RESERVOIR SOLUTIONS

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The industry debate on how to best forecast oil and gas production from tight formations has intensified recently, as evaluators pore over a growing cache of historical well data. Various supportable claims have questioned how unconventional petroleum reserves are estimated, what indicators are key parameters, including reservoir pressures and fluid properties, and whether industry is overestimating oil and gas volumes in these low-permeability reservoirs.

"Several recent claims have been made that the 'sky is falling' in Permian Basin tight oil reservoirs," said **John Lee**, a petroleum engineering professor at Texas A&M University. "Logical rebuttal has been offered by some, but skepticism remains."

Over the last decade, no one has contributed more to the body of knowledge in reserves evaluations than Lee. He discussed various recent claims at the Ryder Scott reserves conference on Sept. 13 in his presentation, "Death by Bubble Point: Fact or Fantasy."

Flow regime trumps GOR

Lee borrowed his title from a premise of petrophysicist **Scott Lapierre**, founder of Houston-based Shale Specialists LLC. Lee said that Lapierre's observation is that oil production rate begins to decline rapidly just when the gas-oil ratio (GOR) begins to increase.

"Scott's diagnosis is that higher-than-expected GORs plus lower (oil) production rates develop as the reservoir pressure drops below bubble point, thus 'bubble point death,'" said Lee.

Oil is the prize. When a well goes to gas, its economic life may be over.

"Investors are faced with a new concern – what are the long-term implications of increasing GORs and how should they affect valuations," he wrote. "It's no secret that traditional forecasting methods are flawed and a new approach is warranted to better understand the true, long-term potential of shale."

Lapierre's solution is what he calls bubble-point decline-curve analysis. His technique is described at https://www.linkedin.com/pulse/bubble-point-death-pxd-oil-mix-challenge-part-2-scott-lapierre/.

"Not everyone agrees with Scott, of course," said Lee. *Please see Permian Basin on page 2*

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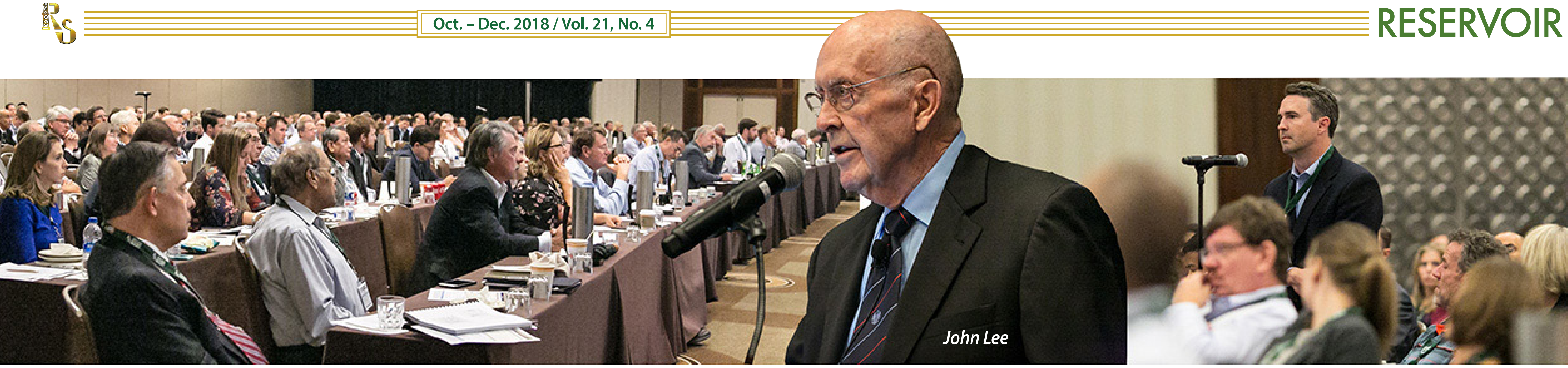
John Lee

Editor's Note: Industry has been searching for answers to reliably forecast production from unconventional oil and gas reservoirs for more than a decade.

*In 2008, **C.L. Kupchenko** et al wrote a seminal paper, "Tight Gas Production Performance Using Decline Curves," for SPE in 2008. The authors stated that "if decline analysis is performed using … transient production data, the main assumption of boundary-dominated flow (BDF) is violated and inaccurate forecasts may result."*

*That same year, **D. Ilk** et al wrote an SPE paper, "Exponential vs. Hyperbolic Decline in Tight Gas Sands: Understanding the Origin and Implications for Reserve Estimates Using Arps' Decline Curves." It suggested that "using the hyperbolic relation by itself may not be appropriate for reserves extrapolations in tight gas reservoirs," so the Power Law method was proposed.*

That DCA method is not designed for use with limited data. Ilk et al stated that the Power Law is not easy to use because it has to be fitted with a four-parameter equation. Also, the final decline rate is somewhat arbitrary and difficult to determine. Since then, other methods have been proposed.

***He Zhang**, a petroleum engineer at Ryder Scott, released the Extended Exponential Decline Curve Analysis (EEDCA) method in a 2015 SPE Paper, "An Empirical Extended Exponential Decline Curve for Shale Reservoirs." The method is simpler and the results are similar to those of other DCA techniques. EEDCA matches early and late well performance of shale producers without switching decline models. The equation can be fitted with three parameters, assuming the "beta late time" variable or βl is the minimum decline, said Zhang. The equation is shown on Page 3 of the October 2015 Reservoir Solutions newsletter at www.ryderscott.com/wp-content/uploads/2015NL_Oct.pdf#*

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C. Clarkson et al, in SPE Paper 178665, "An Approximate Semianalytical Multiphase Forecasting Method for Multifractured Tight Light-Oil Wells with Complex Fracture Geometry," makes a case that a change in the flow regime is the "cause of death." When transient linear flow ends, GOR increases and flow rate decreases. Flow dynamics are the real cause of accelerated oil production decline and GOR is a symptom. The study observed that below bubble point, the GOR remains constant until transient linear flow ends.

"The point is it depends on certain reservoir and completion properties and not just on the fluid and its bubble point. The situation is more complex than that," said Lee.

In transient linear flow, the fluid is draining into the fractures from the matrix in a multiple-fractured horizontal well until interference among the fractures occurs. At that point, oil rate drops and the transient linear-flow trend ceases. Reservoir permeability, length of time to fracture interference and fracture spacing determine the duration of transient linear flow, Lee explained.

Boundary-influenced flow is a "tweener"

This year, the Wood McKenzie research firm found that after five years of production, horizontal wells in the Wolfcamp deep basin experienced annual decline rates of about 14 percent. Industry has been applying 5-to7-percent terminal declines seen in older vertical wells. Higher decline rates decrease EURs (estimated ultimate recoveries) but have less effect on the five-year NPVs (net present values) because industry practice is to discount them 10 percent per year. Wood McKenzie said that the near-term effect on Permian reserves is relatively minimal, but by 2040, the firm says almost 800,000 BOPD of production will be at risk.

Lee questioned whether the wells in the study are really in terminal decline or somewhere between that and linear flow. He termed this sometimes lengthy interlude in flow dynamics "boundary influenced."

Lee added that industry may be prone to miscalculating reserves if it applies the theoretical Wattenbarger type curve to Permian Basin production. That model assumed short-duration, boundary-influenced, single-phase gas flow whereas the volatile, liquids-rich areas of the Permian experience multiphase flow.

Lee researched the Wood McKenzie claim further by analyzing it in a compositional model in a student-assisted simulation study. On a logarithmic scale, the results showed, boundary-influenced flow lasts two log cycles — a factor of more than 10 in duration.

"The effects of the boundaries are beginning to be observed. True boundary-dominated (BD) flow occurs later," said Lee. "There's just no evidence presented in the Wood McKenzie study that a well will stay on that decline for the remaining life. The evidence suggests we may be somewhere in the middle of transition and the final decline may be quite a few years into the future."

Three years ago, Lee also worked on a more rigorous compositional modeling study with one of his students that focused on fluid behavior in nano-pores. Under simulated conditions, the bubble point was depressed, GORs were compressed and relative permeability curves for gas and oil became less favorable to gas. Lee said that the key "takeaway" of that study was a very long-duration, boundary-influenced transition region. The study — published in SPE Paper 175137 in 2015 — was written by **M. Khoshghadam** et al.

Location, variation matter

Lee said, "I don't think we want to make the claim that 'one size fits all.' What kind of behavior we get when we go through bubble point (pressure) and what happens after that depend on fluid composition which varies with location."

He showed a map, published by Ground Truth Consulting LLC, indicating heterogeneity of oil production and GORs in several counties throughout the Midland Basin in the Permian. Ground Truth specializes in oilfield analytics.

Lee showed another slide by the consultant showing GORs and oil rates of four different wells in the Midland Basin. Two wells exhibited death by bubble point, two did not.

"This suggests perhaps we should minimize intuitive interpretations and proceed with a systematic, principles-based analysis," said Lee.

Physics-based models

"Back to science" is a rallying cry for evaluators who want to develop predictive geologic, reservoir-simulation and fracture-propagation models to help industry optimize field development in tight plays. To that end, the Berg-Hughes Center for Petroleum and Sedimentary Systems at Texas A&M and Core Labs plan to conduct a Delaware Basin study.

The objectives of that study are as follows:

- Develop physics-based models to predict rate and GOR and provide basis for decline curve and rate-transient analysis.
- Develop models to forecast rate and GOR as functions of time, cumulative production and other geoscience and engineering parameters.
- Determine geological controls (source, thermal history, maturity and pore size/type) on GOR and fluid composition of the reservoir using experimental and basin modeling tools.
- Infer controls and uncertainty in forecasted rates, GOR and fluid composition using data analytics.
- Predict recovery factors and how they vary regionally.

"Some organizations may lack time and resources to study the claims seriously. The joint project may assist many to reach logical, defensible conclusions," said Lee.

A sunset silhouettes a pump jack in the Permian Basin. Is oil extraction there soon-to-be a sunset industry? Those analyzing flow regimes say no.