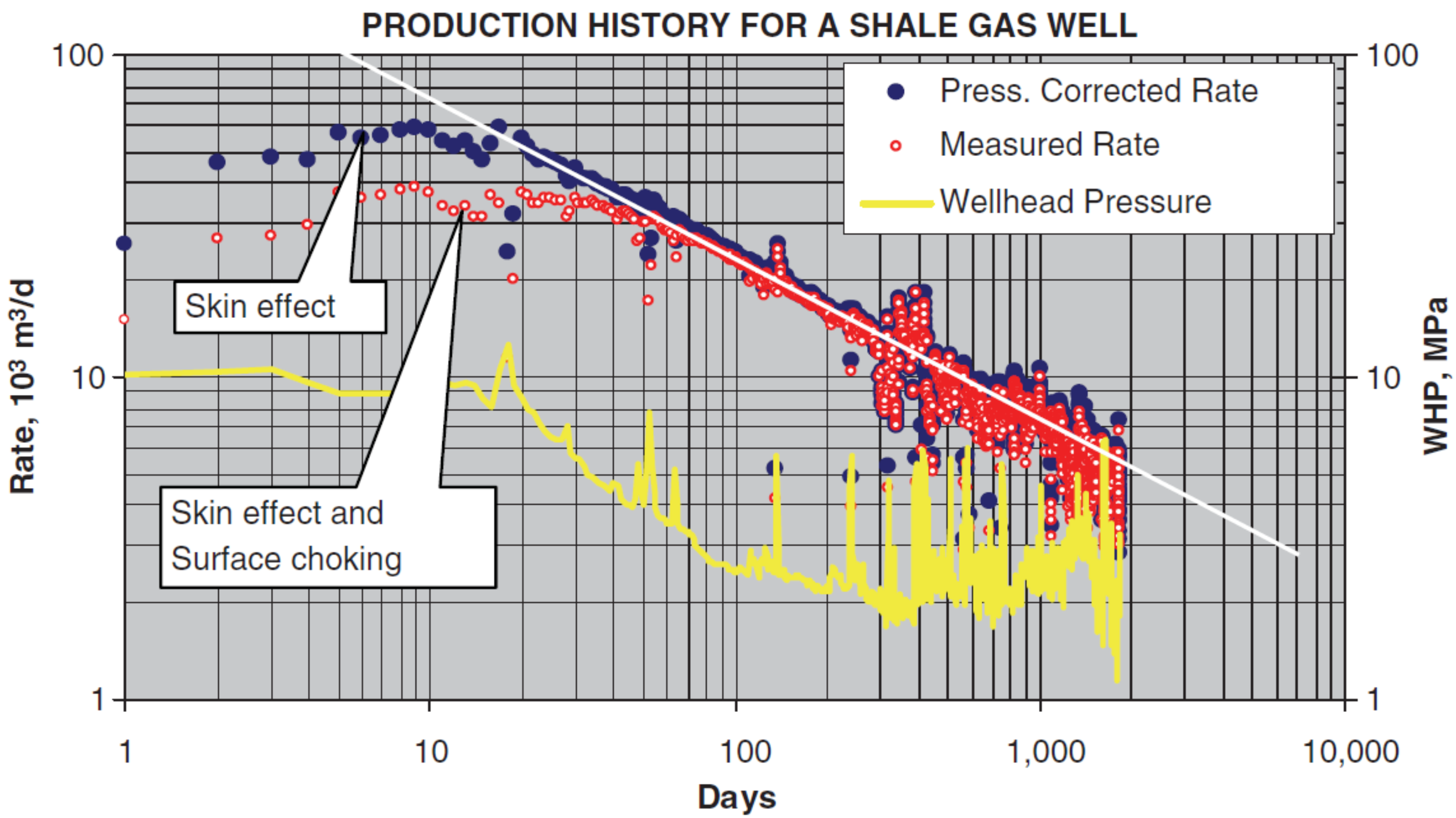
Thoughts on Work Flow for Forecasting with Simple Models

- When BHP data available and time permits, normalize rates before analysis ($\frac{q}{p_i - p_{wf}}$) or $q_{corr} = q_{obs}\left(\frac{p_i - p_{wf,stab}}{p_i - p_{wf,obs}}\right)$
- Data from first 6-12 months (clean-up) may not reflect longer trends and should often be excluded from analysis of historical decline
- Determine flow regimes in available data using diagnostic plot
  - Minimum: log q vs. log t
  - Better: log ($\frac{q}{p_i - p_{wf}}$) vs. log MBT (G_p/q, N_p/q)
- Estimate time to BDF if not observed in data
  - Minimum: switch time from analogy
  - Better: depth of investigation or analytical model

Work Flow (Continued)

- Beyond simple, rapid modeling, may need to consider
  - Flow from unstimulated matrix to SRV and include in model when appropriate
  - ‘Complete’ model that may include early transient flow, switch to BDF model after fracture interference, switch to linear flow model, final switch to BDF model

Correcting Data for Changes in BHP (Duong, SPE 137748)



Early Deviations from Linear Flow: Horizontal Wells in Barnett Shale – Pressure Corrections?

SPE 138987-

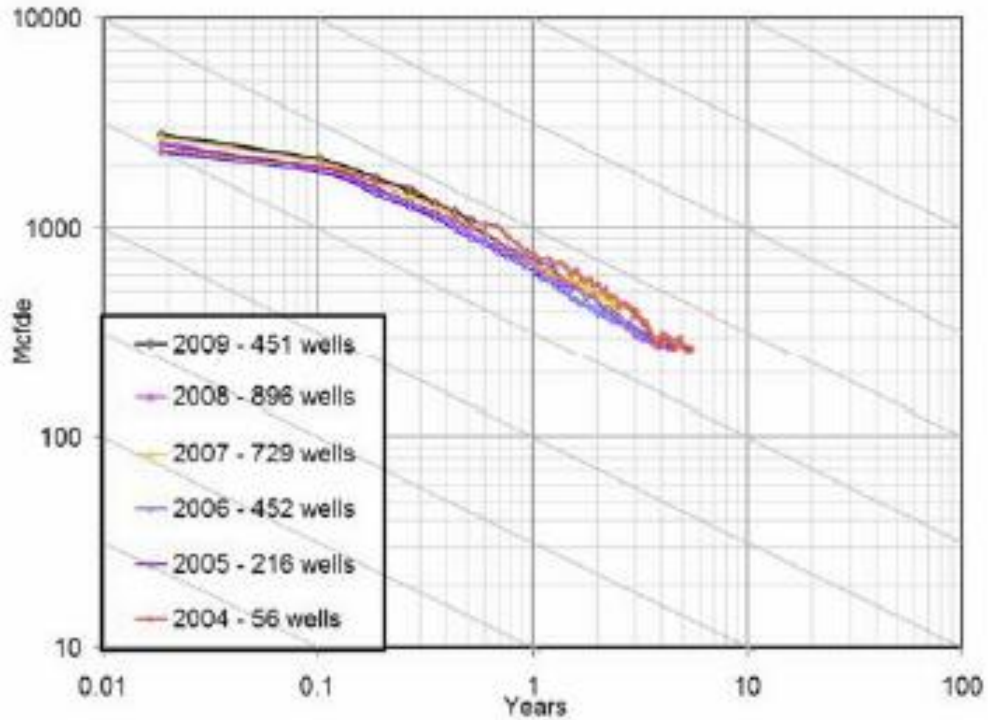
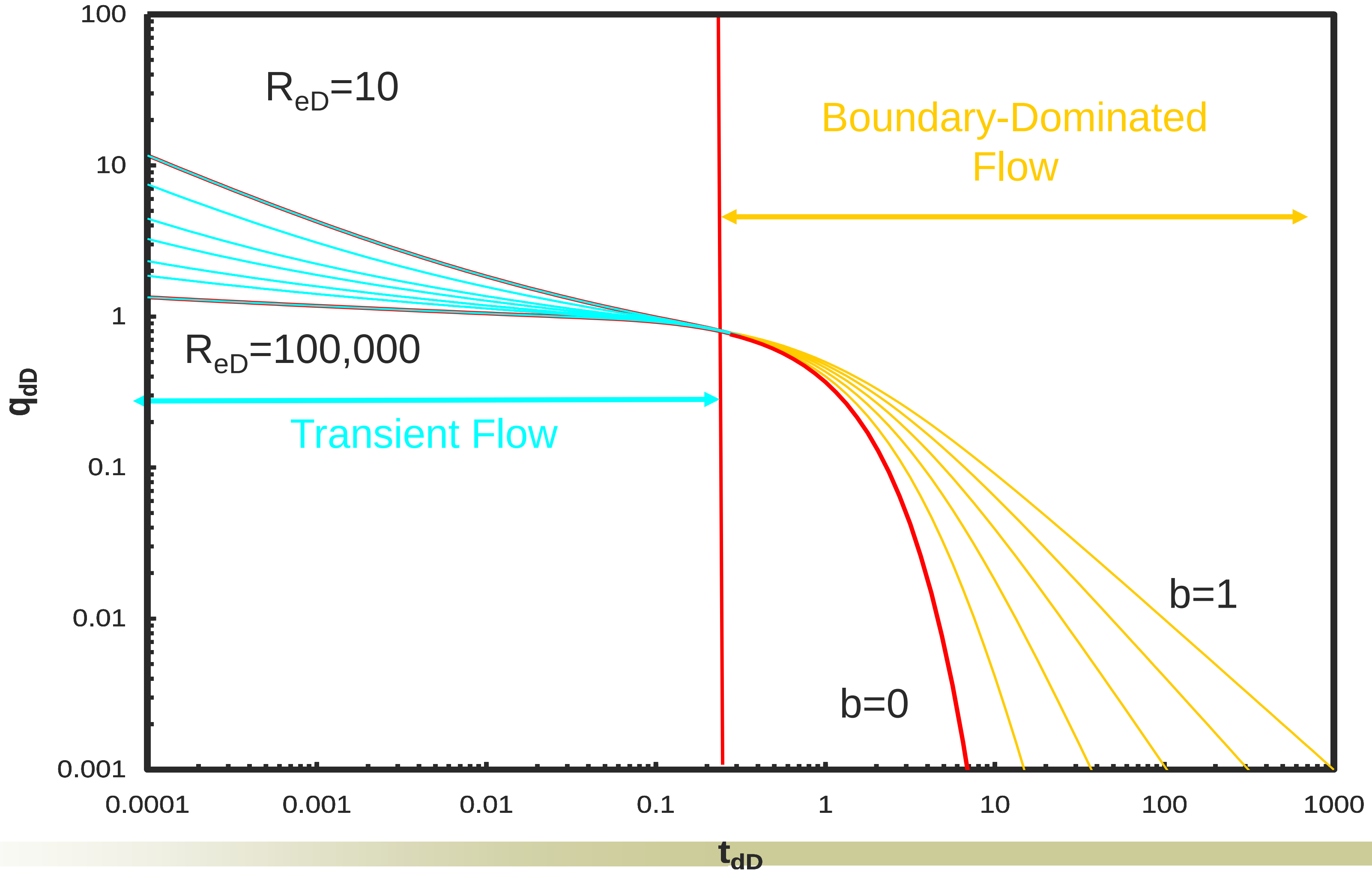
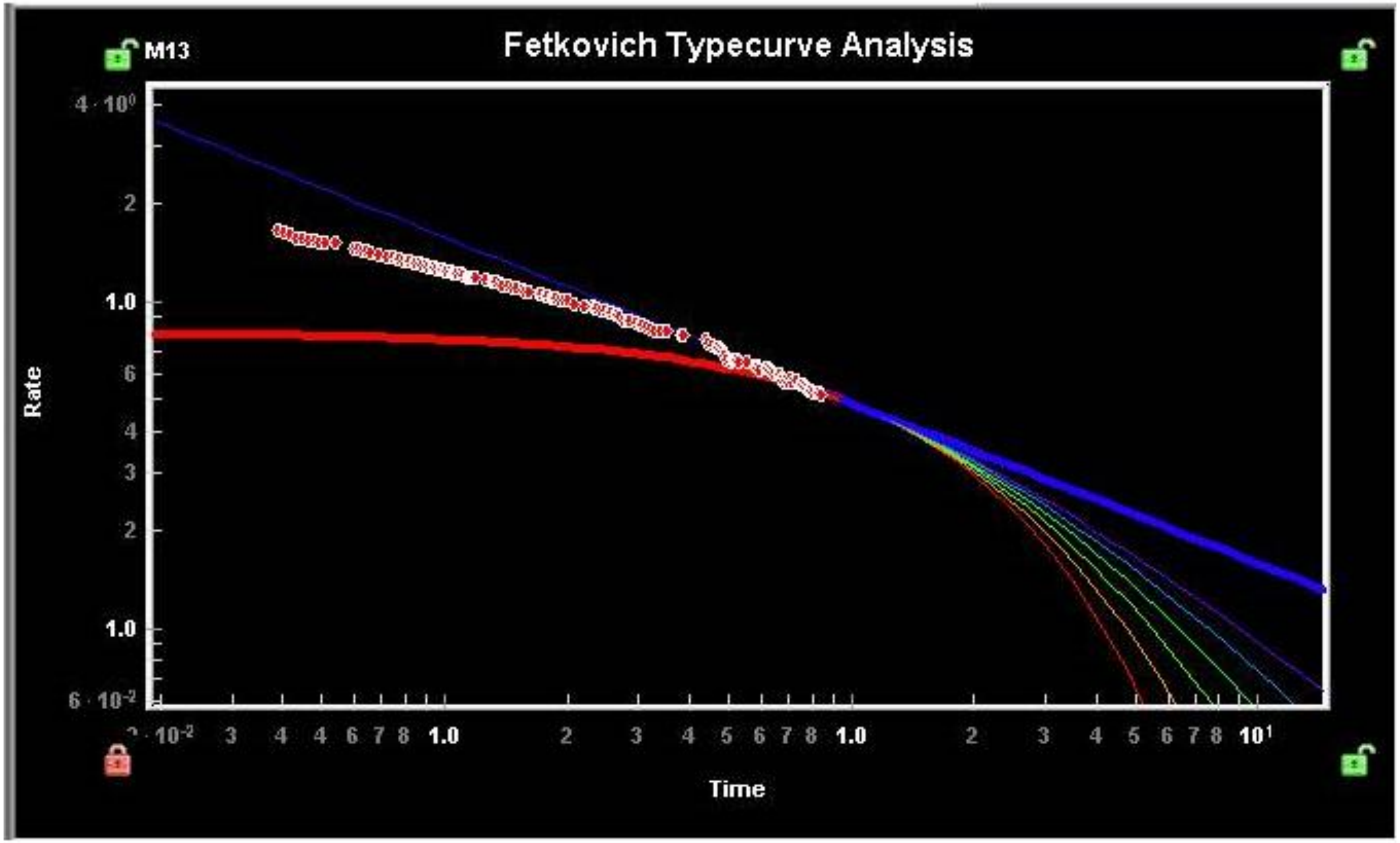


Figure 12 Johnson County Horizontal wells showing a linear decline slope of near 0.50. The rates are very consistent from year to year.

Basic Diagnostic Plot: Fetkovich Type Curve Includes Transient, Stabilized Flow Regimes

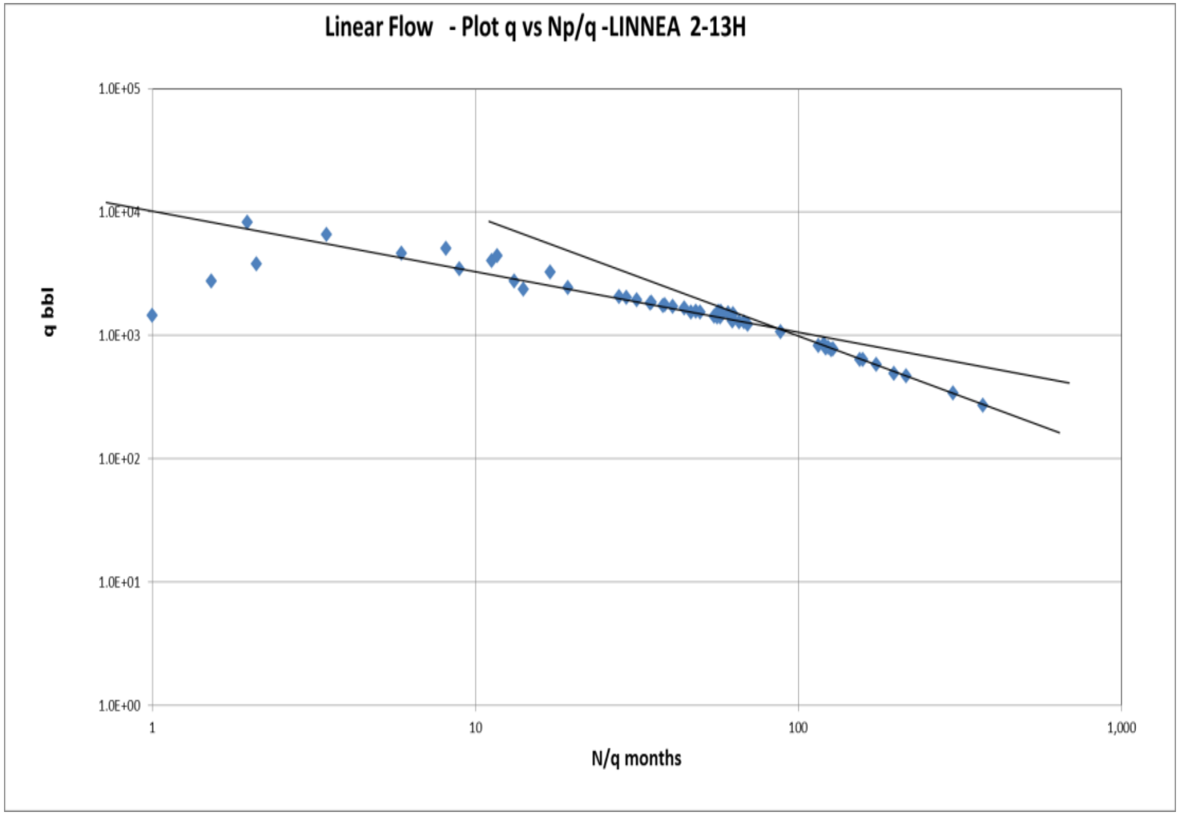


Fetkovich Type Curve with Transient Linear Flow – Data from Marcellus Well



Example: Elm Coulee Bakken Well Diagnostic Plot Using Material Balance Time

- Linear flow followed by BDF



Commonly Used Decline Models

- **Arps Hyperbolic Model**

$$q = \frac{q_i}{(1+bD_i t)^{\frac{1}{b}}}$$

- **Modified Arps Hyperbolic Model**

Switch to exponential decline at pre-selected decline rate

- **Stretched Exponential**

$$q = q_i exp\left(-\left(\frac{t}{\tau}\right)^n\right)$$

Commonly Used Decline Models (Cont'd)

- **Extended Power Law**

$$q = q_i exp\left(-D_\infty t - \widetilde{D}_i t^n\right)$$

- **Transient Linear Flow**

$$\frac{(p_i - p_{wf})}{q} = 16.26 \frac{B}{A_f}\left(\frac{\mu t}{k\phi c_t}\right)^{1/2} + 141.2 \frac{B\mu}{kh} s_f$$

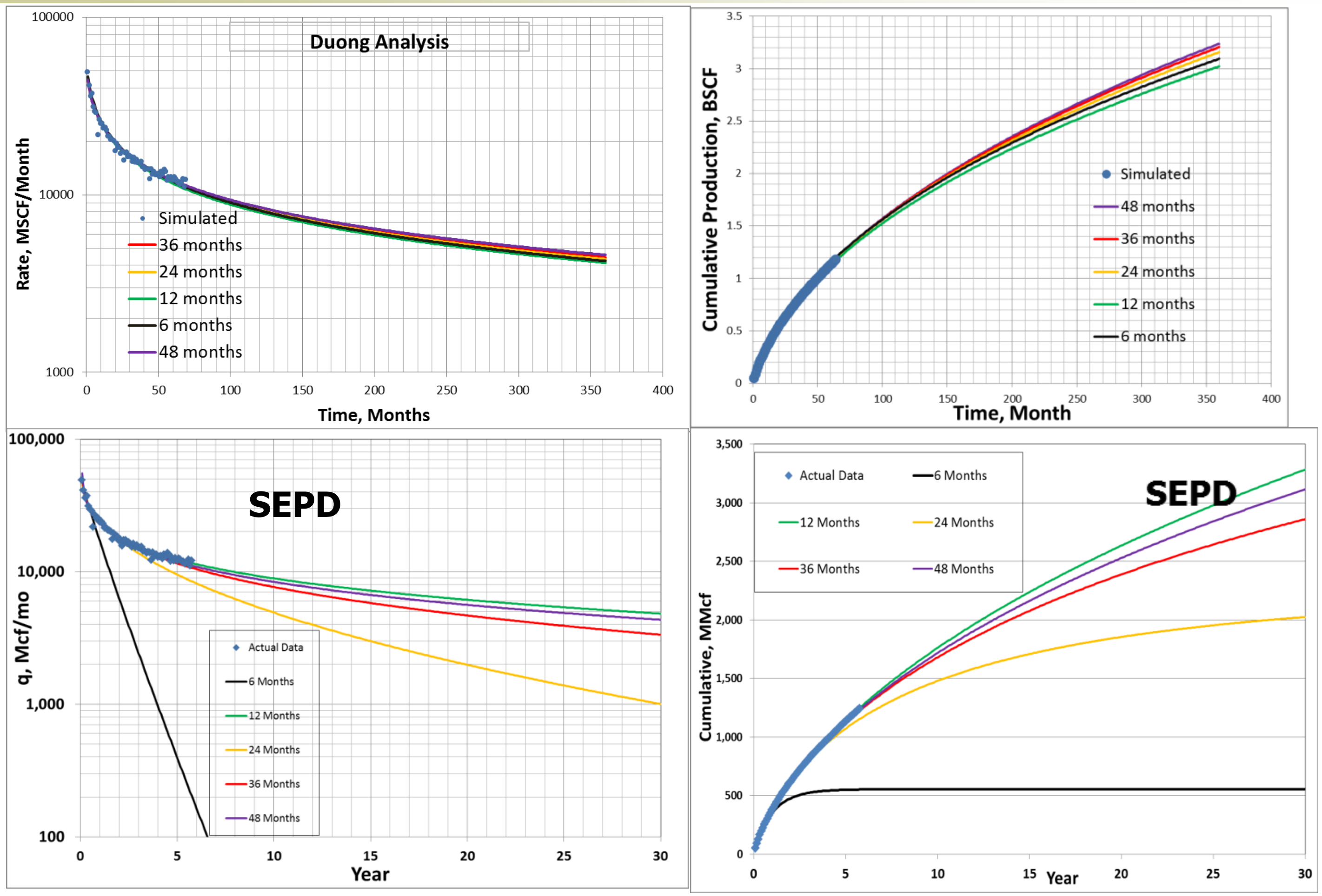
- **Duong**

$\frac{q}{G_p} = at^{-m}$… *m* near 1

- **Modified Duong**

Switch to Arps with appropriate *b* when BDF reached

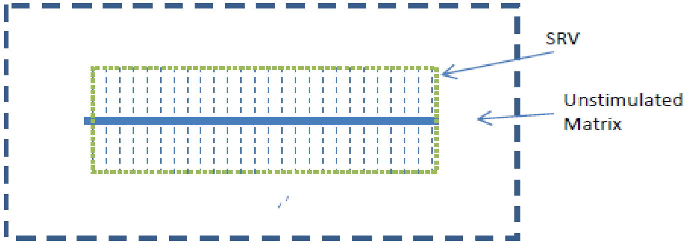
Duong More Realistic Than SEPD for Early Barnett Data: Wise (42-497-35766)



Some Advocate More Complex Linear Flow Model in Shales

Miller, Jenkins, et al. suggest 'emerging industry consensus' on flow regimes in SPE 139067

- 'Internal' transient flow within stimulated reservoir volume (SRV)
- Followed by BDF as result of intra-fracture pressure interference
- Then followed by 'external" transient linear flow from drainage volume into peripheral faces of SRV (key: unstimulated matrix permeability)
- Finally, followed by BDF after (if) well performance influenced by well's drainage boundaries



Comparison of Models to Ideal Model

Decline Model	Reasonable Forecasts for Low Permeability Reservoirs?	Valid for Transient Flow?	Valid for BDF?	Need to Change Parameters with Longer History?	Good with Limited Data (< 2 years)?	Easy to Use, Combine with Economics Software?
Arps - original	no	no	yes	yes	no	yes
Arps- modified	maybe	no	yes	yes	no	yes
Stretched Exponential	maybe	yes	no	no	no	somewhat
Extended Power Law	maybe	yes	yes	no	no	no
Linear Flow	maybe	yes	no	no	maybe	no
Duong	maybe	yes	no	no	yes	no
Duong - Modified	yes	yes	yes	no	yes	no

Strengths and Limitations of Decline Models

Decline Model	Major Strength	Major Limitation
Arps - original	Easy to use, couple with economics software	Requires BDF, constant BHP
Arps - modified	Easy to use, couple with economics software, valid in BDF	Early BDF, late exponential decline required
Stretched Exponential	Transient flow model	Not accurate in BDF, tends to be conservative
Extended Power Law	Transient flow model with smooth transition to BDF	Some difficulties in fitting 4-parameter model
Linear Flow	Correct physics for many fractured wells	Inappropriate for BDF, optimistic
Duong	Correct physics for many fractured wells (essentially linear flow)	Inappropriate for BDF, optimistic
Duong - Modified	Correct physics during transient and BDF	Not available in commercial software

Summary of Key Points

- Full physics, analytical, simple models all have important applications
- All simple models have important limitations, but many also have important strengths
- Most appropriate simple models and parameters found from study with comprehensive models
- Systematic work flow leads to most accurate application of simple models
  - Pressure normalization of rate data
  - Elimination of off-trend data
  - Flow regime identification with diagnostic plots

Review Question

- The best forecasting technique, using simple models, for ultra-low permeability reservoirs is
  - The original Arps decline model
  - Transient linear flow for the life of the well
  - The Stretched Exponential model
  - Situation specific

End