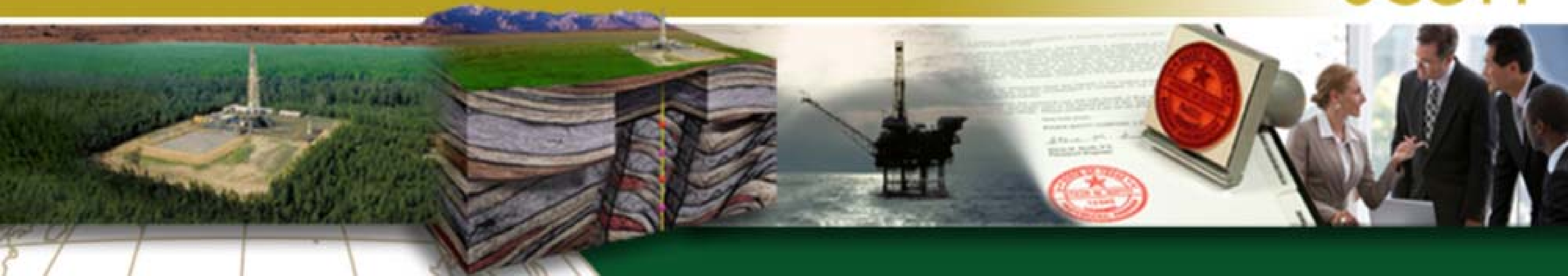
RYDER SCOTT



Production Forecasting in Ultra-Low Permeability Reservoirs: Update

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DISCLAIMER

The comments conveyed herein represent informed opinions of the author about engineering methodology. The applicability of the interpretative guidance provided should be considered on a case by case basis.

Review of Problem

- Extensive development of unconventional resources sheds light on problems with production forecasting and reserves estimation.
- The most used and easy method of production forecasting is Modified Arps methodology in Decline Curve Analysis (DCA) (Arps with $b > 1$ with a minimum exponential tail with decline D_{min}).
- While that method strictly applies only to the boundary dominated flow regime (BDF), it is a good tool that yields acceptable engineering results.
- The ultra-low permeability of unconventional reservoirs (UCR) leads to extremely long transient flow periods, sometimes lasting for years.
- That transient period is modeled with b values greater than 1.

Review of Problem

- **This study supports the use of Arps equations for production forecasting when those equations are tempered with good engineering judgment.**
- **Type wells using average curves from groups of wells appear to be somewhat different for the high, mid, and low ranges of EURs.**

RTA and Modified Arps in Production Forecasting

- Rate Transient Analysis (RTA) encompasses several methods of analysis.
  - But more data is required than for Arps
  - Also requires more time
  - When thorough RTA is performed, one well can take a day to analyze
  - RTA is not possible to do in a reasonable time if hundreds or thousands of wells are in the data set
- In this discussion, Modified Arps was used
  - If good engineering judgment is used, Arps fairly represents production performance
  - Reasonable estimates of EUR are obtained with limited ranges of b and D_i

General Work Flow Comments

- **Accurate production data is vital**
- **In many cases, we do not have daily production and pressure data**
- **Autofitting the data to obtain Estimated Ultimate Recovery (EUR) for the well set can be problematic, particularly with secondary phase ratios**
- **At this stage, the autofit does not have to be excellent or even very good, but a review is necessary to ensure that sufficient data was present to make a reasonable estimate of the forecast**
- **Grouping the wells by EUR can show that curve shapes for the different groups may not be the same (poor wells may not have the same curve shape as good wells)**

Case Example

Bakken Shale Horizontal Wells

Bakken Shale Horizontal Wells

- Monthly production data for over 1,500 Bakken horizontal wells was downloaded from HPDI.
- The data was uploaded into ARIES.
- Autofit of the data was done on all wells. Some of the fits were not useable as a final product, but they gave an initial estimate of EURs.
- Wells with no established trend were excluded from the analysis.
- Hyperbolic b exponent and initial decline rate D_i were estimated by curve fit on each plot.
- Almost 900 wells were used for the type wells.
- Resulting values of b ranged from near 0 (exponential) to over 1.9, while D_i ranged from approximately 10%/yr (which was D_{min} for this study) to over 90%/yr.
- The following slide from Cook's study supports the wide range of b.

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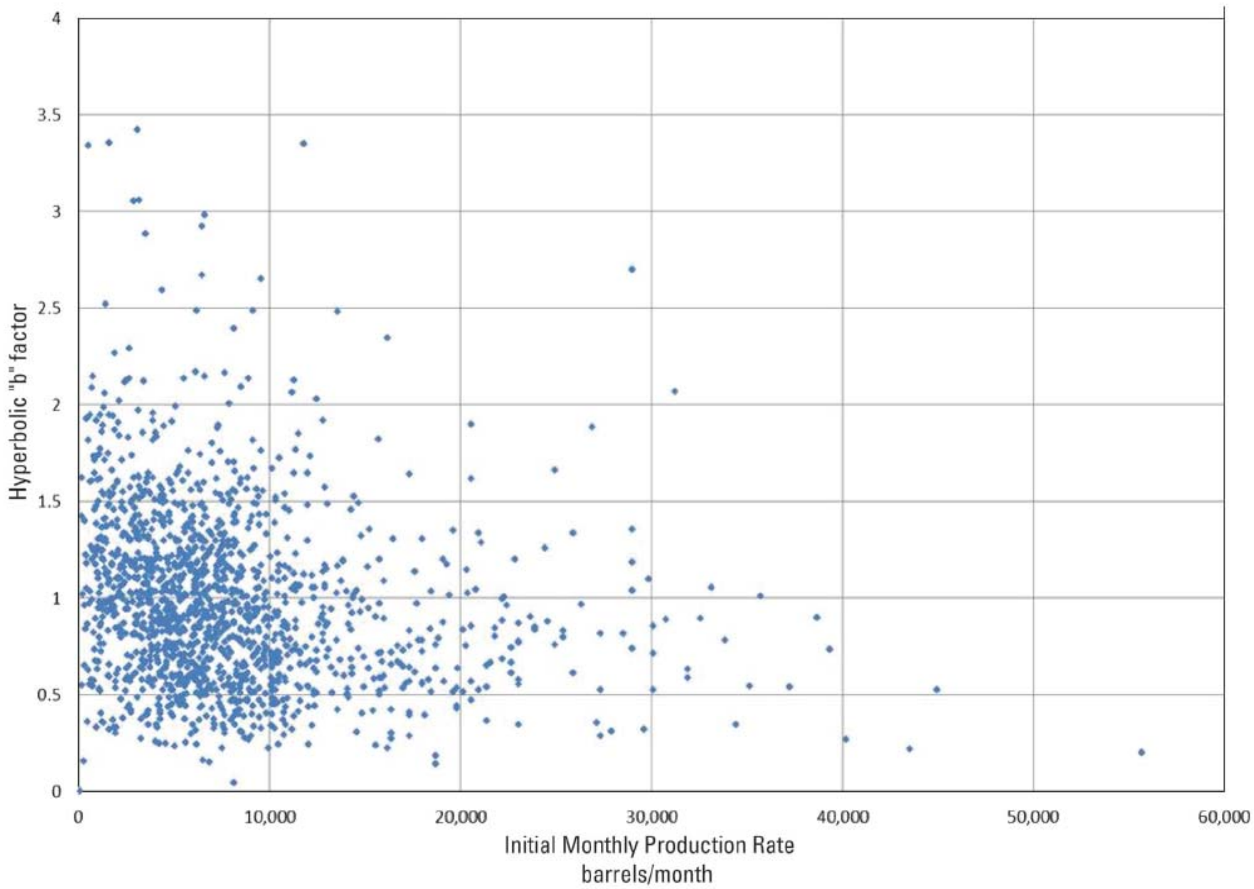


Figure 3. Initial monthly production rates compared to hyperbolic "b" factor for wells with more than 24 months of production data.

From Cook, USGS Report 2013-1109

Normal Practice for Type Wells

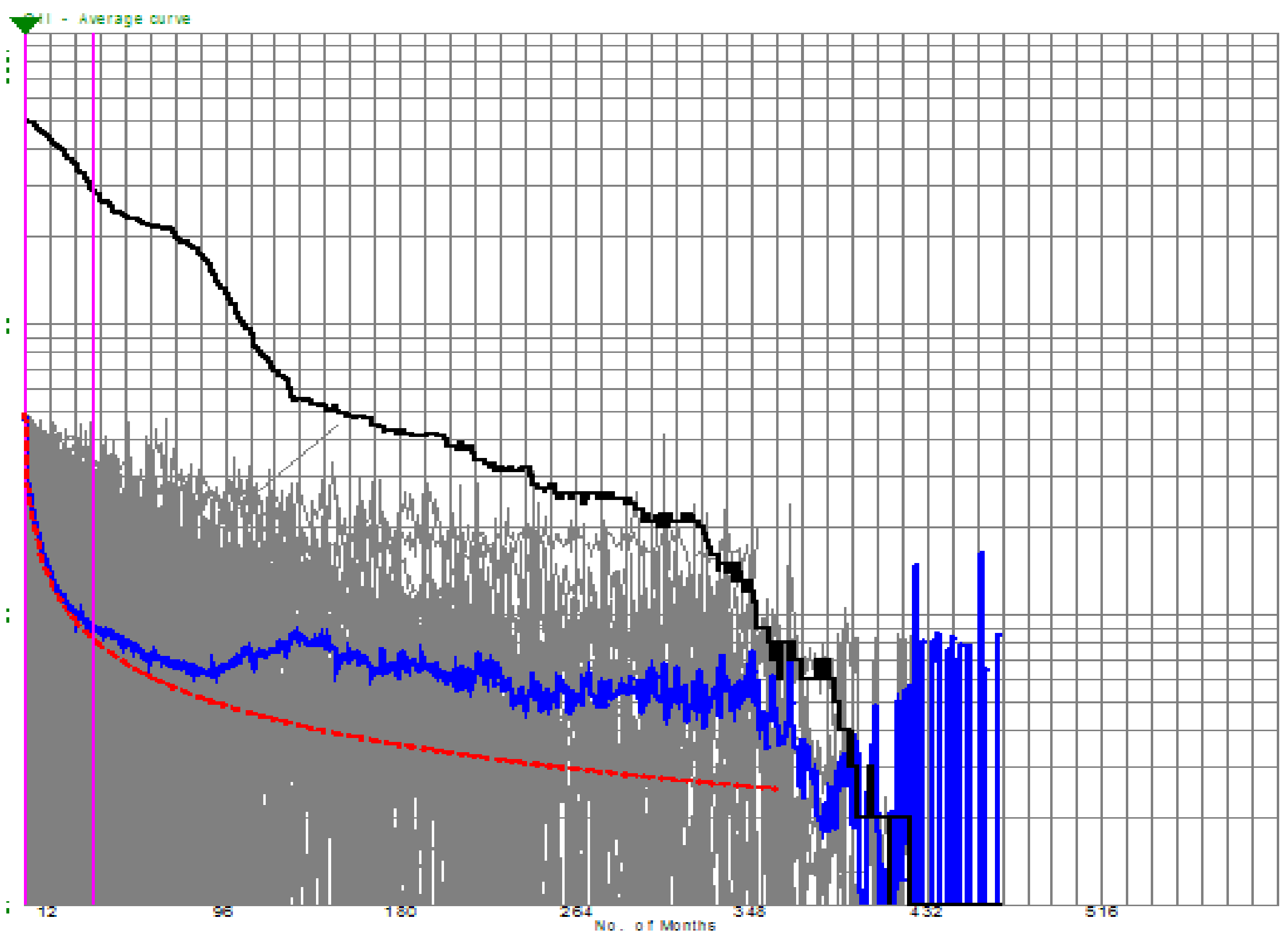
- In most cases, a group of wells is selected and normalized with respect to time and maximum rate.
- Data selected for the type well curve fit is truncated when the well count drops below a selected number (50% or more of the maximum well count usually). The range lines on the ARIES plots below show the range used to calculate the type well parameters.
- The average curve is calculated using the period where the well count is relatively stable.
- A curve fit is then calculated to estimate decline curve parameters.
- The plots below show such a methodology for the 3 groups of Bakken horizontal wells.
- These type wells support the idea that the shapes of the three groups are different.

Normal Practice for Type Wells (Cont.)

- High values of b were found for these type wells. It has been noted that Bakken wells often have long periods of transient linear flow, which results in b = 2. However, b was constrained to a maximum value of 1.5 for the type wells.

Bakken Group 1 Wells (High EUR Case)

Curve fit b = 2
Constrained b = 1.5



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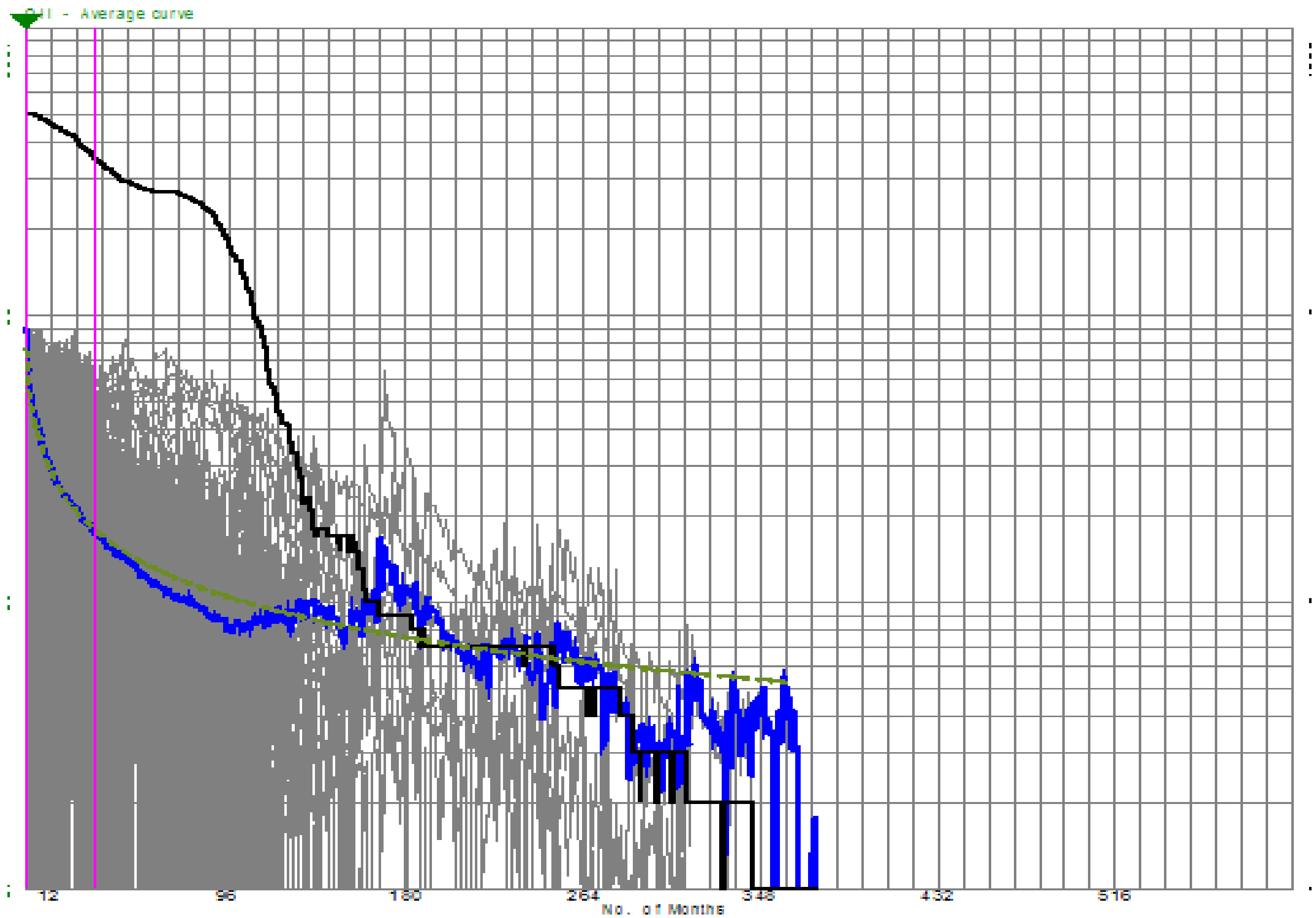
Bakken Group 2 Wells (Middle EUR Case)

Curve fit b = 1.7
Constrained b = 1.5



Bakken Group 3 Wells (Low EUR Case)

Curve fit b = 1.6
Constrained b = 1.5

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Thanks to Virginia Anderson for her help in this study.

Thanks for your attention.

Questions?

ADDITIONAL SLIDES

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