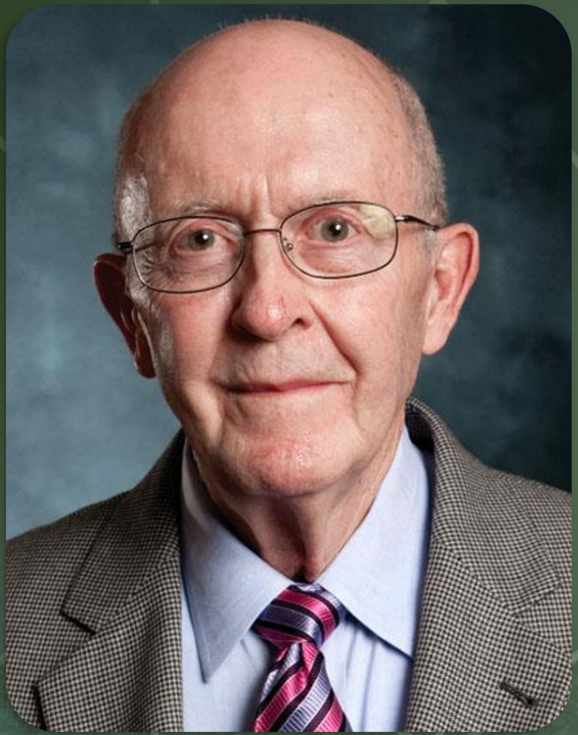
JOHN LEE



Professor of Petroleum Engineering at Texas A&M University

John Lee holds the DVG Endowed Chair in Petroleum Engineering at Texas A&M University. He holds a B.S., an M.S. and a PhD degree in Chemical Engineering from Georgia Tech.

John worked for ExxonMobil early in his career and specialized in integrated reservoir studies. He has taught at Mississippi State University, the University of Houston, and Texas A&M. While at A&M, he also served as a consultant with S.A. Holditch & Associates, where he specialized in reservoir engineering aspects of unconventional gas resources. He served as an Academic Engineering Fellow with the U.S. Securities & Exchange Commission (SEC) in Washington during 2007-2008 to help modernize SEC rules for reporting oil and gas reserves.

John is the author of four textbooks published by SPE and has received numerous awards from SPE, including the Lucas Medal (the society's top technical award), the DeGolyer Distinguished Service Medal and Honorary Membership (the highest recognition awarded society members). He is a member of the U.S. National Academy of Engineering and the Russian Academy of Natural Sciences.

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19TH ANNUAL RYDER SCOTT RESERVES CONFERENCE

Does Increasing GOR Typically Reduce EUR in Shale Wells?

John Lee
Texas A&M University
2023 Ryder Scott Reserves Conference
10 May 2023

What Started the Discussion? This …

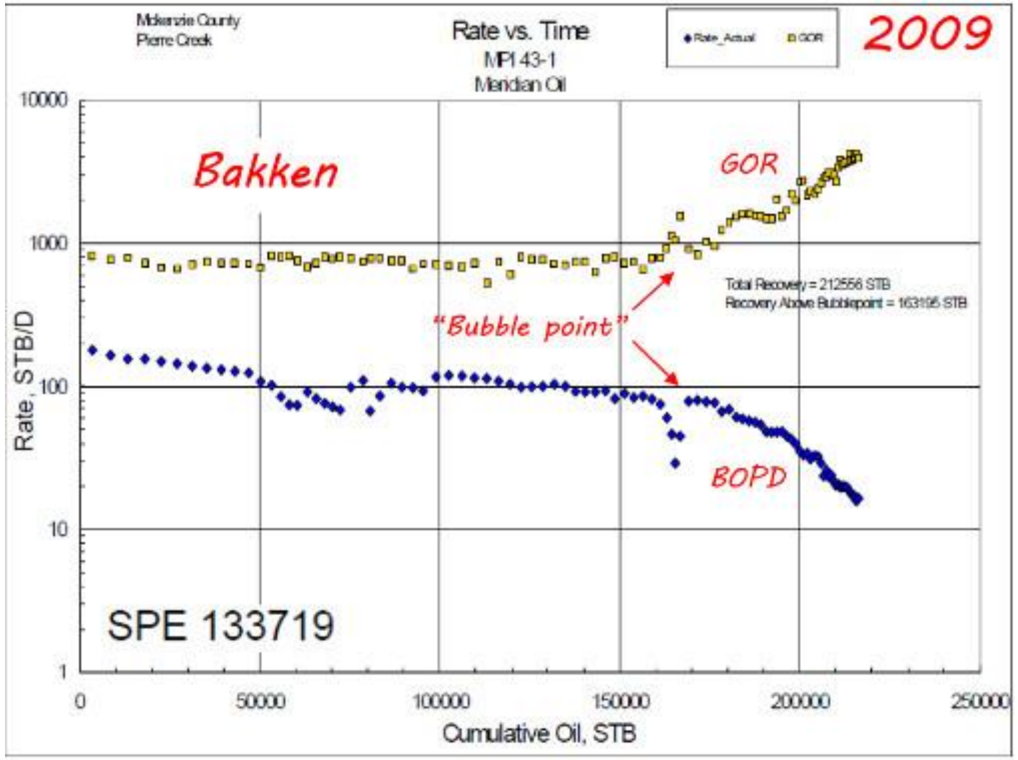


Fig. 5 – GOR vs. Cumulative production.

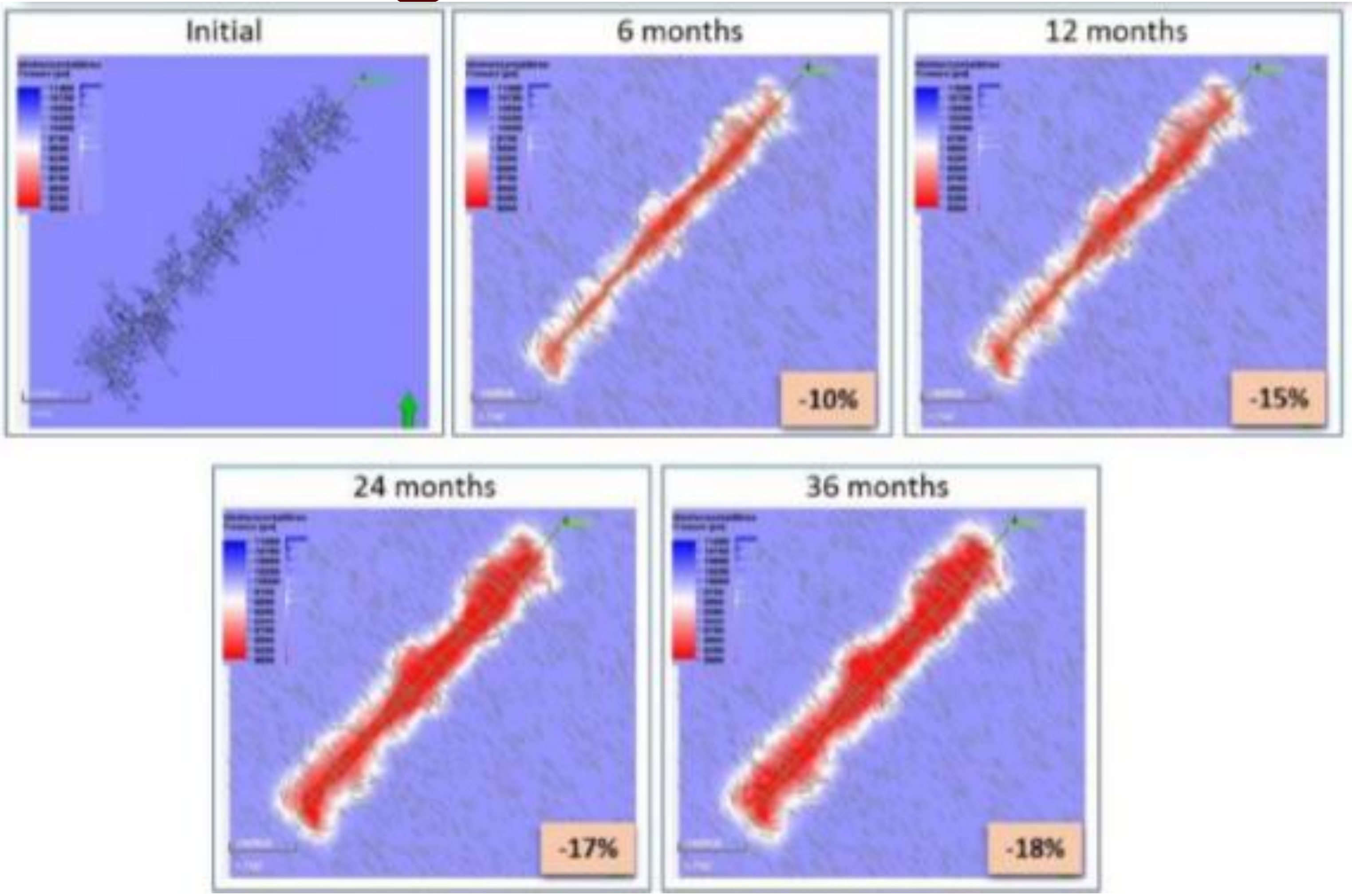
Operator Actually Pleased with Well Performance and Forecast

- Forecasts using DCA increased EUR in this area of Bakken by about 40% (SPE 133719)
- Positive impact on investment and development decisions for this independent, privately held company
- Question remains: why did oil production rate drop dramatically?
  - Decrease in fracture conductivity?
  - Depletion within SRV (BDF)?
  - Is Increasing GOR ***cause*** or ***effect***?
- We shall see…

Simulation Studies Indicate Limited Pressure Reduction Beyond SRV

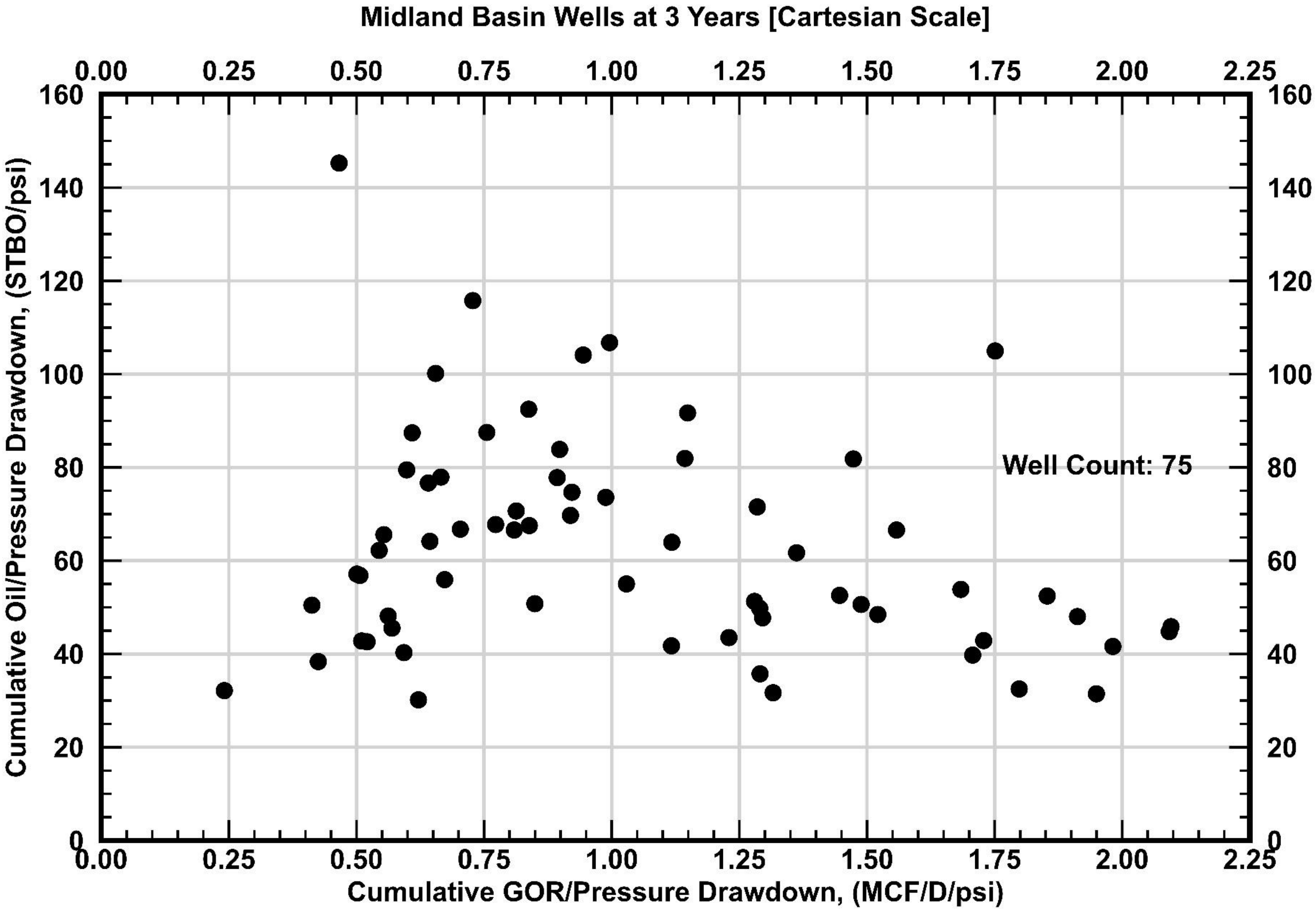
- Pressure in matrix beyond SRV usually remains near initial pressure
  - Free gas phase typically not formed unless initial pressure close to bubble-point pressure for nano-darcy rock
  - Interference with adjacent wells usually requires some overlap of SRVs
- Result: for common well spacing, little free gas saturation develops, no “death by GOR” (Xiong 2023)

Tight Wells Drain Only Rock in and Near SRV, Development of High Gas Saturation Minimal

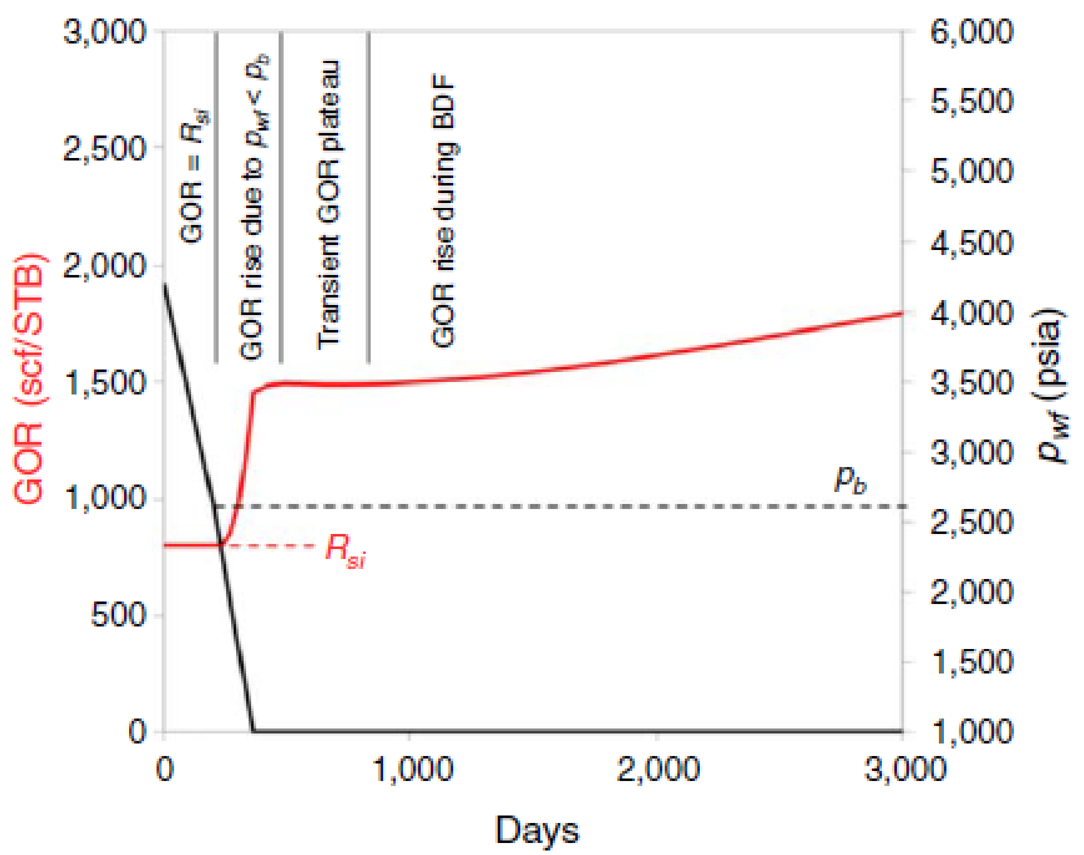


After SPE 191799

How Do GOR and Cumulative Oil Correlate?



What Should We Expect? Idealized Stages in GOR History of MFHW



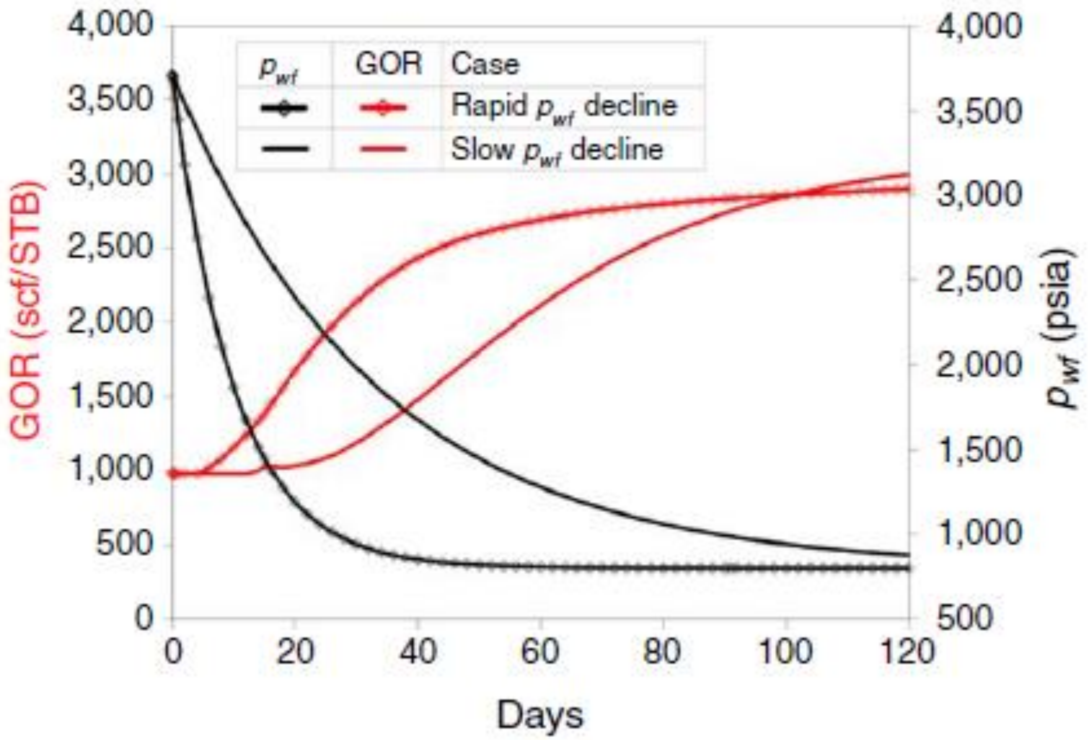
1. GOR rise due to $p_{wf}<p_b$
2. Transient GOR plateau
3. GOR rise during BDF

Possible complications

- Degree of undersaturation
- p_{wf} schedule
- Finite fracture conductivity
- Duration of transient flow

SPE 184397 (Steven Jones)

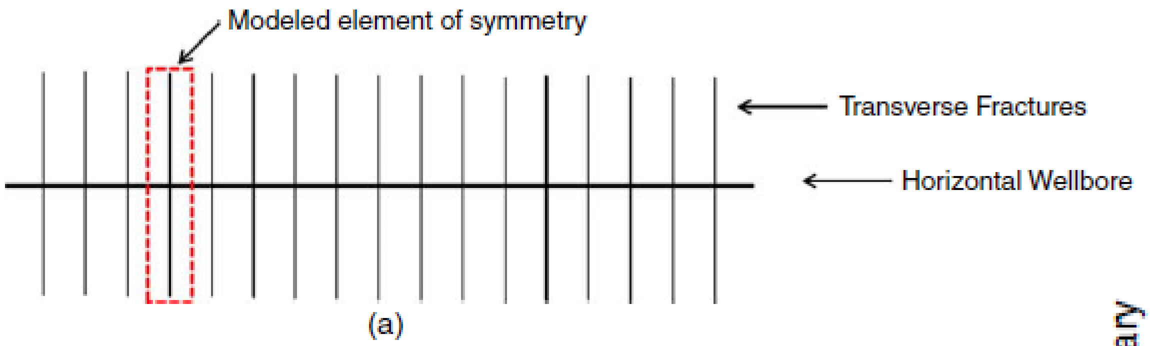
GOR Trend Depends on p_{wf} History

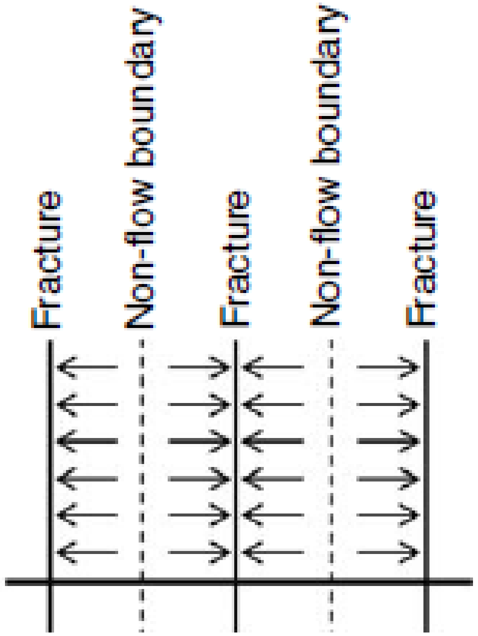


- Simulation shows dependence of GOR on history of p_{wf}
  - Slow decline in p_{wf} leads to slow increase in GOR
  - Rapid decline in p_{wf} leads to rapid increase in GOR

SPE 184397 (Jones)

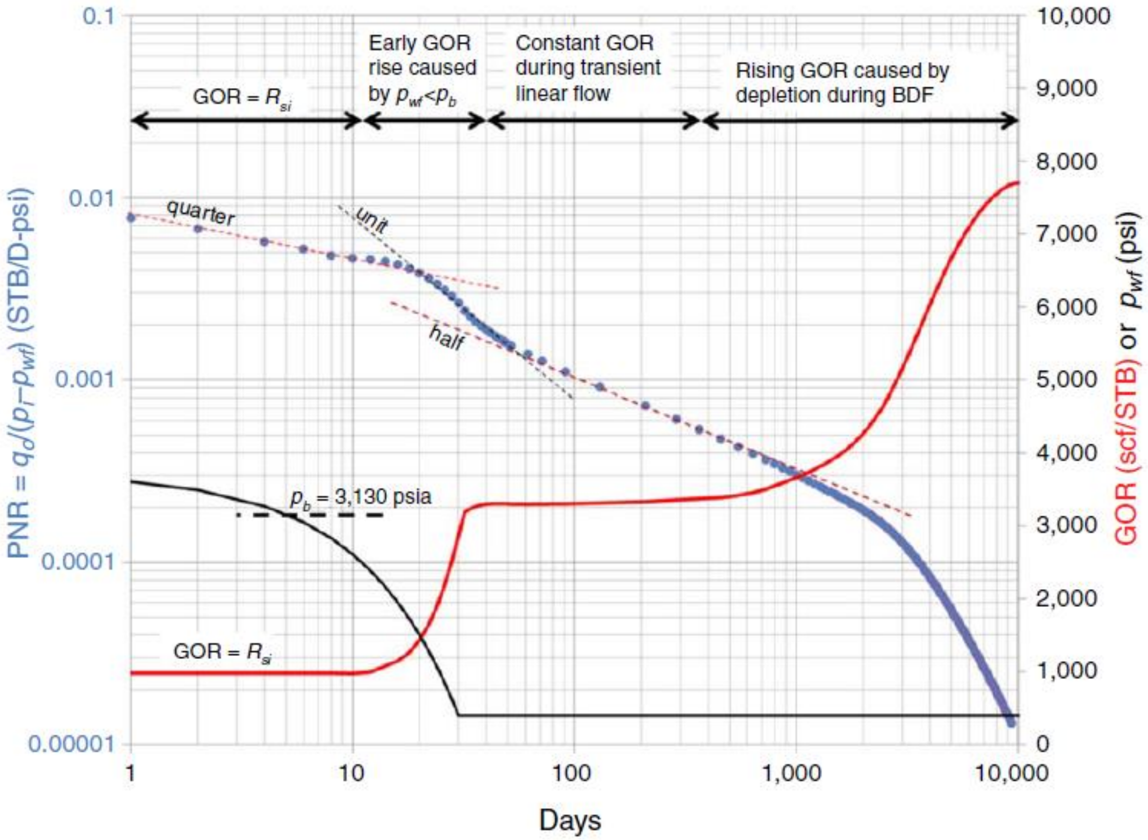
How Did Jones Simulate Well Performance?





SPE 184397 (Jones)

From Simulation: High GOR Appears on Log-Log $\frac{q_o}{(p_i - p_{wf})}$ vs. *t* Diagnostic Plot During BDF



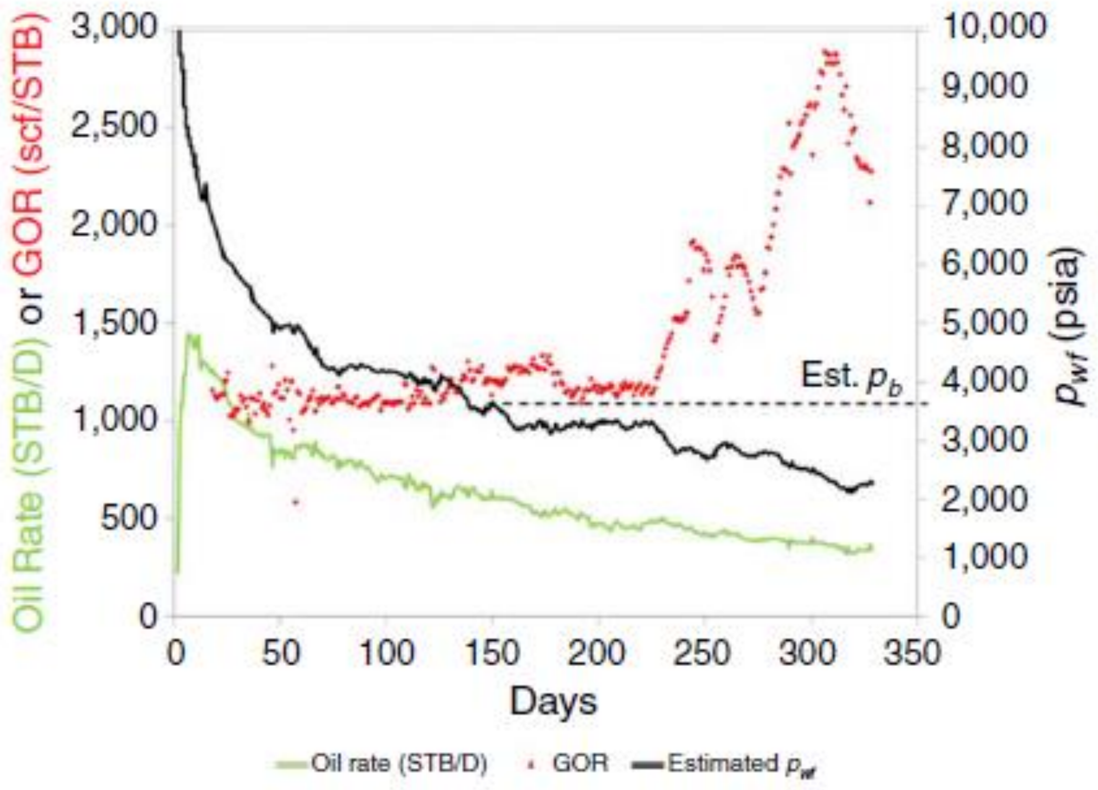
- Quarter-slope caused by finite fracture conductivity
- Unit slope appears as GOR rises, caused by decreasing oil mobility as S_g rises
- GOR plateau appears when p_{wf} constant and ½-slope appears
- Slope steepens in BDF and GOR rises due to depletion
  - Cause: depletion during BDF
  - Effect: rise in GOR, drop in oil rate

SPE 184397 (Jones)

What Does Actual Well Performance Indicate?

- Wells in STACK and SCOOP plays in Anadarko Basin (SPE 184397) confirm predictions from simulation
- 100 wells in Delaware Basin also confirm
  - Up to 7 years of constant GOR, steadily declining oil rate
- Dozens of wells in Midland Basin confirm
  - Constant GOR when p_{wf} constant
  - Steadily increasing GOR when p_{wf} steadily decreases

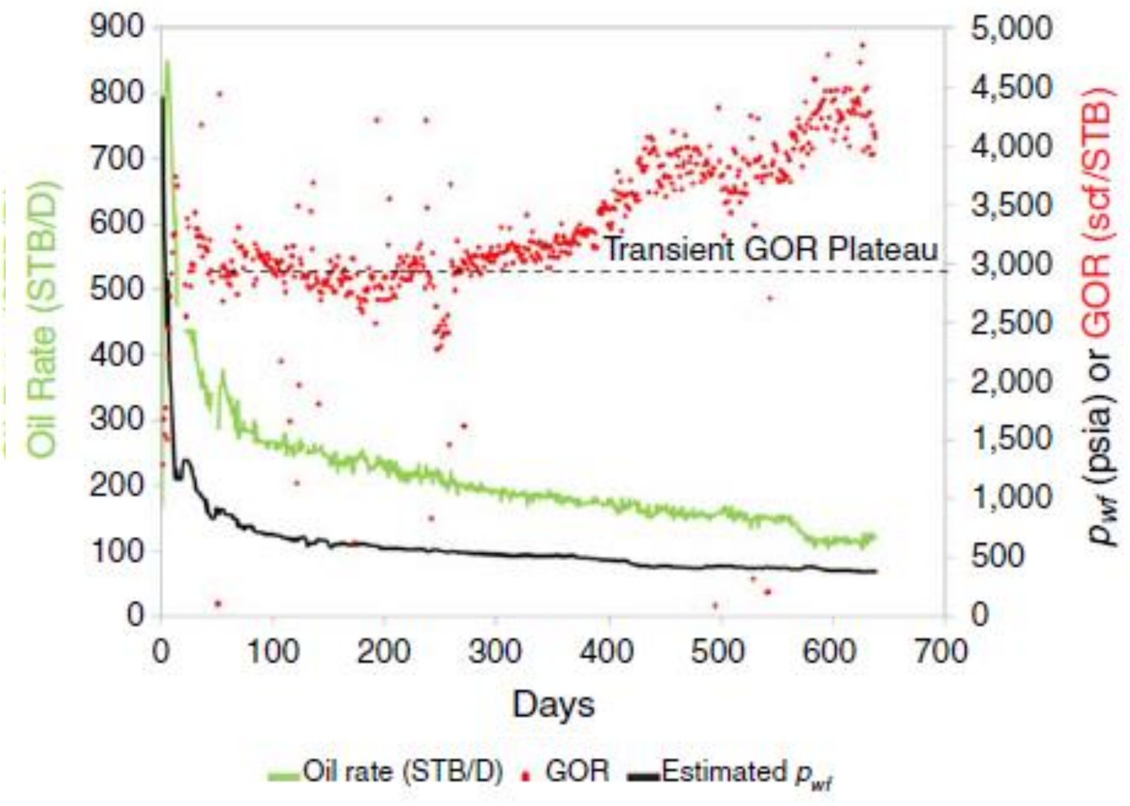
GOR Low in Springer Shale Well, Early Days



- p_{wf} above p_b for 120 days, GOR at Rsi
- p_{wf} slightly below p_b to 230 days, GOR slightly higher
- p_{wf} decreased later, GOR increased notably

SPE 184397 (Jones)

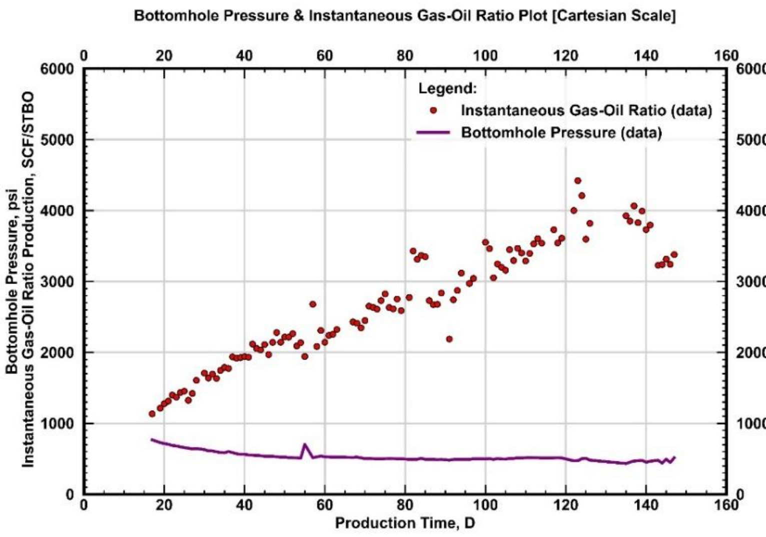
GOR Rose Higher, Sooner in Meramac Well

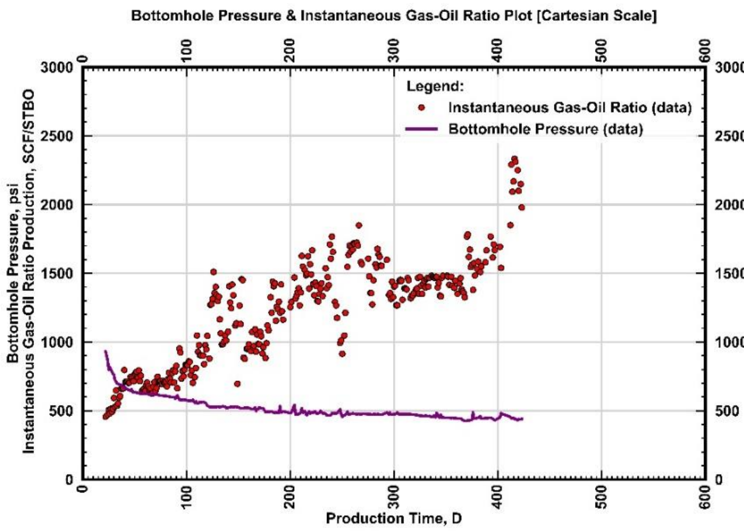


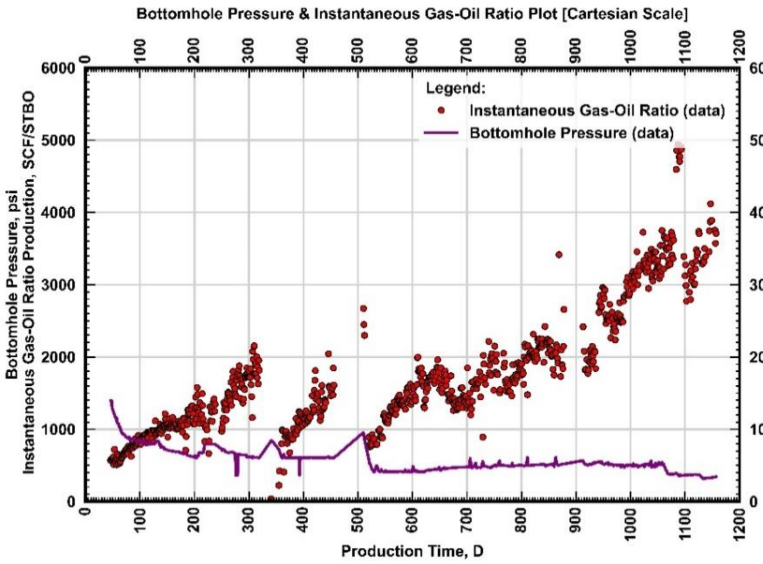
- GOR low for only 12 days
- As p_{wf} decreased rapidly below p_b, GOR rose rapidly

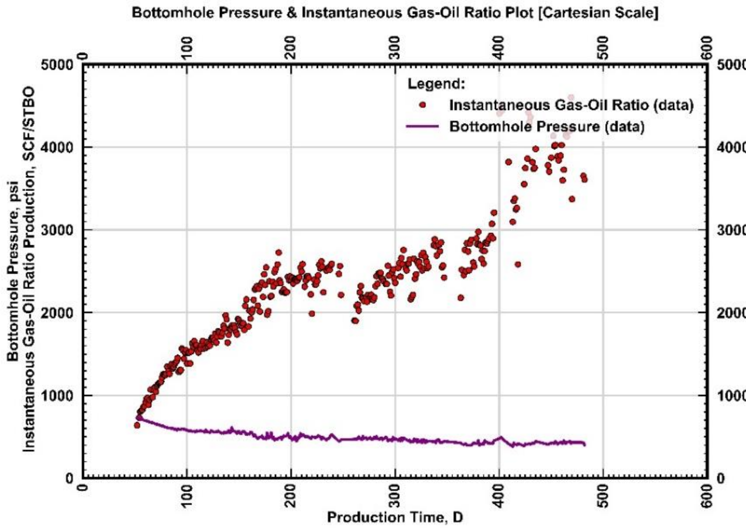
SPE 184397 (Jones)

Example Midland Basin Wells with Decreasing BHP



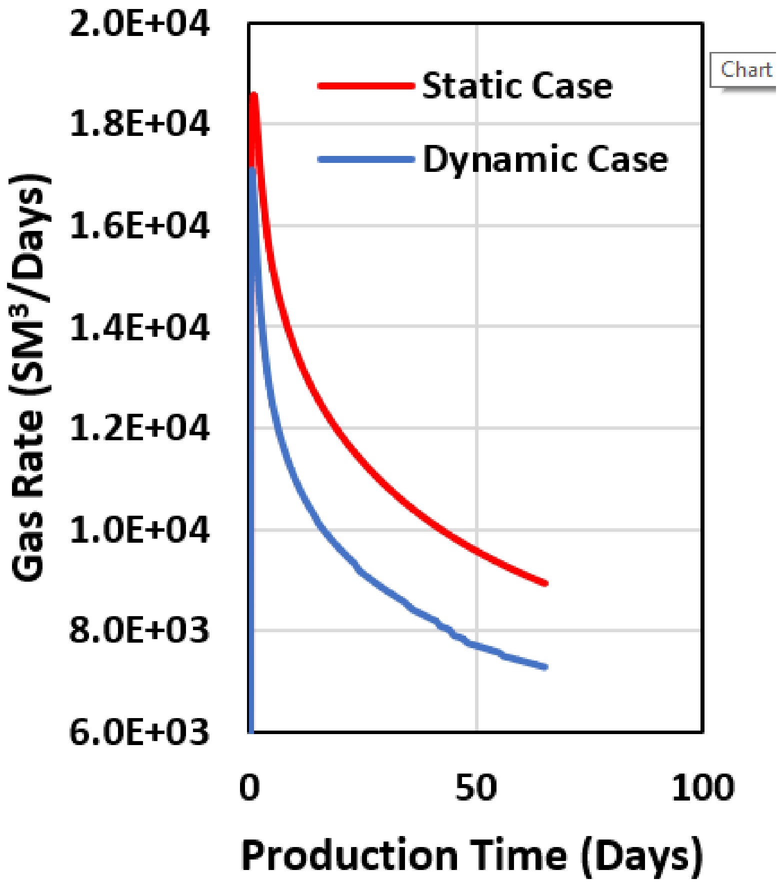




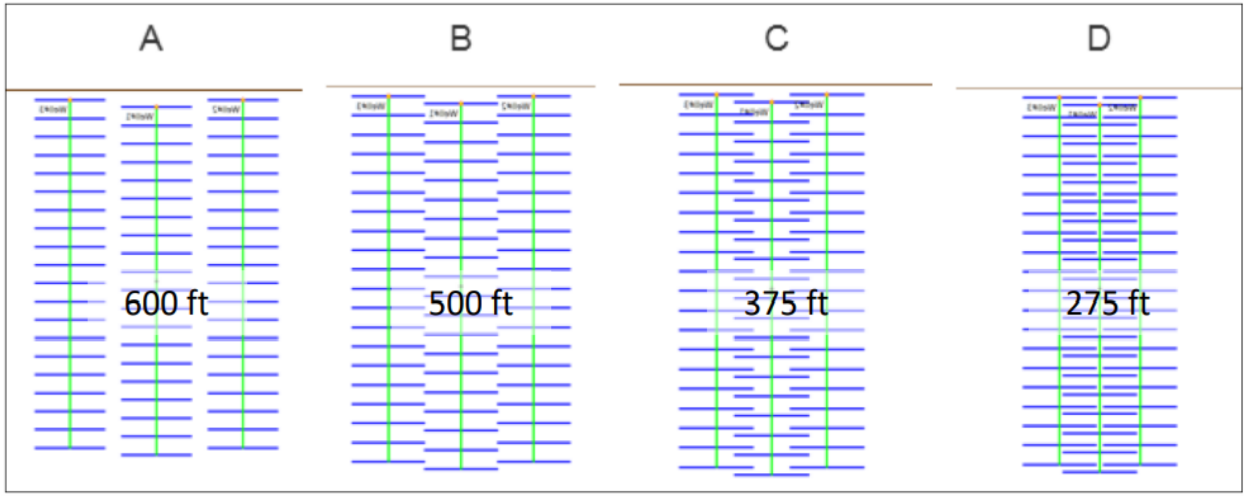


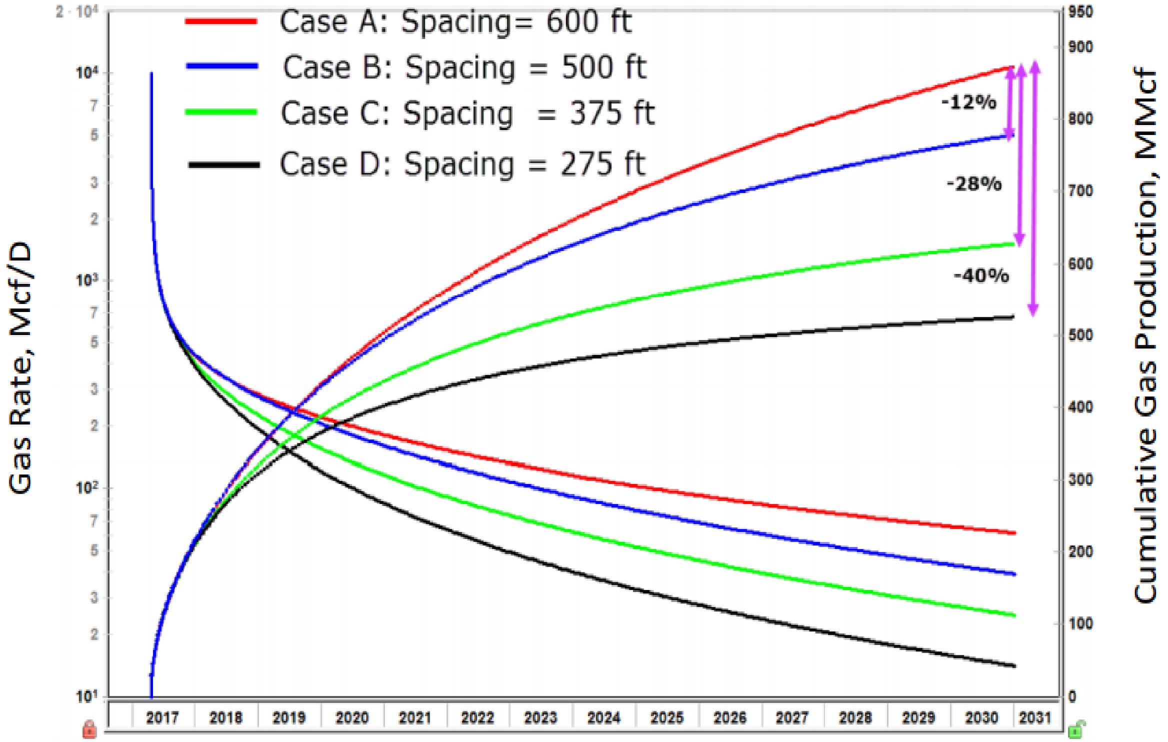
Decreasing Fracture Conductivity Can Dramatically Reduce Cumulative Recovery

- Geomechanical model (described in URTeC 2023 3862595) used in history match of field data shows sharp decline in rate and recovery in Delaware Basin and Vaca Muerta



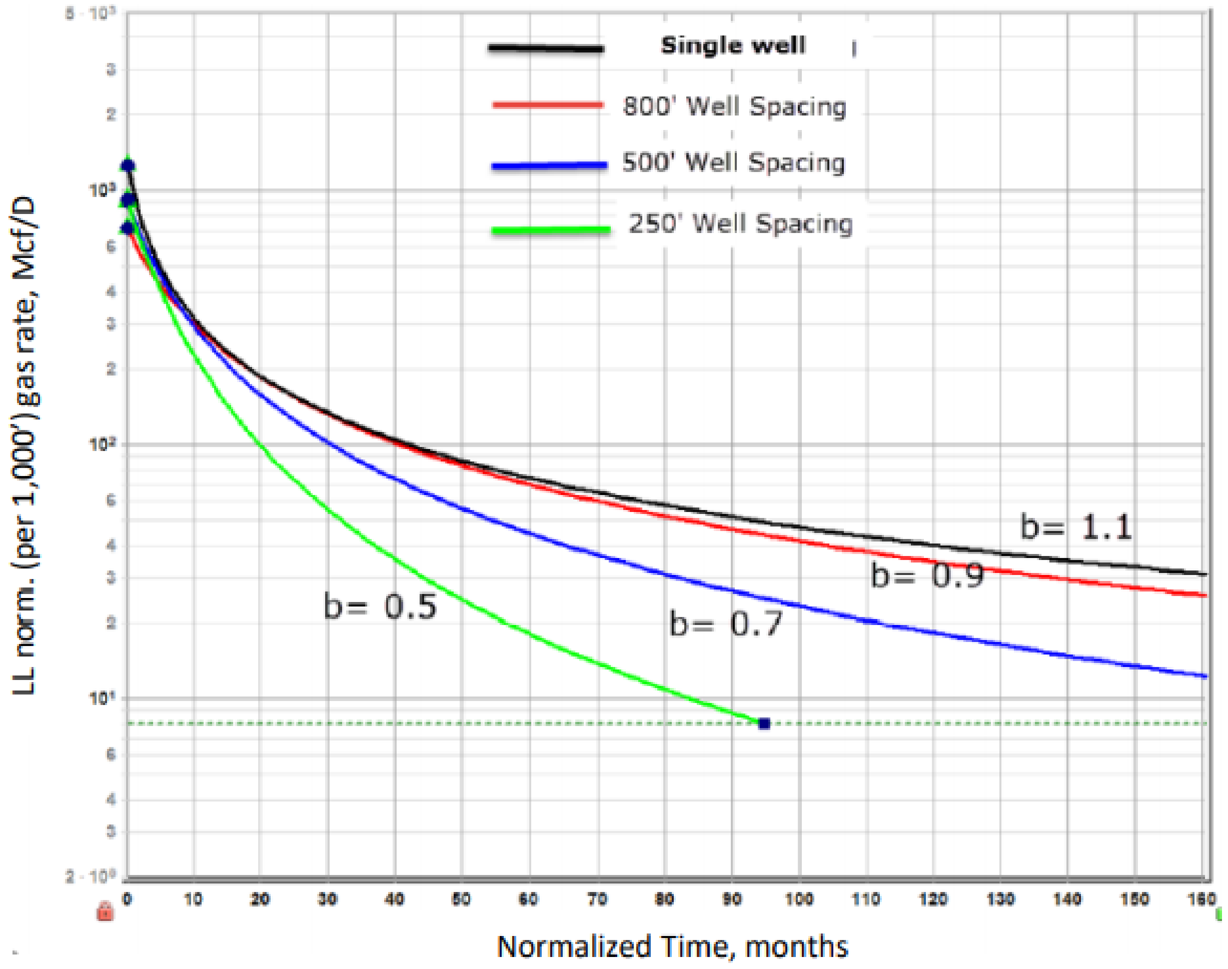
Inter-well Spacing Affected Well Performance in Equinor Eagle Ford Study





After URTeC 2695433

Well Spacing Impacted *b*-factor and EUR in Equinor Eagle Ford Study

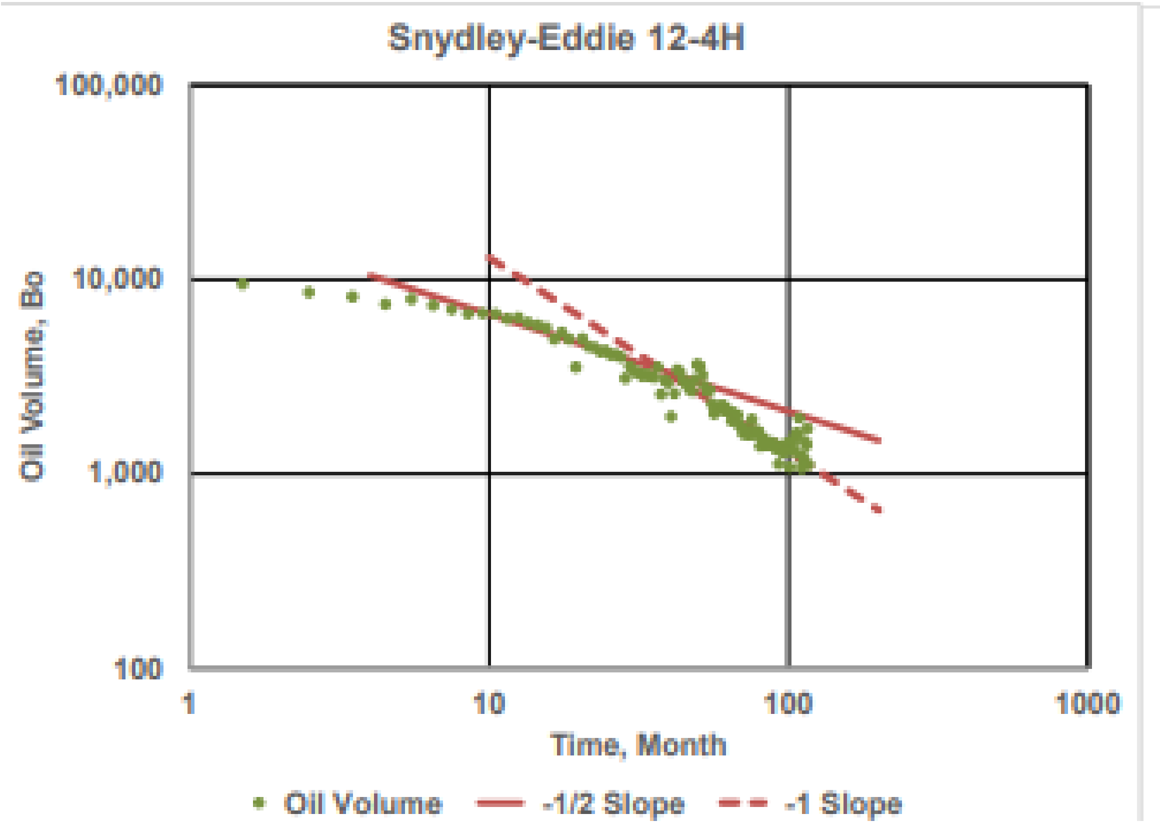


After URTeC 2695433

How Can We Forecast Both Oil and Gas Production?

- Good choice: Build type well production (TWP) profile by combining multi-segment Arps hyperbolic decline model and calibrated numerical simulation model (URTeC 2017 2668394)
  - Allows us to include interference, pressure-dependent fracture conductivity
  - Provides consistent and systematic approach to determine b and D_i for each flow regime (transient, transition, BDF)
  - Eliminates uncertainty in D_{min} choice
  - Takes advantage of rigor of numerical modeling and efficiency of classical DCA
  - Allows ties with operational constraints, such as minimum FBHP and drawdown pressure management

Multi-Segment Arps Decline Model Production Profile Illustrated



SPE 175993

Key Take-Aways Summarized

- Chance of “Bubble-Point Death” minimal in unconventional reservoir matrix
  - Possible when matrix permeability in micro-Darcy (not nano-Darcy) range and bubble-point pressure high (near discovery pressure)
- Greatest challenge: problems in production forecasting
  - Decreasing fracture conductivity with pressure
  - Decreasing effective permeability with pressure
  - Interference between adjacent wells
- Good solution: type-well construction combining multi-segment DCA with numerical modeling

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