New Production Decline Models for Resource Plays

John Lee
University of Houston
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What's New?

- Growing acceptance that we should understand and apply appropriate basic physics in modeling flow and estimating reserves in unconventional resources
- Growing availability of user-friendly software that enhances our ability to produce realistic reserves estimates

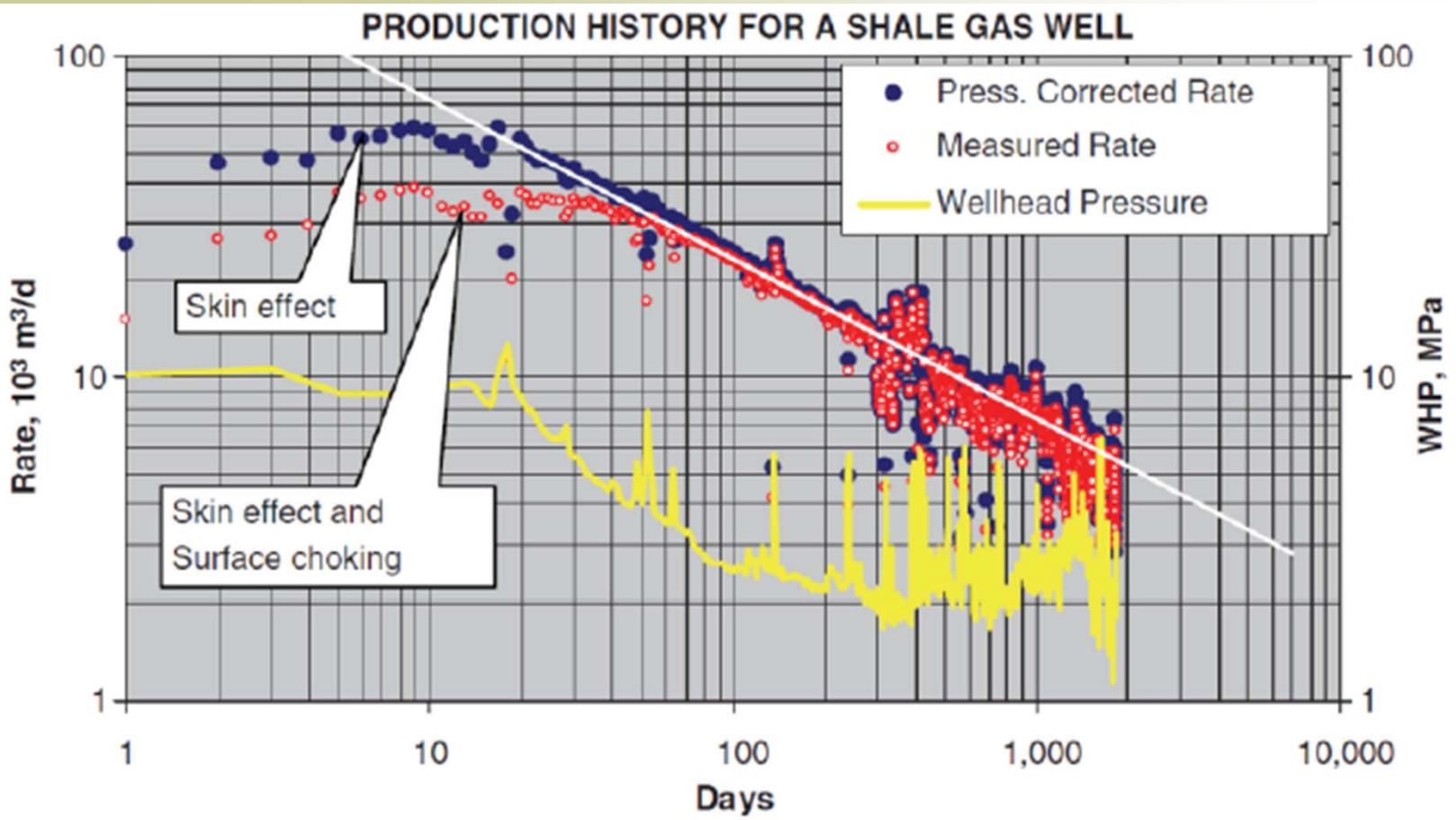
What Else Is New?

- Perception that existing analysis methods (analytical and empirical) for gas shale are adequate for liquids-rich shale
- Questions remain
  - Will we eventually have condensate blocking in retrograde-gas reservoirs?
  - Will multiphase gas-oil flow eventually cause problems in oil shales?
  - What gas-oil relative permeability curves are appropriate for oil shales?

So What Is "Appropriate Basic Physics"?

- Two dominant flow regimes coupled with early and late non-idealities
  - Linear flow early, probably continuing until fracture interference – modeled well by simple transient linear flow equations
  - Boundary-dominated flow later, after fracture interference – modeled well by Arps' hyperbolic flow model with b in range of 0.3 to 0.4
- The non-idealities
  - Early clean-up and choke-back of wells, required use of BHP data in flow modeling [appropriate variable $q/(p_i-p_{wf})$, not q]
  - Complex transitions to BDF, possibly influenced by linear flow from unstimulated matrix outside SRV
  - Possible transient linear flow into SRV from unstimulated matrix at late times

Early Non-Idealities and Later Linear Flow: Use $q/(p_i - p_{wf})$ While Seeking Understanding



Linear Flow: Horizontal Wells in Barnett Shale, Early Non-Idealities

- SPE 138987-Hale (2010)
- No pressures available

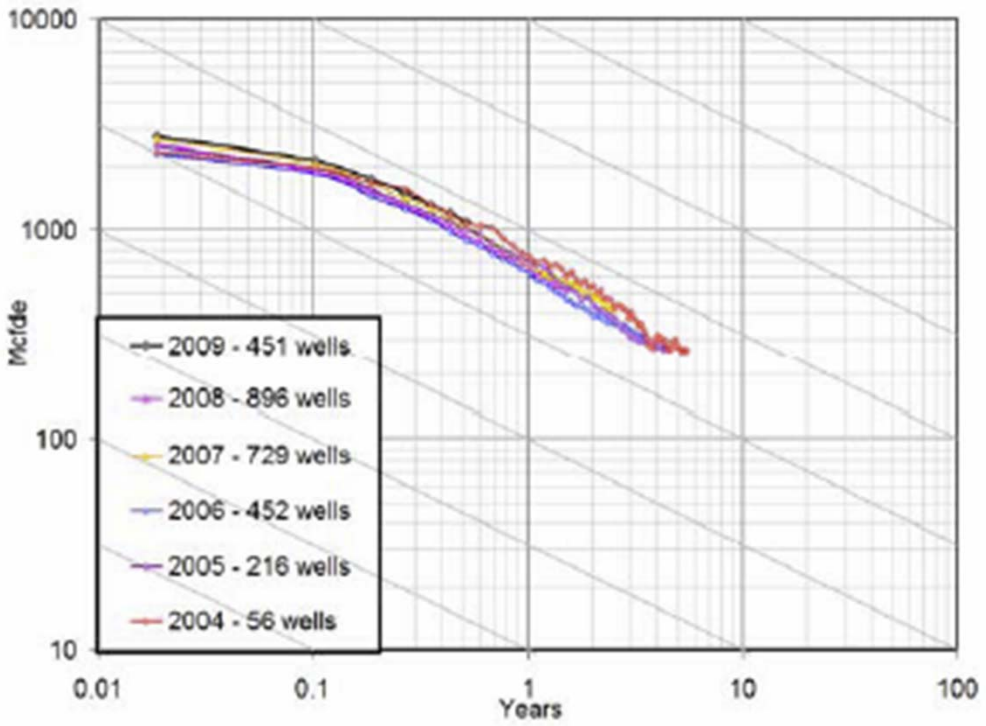


Figure 12 Johnson County Horizontal wells showing a linear decline slope of near 0.50. The rates are very consistent from year to year.

Linear Flow: Vertical Wells in Barnett Shale, Early Non-Idealities

- SPE 138987-Hale (2010)
- No pressures available

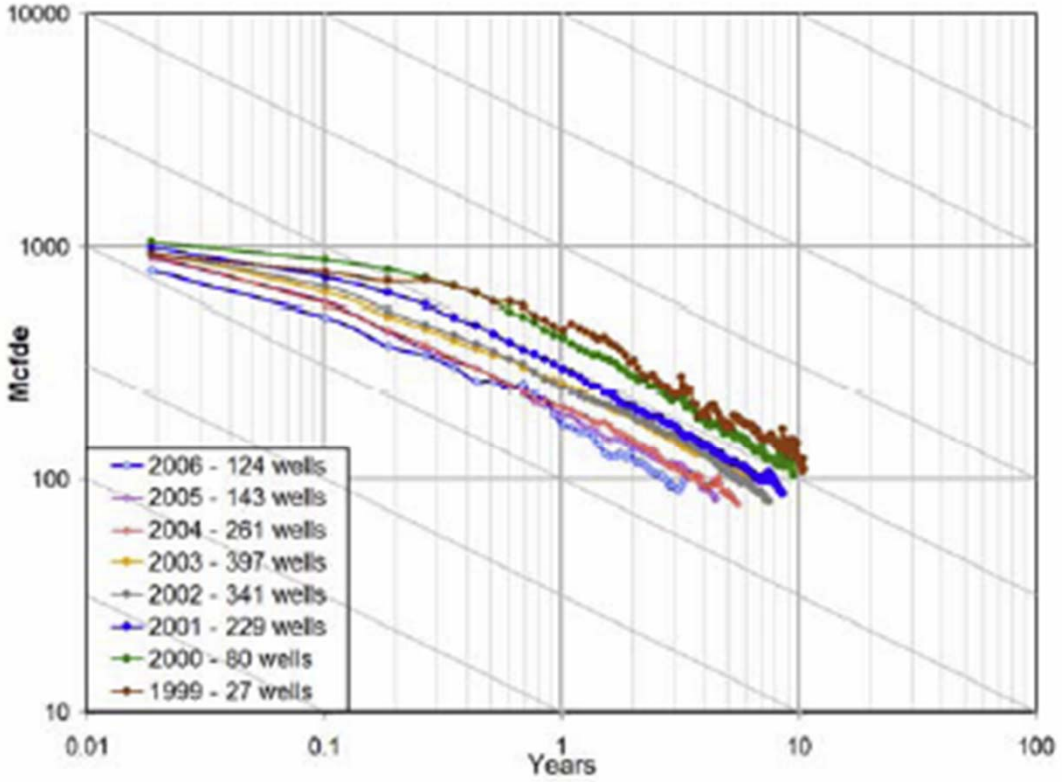
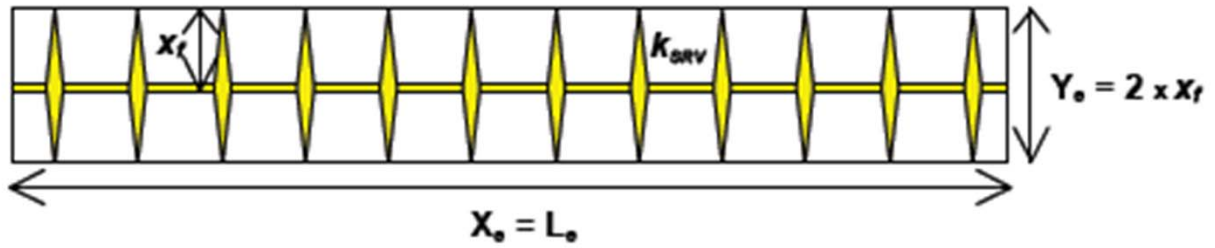
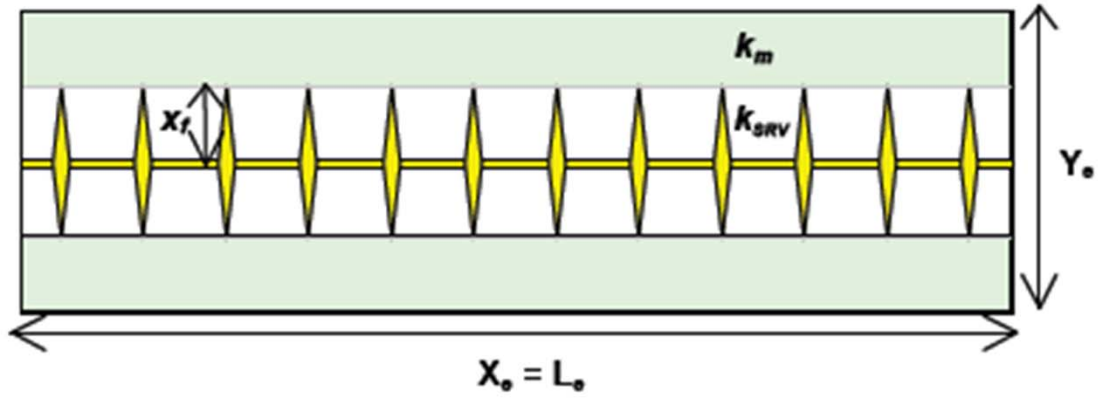


Figure 9 Vertical wells which have not been re-completed show have a half slope except for early time.

BDF in SRV? Or Fracture Interference Followed by Linear Flow From Outside SRV? Use Simulation While Seeking Understanding

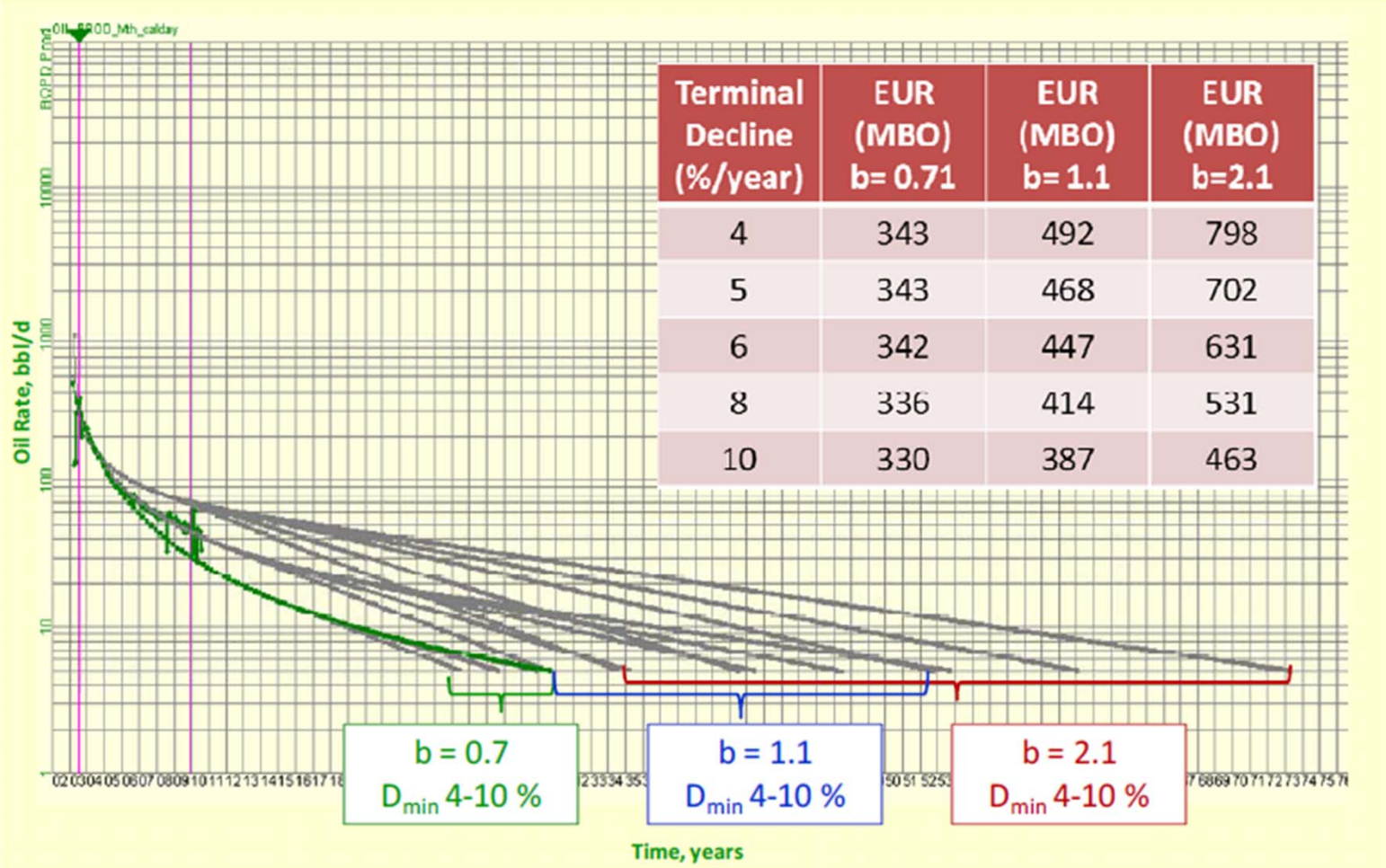


(a) Stimulated Reservoir Volume (SRV) Model



(b) Composite Model

Importance of Selecting Appropriate Model: What Value of *b*? What Value of D_{min}? It Matters…



Terminal Decline (%/year)	EUR (MBO) b= 0.71	EUR (MBO) b= 1.1	EUR (MBO) b=2.1
4	343	492	798
5	343	468	702
6	342	447	631
8	336	414	531
10	330	387	463

How to Determine Appropriate b, D_{min} – or Parameters in Other Models

- Best: Analog, based on field performance
  - Not available yet for shales
- Supporting or fall-back position: Reservoir simulation
  - Both analytical and numerical technologies available and appropriate

What Can We Do if No BDF Appears in Data?

- With no BDF regime, we must ***assume*** drainage area size and shape
- Best choices come from analogy, assigned well spacing, fracture design half-length
- After assuming drainage area configuration, we can forecast using analytical reservoir simulation model

Models Other than Arps with D_{min} Worth Consideration

- Given transient linear flow early in shales, followed by BDF (or fracture interference) later (followed again by linear flow?), honoring basic physics suggests we look for alternatives to Arps
  - General transient model: Stretched exponential
  - Transient linear model: Duong
  - BDF model: Arps, probably with b = 0.3 or 0.4 (why b = 0? ... no basis)

What About Off-Trend Early Behavior?

- Use $q/(p_i-p_{wf})$ instead of q when possible in work stage of seeking understanding
- Accept fact that early flow will be choked back and well will be cleaning up – simple models won't work
  - Suggests ignoring early, off-trend data in establishing 'best fit'

When Did the Industry Realize the Need for Early Transient, Late BDF Models?

- One of our most important intellectual leaders, Mike Fetkovich, told us so in the early 1980's
- Consider original Fetkovich type curve for production decline analysis
  - Early transient radial flow (analytical model)
  - Later boundary dominated flow (Arps model)
  - Use of $q/(p_i-p_{wf})$ also suggested

So Why Don't We Just Use the Fetkovich Type Curve for Analysis and Forecasting?

- Resource play development inevitably involves hydraulic fracturing, which leads to early and long-duration transient linear flow, not radial flow
  - We can still adopt Fetkovich's visionary thinking, coupling early transient flow with later BDF in our simple modeling
  - No need for special emphasis on $b = 0$ ... Fetkovich told us to expect $b = 0.3 - 0.4$ for typical oil or gas wells in BDF

How Might This Approach Work?

- We would be wise to start with either analytical or numerical reservoir simulation, using representative reservoir properties, lateral lengths, fracture spacing, operating practices (like choking wells back)
- We could identify expected types and duration of early transient flow, characteristics of transition flow and BDF regimes
- We could then adapt empirical models for rapid data processing to be consistent with expectations based on more rigorous modeling

What About Time to Switch from Transient Model to BDF Model?

- Use observed field performance (or analogy) if flow regime changes to BDF during available history
- Switch at appropriate decline rate if no BDF has appeared
  - Switch decline rate (D_{sw}) could be based on observations from simulation
  - Example: $t_{sw} = 0.5/D_{sw}$ for switch from transient linear flow to BDF (t_{sw} = 5 years for D_{sw} = 0.1 or 10%)
  - Could be made part of 'empirical DCA' software

What About Switch from BDF Back to Linear Flow (If Required)?

- Need to base ‘empirical’ modeling on guidance from analytical or numerical simulation or on observed field histories (analogy)
- Issue: When is flow from beyond SRV likely to be important, when unimportant?

Summary

- Need for simple, reliable DCA software for routine use remains
- Appropriate software likely to require switch from transient model to BDF model
- Details of switch time or decline rate at switch for given reservoir best based on analytical or numerical simulation, confirmed with analogies
- Need for switch to still different flow regime when flow beyond SRV becomes important

Summary

- Simple DCA models improving
- Understanding of appropriate physics of flow more widespread in industry
- Existing modeling techniques (both simple and more rigorous) appear adequate for liquids-rich shales
  - Verification with longer production histories important

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