

What Would Arps Think About What We Have Done to His Decline Model?

**Dallas Chapter SPEE
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What Is the Arps Decline Model?

- Hyperbolic model is our focus

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

where $0 < b < 1$

How Did Arps Come Up With the Model?

- Worked backward from two definitions
 - Decline rate, D (1/time)

$$D = -\frac{\frac{dq}{dt}}{q} = -\frac{d(\ln q)}{dt}$$

- Parameter b defined as change in $1/D$ (loss ratio) with time

$$b = \frac{d\left(\frac{1}{D}\right)}{dt}$$

- Key empirical observation: for most wells Arps/Cutler analyzed, b was constant (including $b = 0$) throughout all history

Arps' Hyperbolic Decline Model

- Integration for **constant b** leads to Arps' hyperbolic decline model

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

- Implication: Arps hyperbolic decline equation valid only for ***constant b***
- Hyperbolic model thoroughly validated (decades of successful application) for constant b , **which requires BDF**

Why Should Anyone Trust the Model?

- Arps' (and earlier investigators) finding (1944 and earlier) that the model
 - Fit most rate-time data well
 - Led to reasonable forecasts of future production
 - Rests on well-established empirical observation that b is reasonably constant in BDF

What Does the Model Require?

- Production at constant BHP
- Well or reservoir in boundary-dominated flow (BDF) (sometimes inappropriately called “pseudosteady-state flow”)
 - No transient flow data (oops!)
- Constant productivity index
 - No change in damage or stimulation
 - Skin factor constant
- Fixed drainage area
- For stabilized flow (BDF) with no change in productivity index, BHP, or drainage area, ‘ b ’ should be constant for life of well

What Kind of Wells Did Arps Analyze?

- Key: Data that provided basis for model were from 1920's, 1930's, early 1940's
 - All vertical wells
 - No hydraulic fracture stimulation (first in 1947)
 - Conventional permeability thus required for commerciality ... generally, 10's to 100's of md

Why Does Permeability Matter?

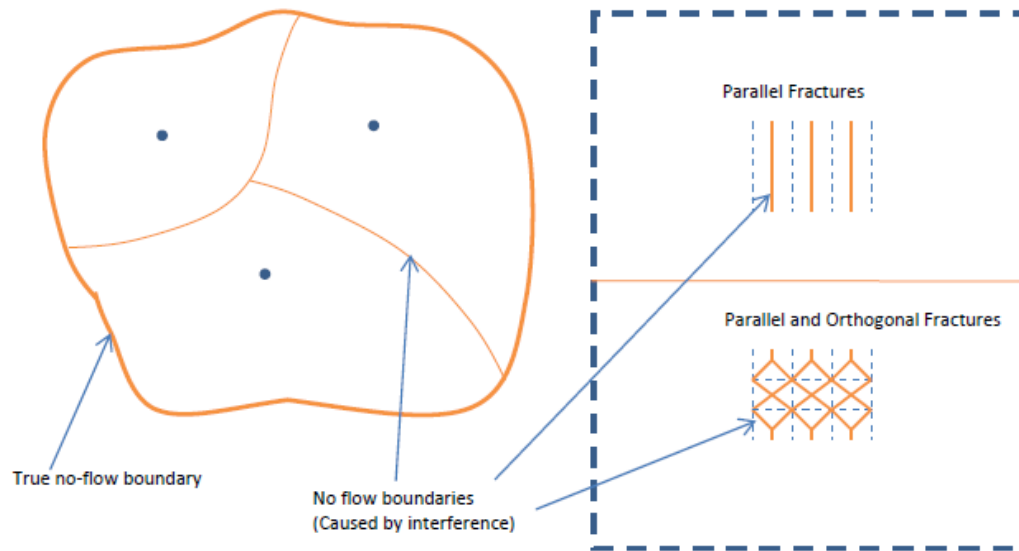
- Time to BDF in vertical wells estimated from

$$t_{bdf} = \frac{40\phi\mu c_t r_e^2}{k}$$

- For 10 md gas reservoir, $t_{bdf} \approx 5$ **days** for 160-acre spacing
- For 100 nd gas reservoir, $t_{bdf} \approx 240$ **years** for 160-acre spacing

... Arps' world and our world are different!

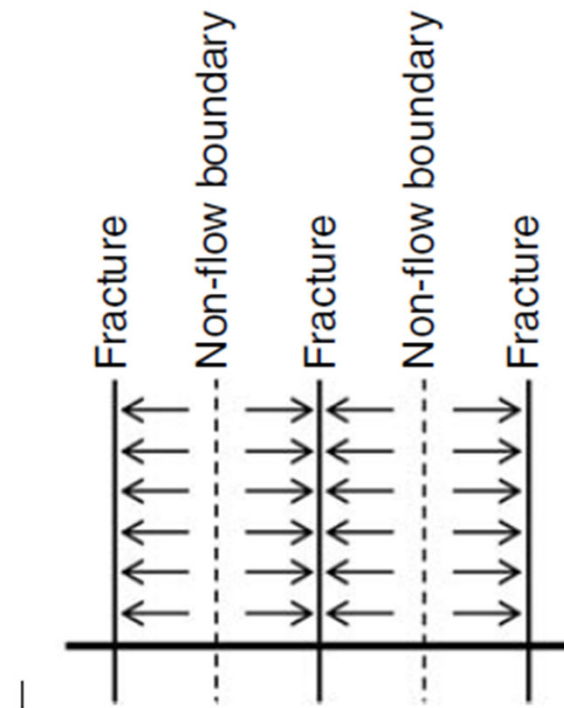
BDF Flow Caused Mostly by Interference



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BDF Caused by Fracture Interference in Horizontal Wells with Multiple Fractures

- Even with close fracture stage spacing, time to BDF can be **months** or **years** in resource plays
- So: Can Arps' hyperbolic model work for modern wells in low permeability reservoirs?

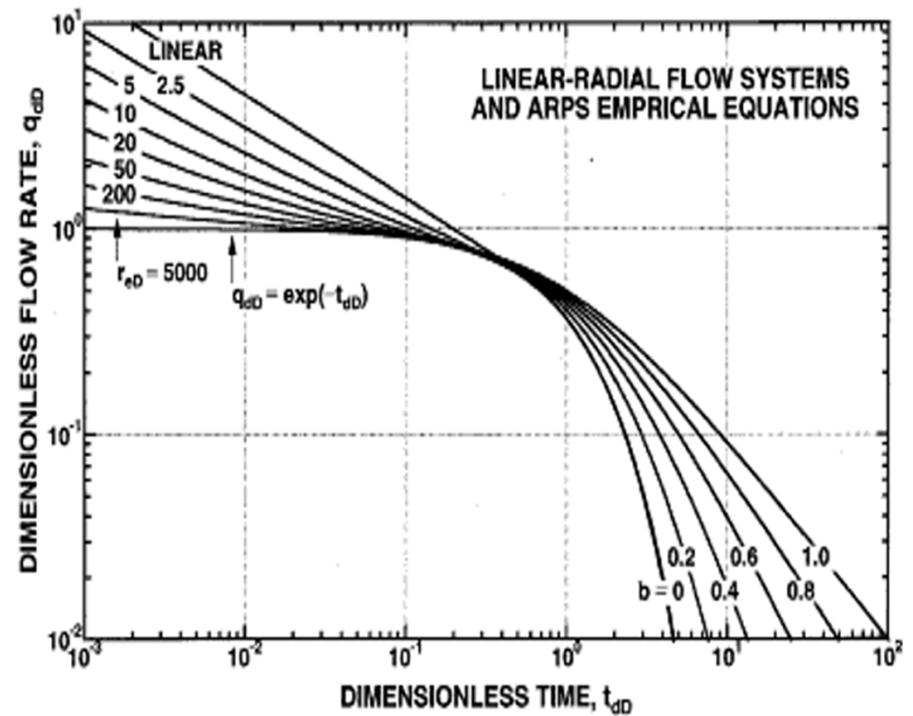


Arps Model in Resource Plays – Can it Work?

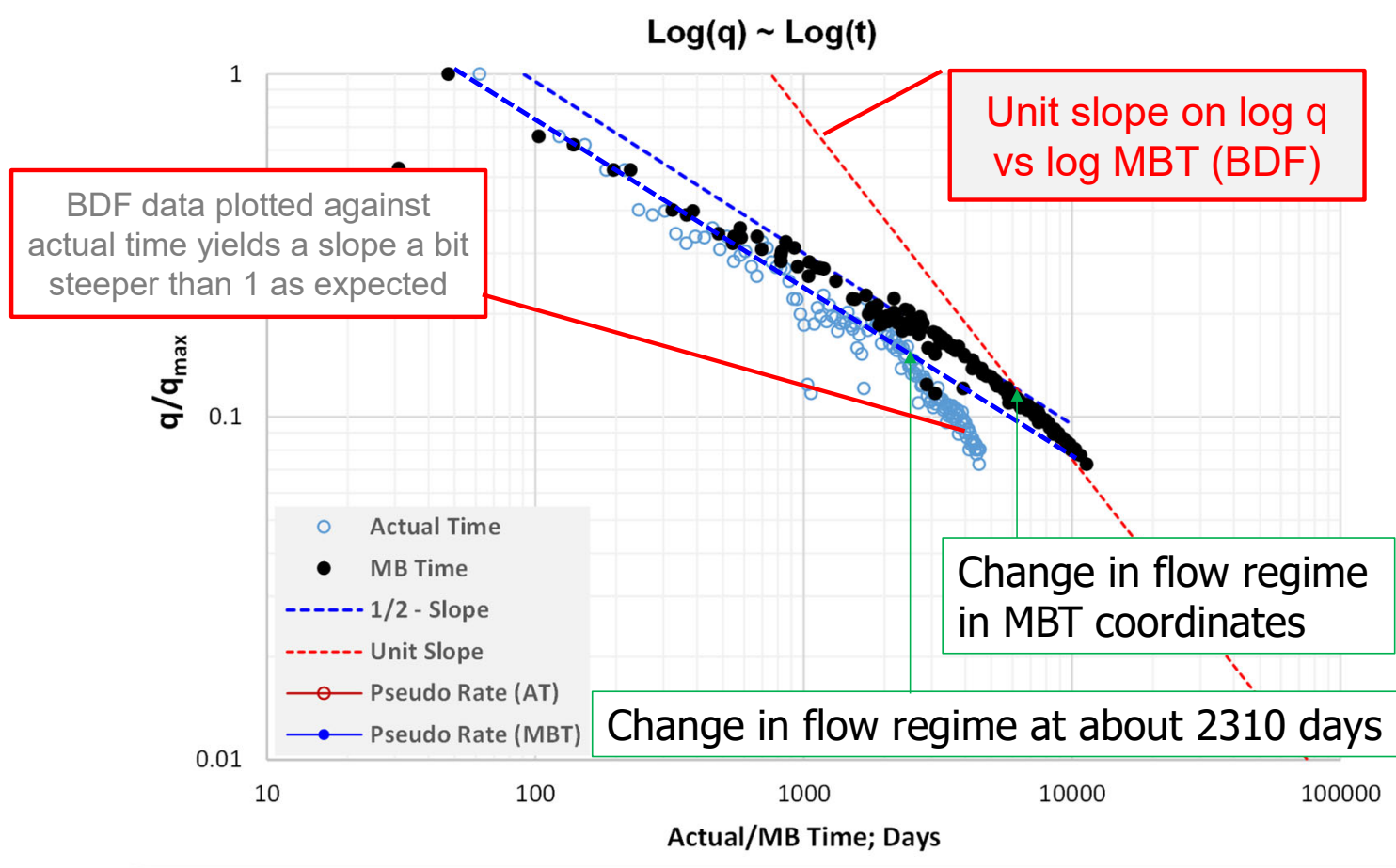
- Short answer: yes!
- How?
 - Divide flow history into multiple segments, apply model to each
 - Transient flow –often near linear flow
 - BDF – where Arps validated model
 - Transition region between transient and BDF
 - Early off-trend ramp-up period
 - How can we identify segments?
 - Log-log rate-time plots, assisted by rate-”material balance time” plots
 - Material-balance time: cumulative production/rate

But Does Data Fall on Straight Line ?

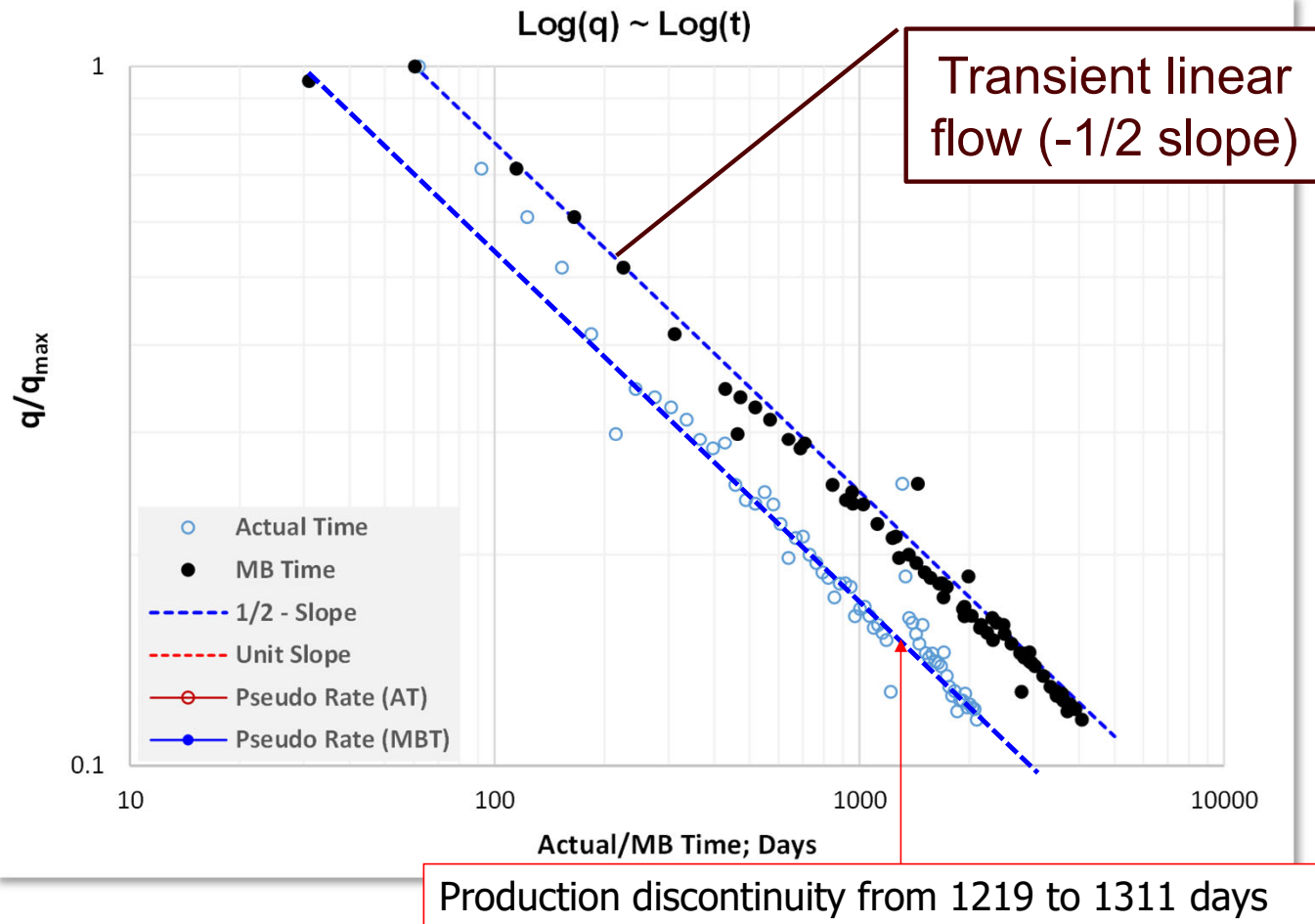
- Sometimes, yes
 - Early time “linear flow” $b = 2$
 - Also “power law” ... straight line
 - BDF:
 - When b large, eventually
- Sometimes, no
 - BDF:
 - When b small, no



What Does Actual Field Data Look Like?



Do We Always See BDF?



Simple Method to Determine “ b ”

- Consider Arps hyperbolic decline model

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

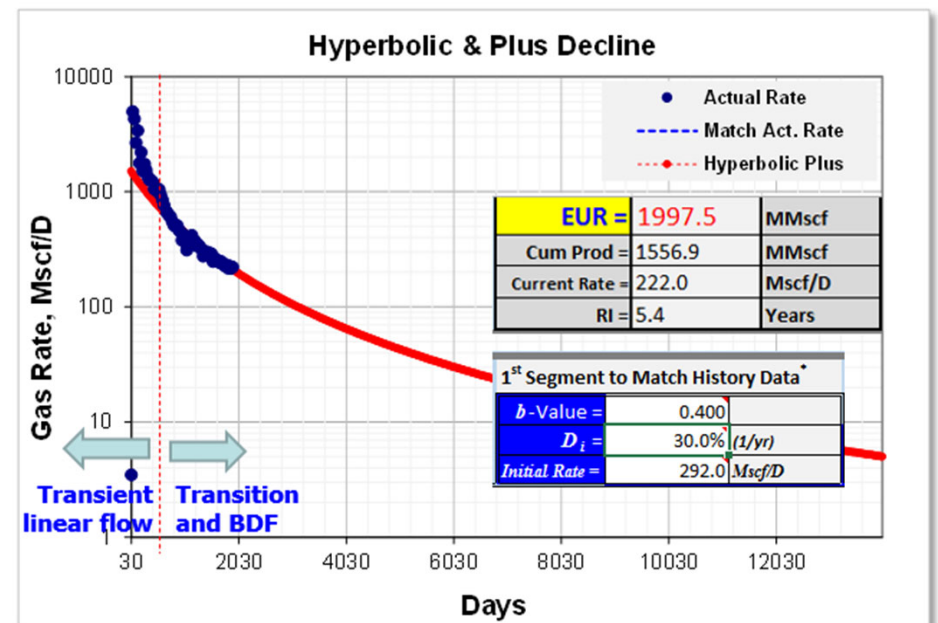
- Suppose $(bD_it) \gg 1$. Then, taking logs,

$$\log(q) = \log(q_i) - \left(\frac{1}{b}\right) \log(bD_it) = \text{constant} - \left(\frac{1}{b}\right) \log(t)$$

- Conclusion: straight line on log-log q vs. t plot, slope = $-\left(\frac{1}{b}\right)$...
slick way to determine b **if** data fall on straight line
- Example: slope = $-\frac{1}{2} \rightarrow b = 2$ during transient flow

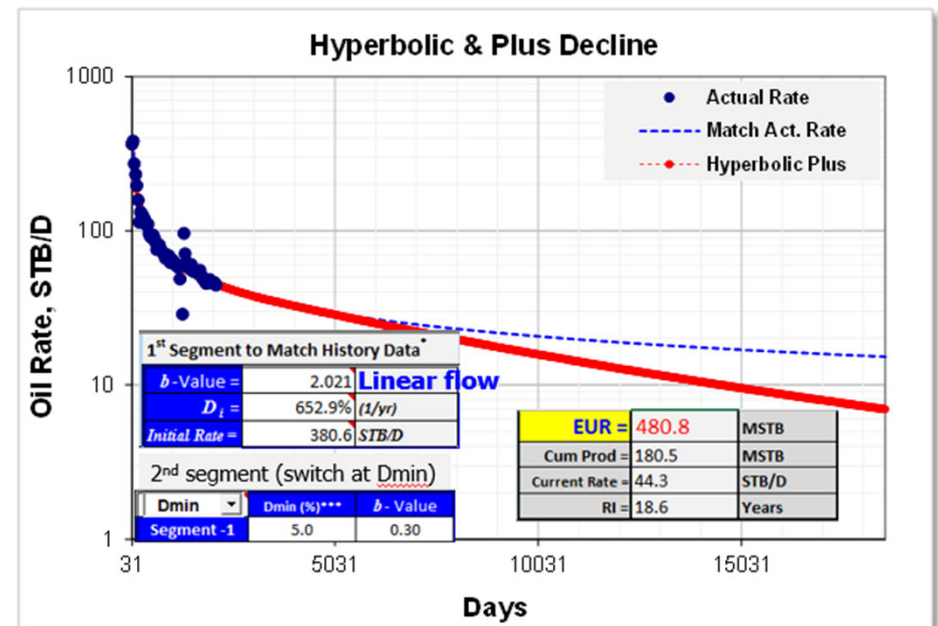
But How Can We Forecast with a Multi-Segment Arps Model?

- When we have some data in BDF, continue trend (same b) to life of well or economic limit rate
 - Assumption: interference with offset wells will have negligible impact




But What if We Have Only Transient Flow?

- Switch to transition model at specified D_{switch} , and switch to BDF model at specified D_{min} with specified b_{BDF}
- Decline rates at switch points and b_{BDF} from analogy or modeling



What Would Arps Think About This Procedure?

- Good reason to believe he would approve
 - Honors early ramp-up period, which he observed
 - Honors hyperbolic decline model he advocated during BDF
 - Adds transient flow regime present in modern low- k wells
 - When data lie on straight line on log-log plot, Arps hyperbolic model still appropriate (b constant)
 - $b > 1$, but not for life of well ... no laws of physics violated
 - Adds transition flow regime with varying b , but can use constant b (from analog) as first approximation



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