2024 SPE-GCS Reservoir Study Group
[14 November 2024 — Houston, TX]

*Perspectives on the Reservoir Engineering Aspects of Unconventional Reservoirs and Thoughts on Petroleum Engineering Education**

** Qualifying Statement — These statements and comments are the expressed opinions / rantings of Thomas A. Blasingame and probably have nothing to do with reality. And if, by some miracle and/or influence of the quantum entity who rules the universe these statements / comments are somehow proven or become correct with the passage of time, this is purely coincidental.*

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Reservoir Engineering Aspects of Unconventional Reservoirs

Start-Up Thoughts

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"Heard on the Street" — Unconventional Reservoirs

Heard a While Back… (*originally compiled in early* 2019)

- "It's a Ponzi scheme" (1st *in get paid, last get nothing, those who stay can't stop drilling*)
- "Unconventionals = energy security of country name here." (*… all countries?*)
- "I only care about IRR and NPV" (*… mid-management + ?*)
- "The supermajors will own every independent before this is over" (*… maybe*)
- "Pump more sand, get more oil…" (*from a consultant's data analytics report*)
- "(oil recovered)/(frack water) has a positive correlation" (*from a recent workshop*)
- "We are the lowest cost, highest margin operator" (*heard often in past 3-4 months*)
- "We MUST understand parent-child well relationships ..." (*heard every day*)
- "How do we forecast EUR with 30/60/90-days of production?" (*… management*)

What We Hear Today… (*recent conversations*)

- "Unconventionals can work at USD 40/bbl" (*… why didn't it work at USD 60/bbl?*)
- "After bankruptcy we will … " (*… move in with your wife's parents?*)
- "Our data analytics says …" (*… you're broke?*)
- "It's the Saudis' fault" (*… you do know they're working in unconventionals too?*)
- "All the experience will be gone after this downturn" (*… we have been here before*)
- "I will never let my kids go into oil and gas" (*… we have heard this before*)
- "Shale is dead" (*… uh-huh, and let me know when Elvis gets here*)
- "US oil industry will be 30% smaller in 5 years (Feb 2020)" (*… missed it by 5 years*)

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Future of Reservoir Engineering — Unconventional Reservoirs

Comments … (*originally compiled in early* 2019)

- "Nano-scale ... Relevant? Essential? Figure it out later..." (*… %@$# academics!*)
- "Is the recovery factor just a concept?" (*for unconventionals*) (*… no comment*)
- "EOR in shales …" (*… everybody wants it, nobody knows how to do it*)
- "GOR(*t*) in shales ..." (*effect on reserves*) (*… is this really an issue?*)
- "Reservoir Characterization = DCA + economics ..." (*… "management" view*)
- "Reservoir Engineering = DCA + economics ..." (*… "management" view*)
- "Reservoir Management = DCA + economics ..." (*… "management" view*)
- "Reservoir Modeling" ([*mgmt says*] *…"takes 2 years and I still don't understand it"*)
- "Measure p_{wf} and T_{wf} at bottomhole conditions … " (*… you better listen to me*)

Things That are Obsolete (*i.e.,* need to be "killed") … (*recent*(*ish*) *conversations*)

- "Killing Darcy — NO Darcy flow in shales" (*… %@$# academics!*)
- "Killing Arps — DCA does not apply in shales" (*… %@$# academics!*)
- "Killing Horner — PTA does not apply in shale" (*… %@$# academics!*)
- "Killing Standing — Bulk PVT does not apply in shales" (*… %@$# academics!*)
- "Killing Peaceman— Macro-scale flow does not apply" (*… %@$# academics!*)

Predictions for 25 Years from Now … (*recent*(*ish*) *conversations*)

- "Reservoir Engineering" (*… still use PTA, RTA. Material Balance, IPR, & bulk PVT*)
- "Reserves" (*… still use Arps' and still fighting over proved, probable, possible*)
- "EOR" (*… still praising future of CO2 and surfactants, still believe in 70% RF*)
- "Reservoir Modeling" (*… still use Eclipse/CMG/etc. and want "more computing power"*)
- "Data Analytics" (*… still get 0% error in training, 50% error in prediction*)

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Reservoir Engineering Aspects of Unconventional Reservoirs

Where RTA Started … SPE 015028

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Where RTA Started …
Muskat's Work [SPE 15028 (1986)]

THE FLOW OF HOMOGENEOUS FLUIDS THROUGH POROUS MEDIA

BY

M. MUSKAT, PH.D.
Chief of Physics Division, Gulf Research & Development Company

SEC. 10.13] *THE FLOW OF COMPRESSIBLE LIQUIDS* 657

10.13. A Well in a Closed Sand.—If the sand is closed off ($f_e = 0$), and the pressure, and hence density, is initially uniform [$g(r) = \gamma_i$], and the flux at the well, $f_w(t)$, has the constant value q, γ is given by

$$\gamma = \gamma_i + q\left[\frac{3}{4} + \log \bar{r} - \frac{1}{2}(\bar{r}^2 + 4\bar{t}) + 2\sum \frac{J_0(x_n\bar{r})e^{-x_n^2\bar{t}}}{x_n^2 J_0^2(x_n)}\right], \quad (2)$$

Solution for the case of a vertical well in a bounded circular reservoir produced at a constant flowrate (Muskat [1937]).

SPE 15028

Variable-Rate Reservoir Limits Testing

by T.A. Blasingame and W.J. Lee, *Texas A&M U.*
SPE Members

$$p_D(r_D, t_D) = -\ln r_D - \frac{3}{4} + \frac{r_D^2}{2} + S + 2\pi t_{DA} - 2\sum_{n=1}^{\infty} \frac{J_o(X_n r_D)}{X_n^2 J_o^2(X_n)} \text{EXP}(-X_n^2 \pi t_{DA}) \quad \ldots(A\text{-}5)$$

where

$$r_D = r/r_e \quad \ldots(A\text{-}6)$$

X_n are the positive roots of $J_1(X_n) = 0$. (A-7)

$$t_{DA} = 0.0002637 \frac{kt}{\phi\mu c_t A} \quad \ldots(A\text{-}8)$$

$$A = \pi r_e^2 \quad \ldots(A\text{-}9)$$

Muskat solution in traditional reservoir engineering (dimensionless) variables (Blasingame and Lee [1986]).

Where RTA Started …
Material Balance Time Formulation [SPE 15028 (1986)]

SPE 15028

Variable-Rate Reservoir Limits Testing

by T.A. Blasingame and W.J. Lee, *Texas A&M U.*
SPE Members

Blasingame, T.A. and Lee, W.J.: "Variable-Rate Reservoir Limits Testing," paper SPE 15028 presented at the SPE Permian Basin Oil and Gas Recovery Conference, Midland, TX, 13-14 March 1986. https://doi.org/10.2118/15028-MS

Superposition Formulation Using Muskat Solution:

$$\frac{\Delta p}{q_m} = 141.2\,\frac{B\mu}{kh}\left[\ln\frac{r_e}{r_w} - \frac{3}{4} + \frac{r_w^2}{2r_e^2} + S\right] + 0.2339\,\frac{B}{\phi h c_t A}\,\bar{t}$$
$$-282.4\,\frac{B\mu}{kh}\left[\sum_{j=1}^{m}\frac{(q_j - q_{j-1})}{q_m}\sum_{n=1}^{\infty}\frac{J_o\left(\frac{X_n r_w}{r_e}\right)}{X_n^2 J_o^2(X_n)}\text{EXP}\left(-X_n^2\pi(0.0002637)\frac{k}{\phi\mu c_t A}(t-t_{j-1})\right)\right], \ldots(A\text{-}13)$$

Definition of Variable-Rate Time Plotting Function:

$\bar{t} = Q_m/q_m$ **("Material Balance Time")**

Key Assumption:

$\text{EXP}\left(-X_n^2\pi(0.0002637)\frac{k}{\phi\mu c_t A}(t-t_{j-1})\right)$ **→ 0 (large times)**

Final Relation:

$$\frac{\Delta p}{q_m} \cong 141.2\,\frac{B\mu}{kh}\left[\ln\frac{r_e}{r_w} - \frac{3}{4} + \frac{r_w^2}{2r_e^2} + S\right] + 0.2339\,\frac{B}{\phi h c_t A}\,\bar{t} \quad \ldots(A\text{-}14)$$

Discussion:
- **Variable-rate time (*i.e.*, Material Balance Time) creates an equivalent constant rate PSS response.**
- **Material balance time (in general) provides a zero-order deconvolution.**
- **Although developed as a means of assessing reserves, evolved into a diagnostic methodology.**
- **The "key assumption" condition is critical for the validity of the methodology.**

Where RTA Started …
Direct (Short-Cut) Derivations of the RTA and FMB Results

"Black Oil" Material Balance Relation:

$$\bar{p} = p_i - m_{o,pss}\,N_p \quad \left[\text{where: } m_{o,pss} = \frac{1}{Nc_t}\frac{B_o}{B_{oi}}\right]$$

"Black Oil" Boundary-Dominated Flow Relation:

$$\bar{p} = p_{wf} + b_{o,pss}\,q_o \quad \left[b_{o,pss} = 141.2\frac{\mu_o B_o}{kh}\left[\frac{1}{2}\ln\left[\frac{4}{e^{\gamma}}\frac{1}{C_A}\frac{A}{r_w^2}\right] + s\right]\right]$$

Rate Transient Analysiys (RTA) Form:

[Equating and solving for $(p_i - p_{wf})/q$ yields the required result]

$$\frac{(p_i - p_{wf})}{q} = b_{o,pss} + m_{o,pss}\frac{N_p}{q}$$
$$= b_{o,pss} + \frac{1}{N}\frac{B_o}{c_t B_{oi}}\bar{t} \quad \left[\bar{t} = \frac{N_p}{q}\right]$$

[slope yields $1/N$]

Flowing Material Balance (FMB) Form:

[Equating and solving for $q/(p_i - p_{wf})$ yields the required result]

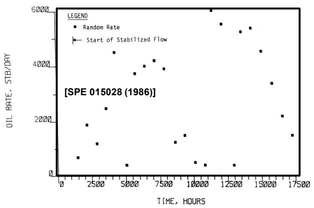
$$\frac{q}{(p_i - p_{wf})} = \left[\frac{1}{b_{o,pss}}\right] - \left[\frac{m_{o,pss}}{b_{o,pss}}\right]\frac{N_p}{(p_i - p_{wf})}$$
$$= \left[\frac{1}{b_{o,pss}}\right] - \left[\frac{1}{b_{o,pss}N}\right]\frac{B_o}{B_{oi}}\frac{N_p}{(p_i - p_{wf})c_t}$$

[x-intercept yields $N_{p,\max}$ (*i.e.*, *EUR*)]

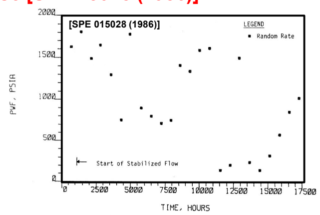
Blasingame, T.A. and Lee, W.J.: "Variable-Rate Reservoir Limits Testing," paper SPE 15028 presented at the SPE Permian Basin Oil and Gas Recovery Conference, Midland, TX, 13-14 March 1986. https://doi.org/10.2118/15028-MS

Mattar, L. and McNeil, R.: "The "Flowing" Gas Material Balance," paper number PETSOC-98-02-06, Feb 1998, Vol. 37, No. 2, Petroleum Society of Canada. https://doi.org/10.2118/98-02-06

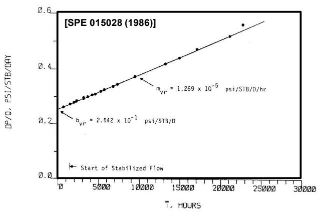
Where RTA Started …
Concept Validation Case [SPE 15028 (1986)]



Random flowing bottomhole pressure profile (synthetic case, numerical simulation) (Blasingame and Lee [1986]).



Random flowing bottomhole pressure profile (synthetic case, numerical simulation) (Blasingame and Lee [1986]).



Reciprocal productivity index versus variable-rate time plotting function (now known as material balance time) generated using a randomized rate profile (synthetic case, numerical simulation) (Blasingame and Lee [1986]).

Discussion:

- Exhaustively modeled a number of rate scenarios (different functional forms as well random and square wave rate cases).
- Conceptually, if the random rate case can be shown to work, then the methodology should apply to all rate scenarios.
- In reality, the methodology works when the influence of the rate changes is less than the prevailing flow behavior (i.e., pseudosteady-state flow).

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Reservoir Engineering Aspects of Unconventional Reservoirs

A Few Recent Developments …

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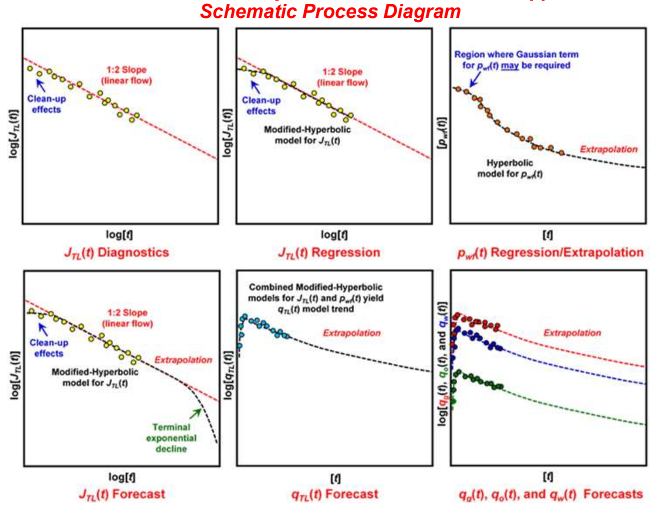
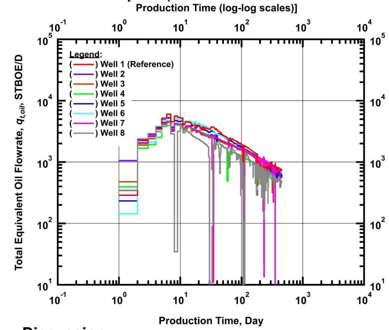
URTeC ID-2019-178 — Hybrid Time-Rate-Pressure Approach
Schematic Process Diagram



Jones, M.R. and Blasingame, T.A.: "A Direct Method for Short-Term Forecasting of Multiphase Production Rates Using Flowback Data" paper Control ID: 178 presented at the 2019 Unconventional Resources Technology Conference in Denver, CO, 22-24 July 2019. https://doi.org/10.15530/urtec-2019-178

URTeC ID-2022-3724101 — Multiwell DCA Type Curve Approach
Matching Oil Rate Cases to a Reference Well

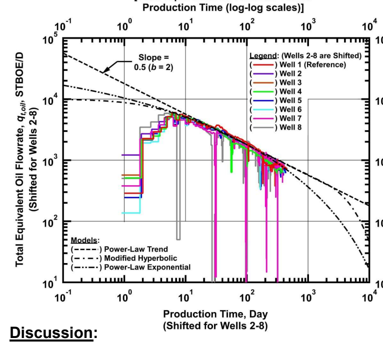
q_o vs. t Plot (log-log)
All wells are UNSHIFTED.



Discussion:

- Unshifted rate data shows similar "character," red trend is reference (Well 1).
- Well "shifts" are performed by hand, similar character leads to relatively minor shifts.

q_o vs. t Plot (log-log)
All wells SHIFTED to the reference well (Well 1).

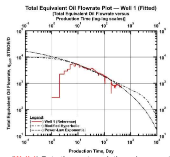


Discussion:

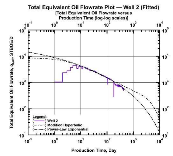
- Slope of 1/2 (0.5) is very well-defined.
- Modified Hyperbolic DCA match is very good.
- Power-Law Exponential DCA match is excellent.

Blasingame, T.A.: (2022) "Multiwell Decline Curve Analysis Using a Type Curve Approach" paper Control ID: 2022-3724101 presented at the 2022 Unconventional Resources Technology Conference, Houston, TX, 20-22 June 2022. https://doi.org/10.15530/urtec-2022-3724101

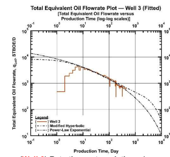
URTeC ID-2022-3724101 — *Multiwell DCA Type Curve Approach Matching Oil Rate Cases to a Reference Well*



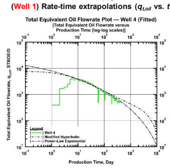
(Well 1) Rate-time extrapolations ($q_{o,eq}$ vs. t).



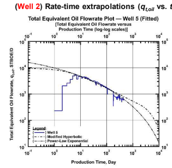
(Well 2) Rate-time extrapolations ($q_{o,eq}$ vs. t).



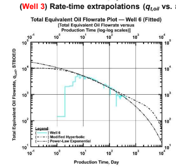
(Well 3) Rate-time extrapolations ($q_{o,eq}$ vs. t).



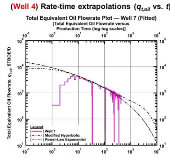
(Well 4) Rate-time extrapolations ($q_{o,eq}$ vs. t).



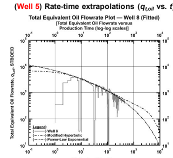
(Well 5) Rate-time extrapolations ($q_{o,eq}$ vs. t).



(Well 6) Rate-time extrapolations ($q_{o,eq}$ vs. t).



(Well 7) Rate-time extrapolations ($q_{o,eq}$ vs. t).



(Well 8) Rate-time extrapolations ($q_{o,eq}$ vs. t).

$$q_{well}[t] \equiv \frac{1}{y_{shift}} q_{reference}\left[\frac{t}{x_{shift}}\right]$$

Discussion:
- "Deconstruction" of reference trend performed using "inverse transform" given above.
- MH model → very good results.
- PLE model → exceptional results.

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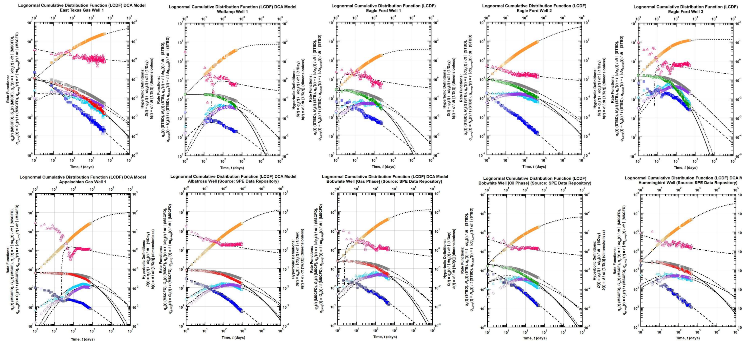
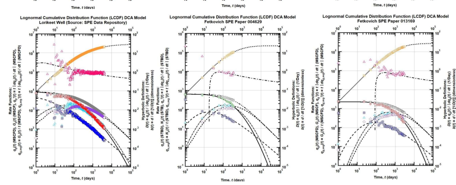
URTeC—2023-3870942 — *The Lognormal Cumulative Distribution Function (LCDF) A Statistical Approach for Decline Curve Analysis*





Governing Relation: *LCDF DCA Model*

$$q_{LCDF}(t) = q_{i,LCDF}\left[1-\left[\frac{1}{2}+\frac{1}{2}\operatorname{erf}\left[\frac{\ln(t)-\mu_{LCDF}}{\sqrt{2}\,\sigma_{LCDF}}\right]\right]\right]$$

Waters, D., Bryan, E.W., Symmons, D., Ilk, D. and Blasingame, T.A.: (2023) "The Application of the Lognormal Cumulative Distribution Function (LCDF) for Time-Rate Interpretation and Forecasting of Wells in Unconventional Reservoirs" paper Control ID: 2023-3870942 presented at the 2023 Unconventional Resources Technology Conference, Denver, CO, 13-15 June 2023. https://doi.org/10.15530/urtec-2023-3870942

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Reservoir Engineering Aspects of Unconventional Reservoirs

Evolution of Unconventional Reservoir Technologies

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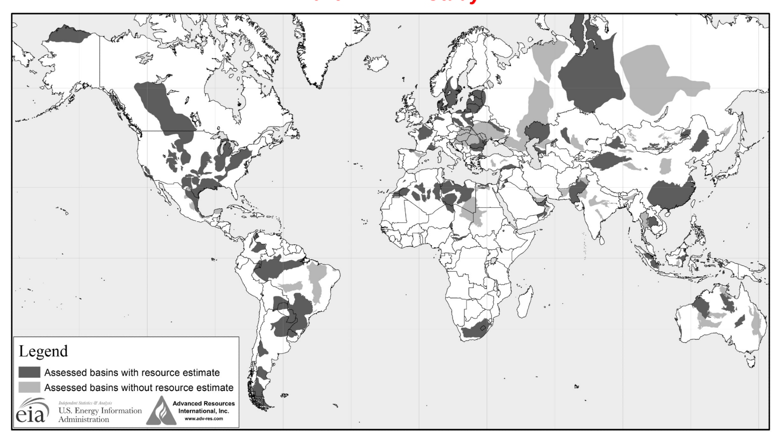
Where are the Shale Resources? 2015 EIA-ARI Study



(2015)

Discussion:
- Current major developments in Middle East (SA, BH, OM), China (CN), and Argentina (AR).
- Evolving developments in North Africa (DZ) and Australia (NT).
- Development costs are a multiple of the US-shale plays, which is a major impediment.

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Recent Technologies Applied to Unconventional Reservoir Development
Assessment of Urgent and Technical Challenges

Most Urgent Technical Challenges:

- *Completion optimization for enhanced hydrocarbon recovery.*
- Quantitative description of heterogeneity.
- Should we care about the rock permeability?
- *Increasing water-production/WOR and increasing GOR with time.*
- *Parent-child relationship — depletion impacts on the child well.*

Most Important Technical Challenges:

- Improving average EUR and productivity.
- Multiphase flow at multiple scale of pores/fractures [or GOR(t)].
- *Placement of wells/clusters/stages for optimal EUR/recovery.*
- Oil sweet-spot characterization for infill drilling.
- *EOR technologies for tight oil reservoirs.*
- *Impact/importance of artificial lift selection and operations.*
- Validity of EUR's using 30/60/90-days of production data?

Relating the Present with the Past:

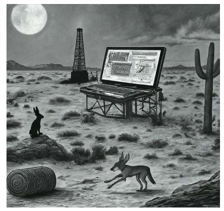
- *Can we/do we obtain consistent results from data analytics?*
- Improvements in rock characterization, fracturing, and production.
- Microseismic needs more fundamental work (happening now?).
- *Economics, disruptive changes, etc. versus the "herd mentality."*

Data/Information Needed and Will be Needed:

- *Distributed pressure and temperature measurements.*
- High accuracy bottomhole pressure measurements in every well.
- Reservoir simulation as a reliable technology (for SEC).
- Continuous and accurate well flowrate measurements.
- *Need an industry/academia data repository.*
- Detailed geochemical mapping of intervals to SRV.
- Need more deployments of intelligent field technologies.

Crowd-Sourcing Exercise (08-09 October 2017)

Data Analytics in the Permian Basin (ChatGPT-4o).



Data Analytics in the Permian Basin (Gemini).

Discussion:
- **Improvement of drilling efficiency.**
- **Optimization of completion techniques.**
- **Integration of data-driven decisions and high-fidelity data.**

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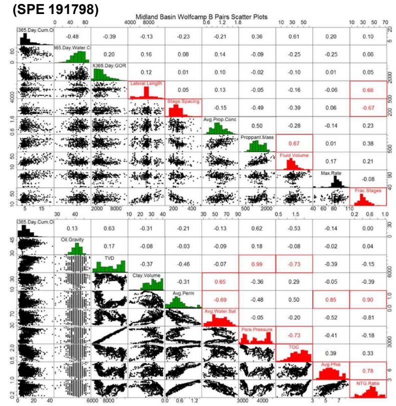
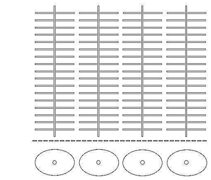
Recent Technologies Applied to Unconventional Reservoir Development
Data Analytics — Monitoring and Correlations

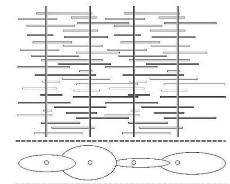
(SPE 191798)



Correlation of Completion, Reservoir, and Petrophysical Properties.



Optimal Completion.



Non-Optimal Completion.

Discussion:
- **Consistency in results from data analytics.**
- **Improvements in production characterization and correlation.**
- **Addressing microseismic and other monitoring needs.**

Presenter's Disclaimer:
"I am only the messenger,"
I am NOT showing this diagram to start a fight, but it one starts, it will be good for my ratings.

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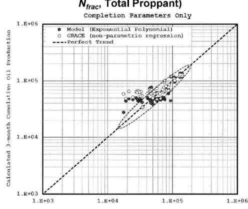
Recent Technologies Applied to Unconventional Reservoir Development
Performance = (Lateral Length, Well Spacing, # Fracture Stages, Cluster Spacing, Proppant Volume)

$N_{p,3\text{-month}} = f$(Clusters/Stage, Lateral Length, N_{frac}, Total Proppant)

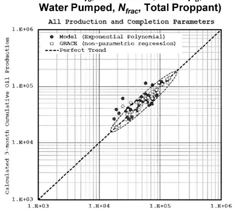



```
y = EXP[C0
     + C1*ln(x1)            + C2*ln(x2)
     + C3*ln(x8)            + C4*ln(x7)
     + C5*ln(x1)*ln(x2)  + C6*ln(x1)*ln(x7)
     + C7*ln(x1)*ln(x8)  + C8*ln(x2)*ln(x7)
     + C9*ln(x2)*ln(x8)  + C10*ln(x7)*ln(x8)
     + C11*ln(x1)*ln(x2)*ln(x7)
     + C12*ln(x1)*ln(x2)*ln(x8)
     + C13*ln(x1)*ln(x7)*ln(x8)
     + C14*ln(x2)*ln(x7)*ln(x8)
     + C15*ln(x1)*ln(x2)*ln(x7)*ln(x8)]

x1 = Clusters per Stage
x2 = Lateral Length
x7 = # Fracture Stages
x8 = Total Proppant
y  = 3-month Cum Oil Prod
```

Discussion: (Crl = 29.8 %, GRACE = 24.6%)
- This correlation fails at low values of 3-month Cumulative Oil Production.
- Completion parameters are insufficient to define behavior.
- Interesting that both the model correlation and the GRACE correlation confirm this behavior.

$N_{p,3\text{-month}} = f$(Clusters/Stage, Lateral Length, Max q_o, Max Choke, Initial p_{tf}, Water Pumped, N_{frac}, Total Proppant)

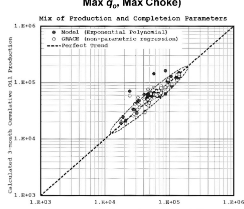



```
y = C10*(FCN_X-C9)^C11
    FCN_X = C0*(x1^C1)*(x2^C2)*(x3^C3)
              *(x4^C4)*(x5^C5)*(x6^C6)
              *(x7^C7)*(x8^C8)

x1 = Clusters per Stage
x2 = Lateral Length
x3 = Maximum Oil Rate
x4 = Maximum Choke (64 ths)
x5 = Initial Surface Pressure
x6 = Barrels of Water Pumped
x7 = # Fracture Stages
x8 = Total Proppant
y  = 3-month Cum Oil Prod
```

Discussion: (Crl = 20.1 %, GRACE = 9.5%)
- Includes all parameters.
- GRACE (non-parametric) correlation gives < 10 percent error.
- Power-Law correlation model is insufficient to capture inter-relationships of parameters (> 20 percent error).

$N_{p,3\text{-month}} = f$(Clusters/Stage, Lateral Length, Max q_o, Max Choke)




```
y = EXP[C0
     + C1*ln(x1)            + C2*ln(x2)
     + C3*ln(x8)            + C4*ln(x7)
     + C5*ln(x1)*ln(x2)  + C6*ln(x1)*ln(x7)
     + C7*ln(x1)*ln(x8)  + C8*ln(x2)*ln(x7)
     + C9*ln(x2)*ln(x8)  +
C10*ln(x7)*ln(x8)
     + C11*ln(x1)*ln(x2)*ln(x7)
     + C12*ln(x1)*ln(x2)*ln(x8)
     + C13*ln(x1)*ln(x7)*ln(x8)
     + C14*ln(x2)*ln(x7)*ln(x8)
     + C15*ln(x1)*ln(x2)*ln(x7)*ln(x8)]

x1 = Clusters per Stage
x2 = Lateral Length
x3 = Maximum Oil Rate
x4 = Maximum Choke (64 ths)
y  = 3-month Cum Oil Prod
```

Discussion: (Crl = 16.7 %, GRACE = 14.4%)
- This can be thought of as a "balanced" model, with both production and completion parameters.
- Maximum oil rate and maximum choke setting exert a strong influence.
- Good comparison of Model and GRACE statistics.

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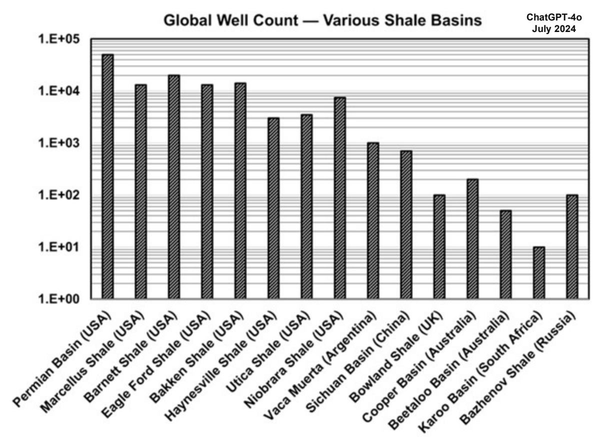
Recent Technologies Applied to Unconventional Reservoir Development
State of Development — Global Shale Basins



Discussion:
- **Differences in deployment levels compared to North America.**
- **Ongoing need for development of people and technology.**
- **Emphasis on continuous improvement and innovation (particularly in well completions).**

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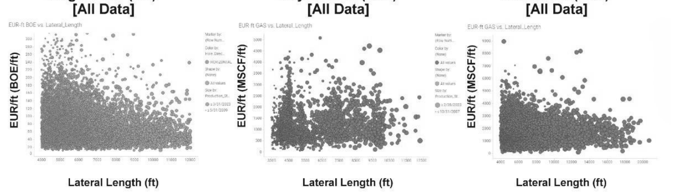
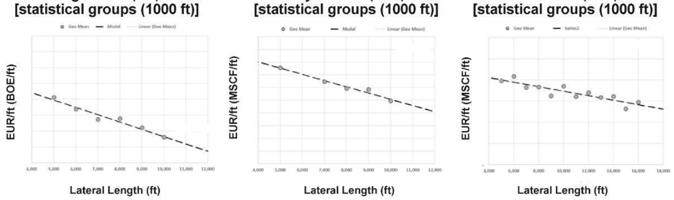
Visions for Unconventional Reservoir Development
EUR/ft vs. Lateral Length (Gas)

Eagle Ford (Oil) [All Data] — **Haynesville (Gas) [All Data]** — **Marcellus (Gas) [All Data]**



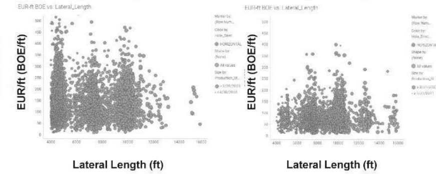
Eagle Ford (Oil) [statistical groups (1000 ft)] — **Haynesville (Gas) [statistical groups (1000 ft)]** — **Marcellus (Gas) [statistical groups (1000 ft)]**



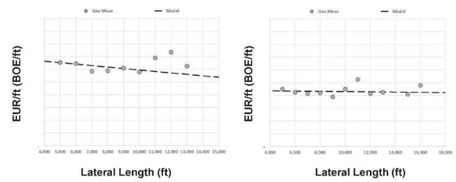
Discussion:
- Advancements in drilling and well completions.
- Opportunities for enhanced oil recovery (EOR) applications.
- Development of new reservoir characterization methods.

Visions for Unconventional Reservoir Development
EUR/ft vs. Lateral Length (Oil)

Wolfcamp-Delaware (Oil) [All Data] — **Wolfcamp-Midland (Oil) [All Data]**



Wolfcamp-Delaware (Oil) [statistical groups (1000 ft)] — **Wolfcamp-Midland (Oil) [statistical groups (1000 ft)]**



Discussion:
- Integration of renewable energy and unconventional resources.
- Role of carbon capture and storage (CCS).
- Strategic development opportunities such as LNG. (*using unconventional gas*)

Visions for Unconventional Reservoir Development
Major Plays, Technical Applications/Needs, Impact on Society …

Locations of Major Shale/Unconventional Plays:
- US: DELW, MIDL, EGFD, BKKN, MARC, UTCA …
- CA: Montney, Duvernay, …
- AR: Vaca Muerta, Neocomiano, Inoceramus
- CN: Sichuan Basin, Ordos Basin
- AU: Cooper, Canning, Beetaloo, Georgina
- RU: Bazhenov

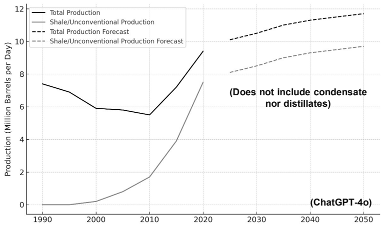
Technical Applications/Developments:
- Advances in Hydraulic Fracturing.
- Digital and Automation Technologies.
- Asynchronous and Real-Time Analytics.
- Cost-Effective Monitoring (all aspects).

Required Technical Needs/Advances:
- EOR (Rich/Lean Gas, Solvent, CO_2, ???)
- Water Management (Use, Recycling, Disposal).
- Methane/CO_2 Mitigation
- Remote Power (mostly US?)

Impact on the Global Oil and Gas Supply:
- Increased security of supply. (*good for market*)
- Diversity of supply. (*good for market*)
- Potential to meet demand for next 50-100 years.
- Local/regional economic benefits.
- Low-carbon focus will be required.

(ChatGPT-4o)

Schematic Illustration of Global Shale Plays.



US Oil Production — 1990-2050

2024 SPE-GCS Reservoir Study Group
[14 November 2024 — Houston, TX]

Thoughts on Petroleum Engineering Education

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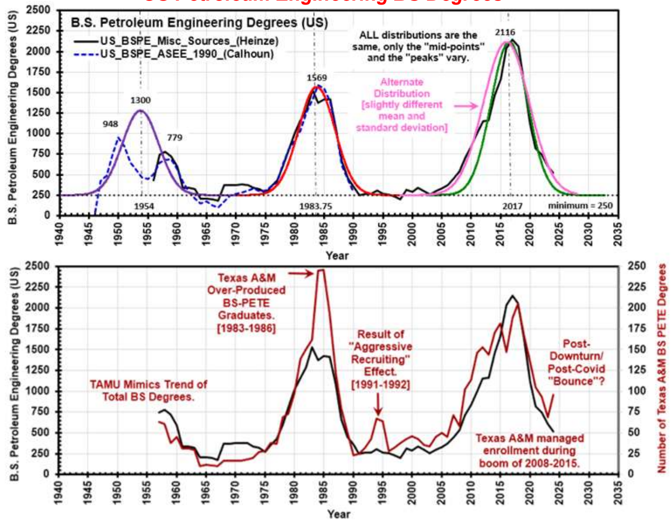
Historical Trends
US Petroleum Engineering BS Degrees



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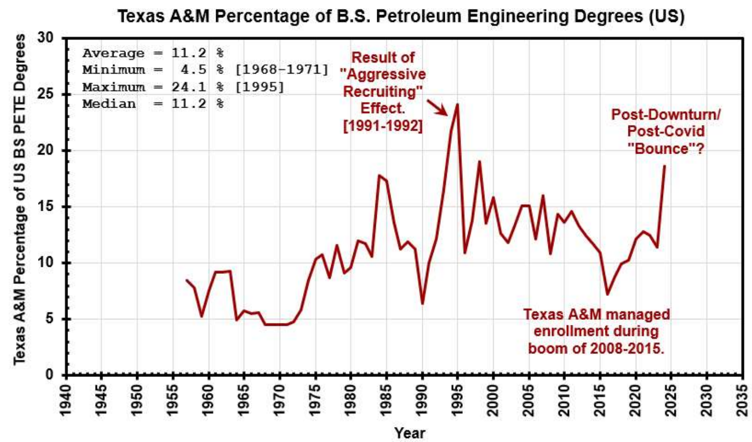
| 2024 SPE-GCS RSG | *Reservoir Engineering Aspects of Unconventional Reservoirs and Thoughts on Petroleum Engineering Education* | | Thursday 14 November 2024 |

Historical Trends
Where is Texas A&M in Percentage Terms of PETE Degrees?



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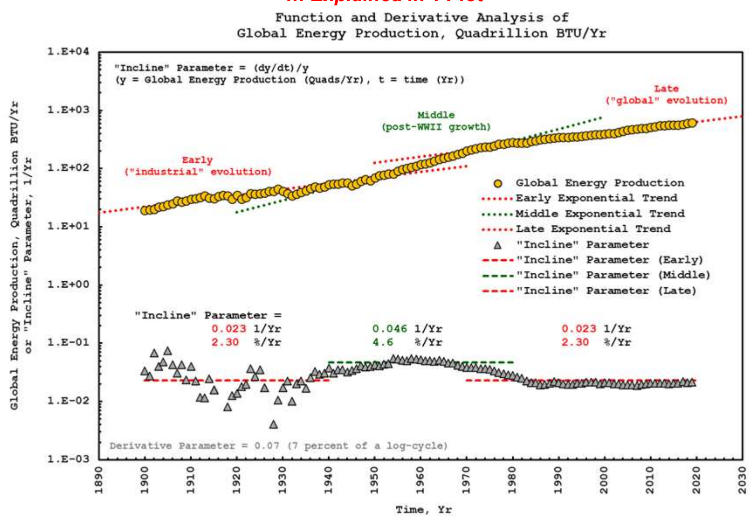
Global Energy Production
… Explained in 1 Plot



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| 2024 SPE-GCS RSG | *Reservoir Engineering Aspects of Unconventional Reservoirs and Thoughts on Petroleum Engineering Education* | | Thursday 14 November 2024 |

Future of Petroleum Engineering
Petroleum Engineering Education Workshop (August 2024) [*ChatGPT4o Extraction*]

Fundamentals Remain Essential and Curriculum Modernization:
- Core petroleum engineering subjects like fluid flow, thermodynamics, and reservoir characterization continue to be foundational.
- Curricula should integrate transition technologies and digital tools such as AI, machine learning, and generative AI for enhanced student preparation.
- Emerging fields like CCUS, geothermal energy, and hydrogen must be incorporated into elective sequences or new certifications to stay relevant.

Adaptability and Continuous Learning:
- Graduates must adopt a mindset of lifelong learning to navigate the rapid changes in the energy sector.
- Universities should promote student autonomy through elective courses, certifications, and interdisciplinary projects.
- Programs should foster adaptability, equipping students to transition between technical roles and business or management roles.

Multidisciplinary Collaboration and Soft Skills:
- The energy sector increasingly demands employees capable of working in multidisciplinary teams with engineers from other fields.
- Soft skills, including communication, teamwork, and project management, are essential for navigating complex team environments.
- Business acumen and the ability to collaborate across diverse teams will enhance career flexibility and effectiveness in industry roles.

Industry-Academia Collaboration:
- Universities should prioritize partnerships with industry to stay ahead of market trends, ensuring students gain relevant knowledge.
- Programs should seek feedback from industry to identify critical skill gaps and align course offerings with evolving workforce needs.
- Examples like the GeoNetZero Centre in the UK illustrate the importance of collaboration over competition among institutions.

Sustainability and Energy Transition Integration:
- Petroleum engineering programs should embed topics like CCUS, hydrogen systems, and energy resource economics into their core curricula.
- Students must be prepared to work on projects involving a mix of conventional and renewable energy sources, with an understanding of carbon pricing and policy frameworks.
- Addressing methane leakage, well abandonment, and emissions management should be key components of the curriculum.

Career Flexibility and Pathway Diversity:
- Students should have access to specialized minors or certificates in sustainable energy or emerging energy systems to diversify their expertise.
- Graduates need the ability to switch between technical and managerial roles, reflecting the evolving nature of the industry.
- Universities must prepare students to succeed in multidisciplinary roles that blend traditional and non-traditional fields.

Addressing Enrollment and Workforce Challenges:
- Programs need to actively combat negative public perceptions and declining enrollments by promoting the value of petroleum engineering careers.
- Outreach initiatives aimed at younger students can help raise awareness about the importance of energy engineering in the transition era.
- Industry participation in internships and mentoring programs will be critical to attracting and retaining talent in the sector.

Public Awareness and Industry Perception:
- Petroleum engineering programs must highlight the role of hydrocarbons in energy transition to counteract public skepticism.
- Promoting the sector’s contribution to sustainable energy development and environmental management is essential.
- Engaging with policymakers and communities can enhance the public image and relevance of petroleum engineering.

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Future of Petroleum Engineering
Petroleum Engineering Education Workshop (August 2024) [*Gemini Extraction*]

Fundamentals Remain Essential and Curriculum Modernization:
- Core petroleum engineering subjects like fluid flow, thermodynamics, and reservoir characterization continue to be foundational.

Modernizing Petroleum Engineering Curricula:
- Retain core subjects: Fluid mechanics, reservoir characterization, thermodynamics.
- Integrate energy transition technologies: CCUS, geothermal energy, hydrogen systems.
- Incorporate digital skills: AI, machine learning, data analytics.
- Address emerging challenges: Methane leakage, well abandonment.

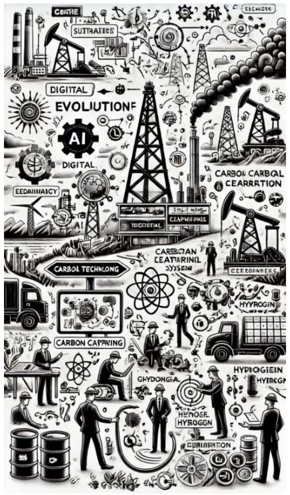
Fostering Lifelong Learning and Adaptability:
- Cultivate a mindset of continuous learning in a dynamic industry.
- Encourage career flexibility and exploration of diverse energy sectors.
- Provide opportunities for specialization: Minors, certifications in sustainable energy or energy systems.

Strengthening Industry-Academia Collaboration:
- Partner with industry on evolving workforce needs.
- Secure research funding in key areas: Geothermal, solar, carbon sequestration.
- Promote collaborative research initiatives and knowledge sharing between universities.

Developing Essential Skills for the Future Workforce:
- Emphasize multidisciplinary teamwork and collaboration.
- Cultivate soft skills: Communication, project management, and business acumen.
- Address skill gaps through micro-learning experiences and Innovation Labs.

Promoting Public Awareness and Student Engagement:
- Highlight the role of petroleum engineering in a sustainable energy future.
- Counteract negative perceptions of the oil and gas industry.
- Attract and retain talent by showcasing diverse career pathways.

Addressing Enrollment and Retention Challenges:
- Emphasize the long-term value and transferability of petroleum engineering skills.
- Demonstrate the applicability of these skills across various energy sectors.
- Prepare graduates for a complex regulatory environment and evolving energy policies.



A Future View or Petroleum Engineering

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2024 SPE-GCS Reservoir Study Group
[14 November 2024 — Houston, TX]

Blasingame Bio

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Brief Biography
Tom Blasingame (2024)

Role:
- Professor, Texas A&M U.
- B.S., M.S., Ph.D. from Texas A&M U.

Counts: (February 2023)
- 200+ Technical Articles
- 18 Ph.D. Graduates
- 79 M.S. (thesis) Graduates


[2022] (Tom in natural habitat)


[2019] (China visa photo)


[2012] (civilized photo)


[self-image] (2008)


[how others see me]

Historical Technical Contributions:
- (1980's) Material Balance DCA [so-called "Rate Transient Analysis" (or RTA)]
- (1990's) Analysis of Water-Oil-Ratio (WOR) Behavior
- (1990's) Direct Estimation of Average Reservoir Pressure from Pressure Buildup Tests
- (2000's) Pressure Integral and "Beta" Derivative for PTA and RTA Methodologies
- (2000's) DCA and CEUR Relations for Unconventional Reservoirs
- (2010's) Diagnostic Analysis of Time-Rate Data [*i.e.*, the *qDb*-plot]
- (2020's) Unconventional Reservoir Engineering [PVT, Petrophysics, Diagnostics, RTA, PTA]
- (career) Correlations for Rock and Fluid Properties
- (career) Deconvolution Methods [approximate, direct, and numerical]

Historical Professional Recognition:
- SPEi Distinguished Member (2000)
- SPEi Distinguished Service (2005)
- SPEi Uren Award (2006)
- SPEi Lucas Medal (2012)
- SPEi DeGolyer Service Medal (2013)
- SPEi Distinguished Faculty Award (2014)
- SPEi Honorary Member (2015)
- SPEi Director (Reservoir) (2015-2018)
- SPEi President (2021)

Research Interests:
- PTA/RTA/DCA in Unconventional Reservoirs
- Unconventional Reservoir Fluids
- Numerical Analysis/Interpretation of Data
- Analytical Solutions for Reservoir Behavior
- CCS Project Management
- Injection Well Analysis
- Data Diagnostics for Well Performance
- Multi-Well Performance Aspects (Unconventionals)
- Field Development Strategies (Unconventionals)
- Energy Transition/Addition

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Tom + RTA
(History of being the "father" of Well Performance Analysis (WPA) [aka "RTA"])

History:

(1983) Visited with Dr. John Lee (TAMU) (senior project idea). *(variable-rate PBU analysis)*
(1984) Started playing with DCA, wrote a computer program in BASIC. *(it was junk, but ...)*
(1984) Realized that DCA + pressure could be like PTA. *(seed was planted)*
(1985) Using numerical model, simulated every case I could think of. *(empirical attack)*
(1985) Dr. Lee told me my idea was crap unless I could prove it analytically. *(big frown)*
(1985) Spent summer working on analytical proof. *(thank God for Muskat)*
(1986) SPE 015028 (MBT → *N* [also *FMB oil*]) *(the audience was kind, but zero traction)*
(1987) SPE 017708 (MBT → *G*) *(same reaction … interesting, but "so what")*
(1991) SPE 021513 (DCA Type Curves — Variable Rates/Pressures) *(… "what's this?")*
(1992) Phone call from Fetkovich. *("Boy, you need to plot data as q/Δp, NOT Δp/q")*
(1993) SPE 025909 (DCA Type Curves [gas]) *("official birth" of RTA [and FMB gas])*
(1994) SPE 028688 (WPA — Bounded Circular Reservoir) *(the complete "RTA" suite)*
(1994) SPE 029572 (WPA — Horizontal Wells) *(student was very smart)*
(1995) SPE 030774 (WPA — Water Influx/Waterflood) *(... waterfloods)*
(1996) SPE 035205 (WPA — Fractured Wells [Infinite F_{cD} case]) *(... fractured wells)*
(1997) Wrote first "RTA" program ("WPA") [in FORTRAN!] *(gave away as "shareware")*
(2001) SPE 071517 (WPA — Multi-Well) *(the clouds parted, this really helped)*
(2003) SPE 084287 (WPA — Fractured Wells [Finite F_{cD} case]) *(needed this tool)*
(2007) SPE 106308 (WPA — Elliptical Fracture [Finite F_{cD} case]) *(transition flow regimes)*
(2007) SPE 110187 RTA in tight gas reservoirs. *(perfect application for RTA)*
(2010-) Numerous "field studies" using RTA in unconventional plays. *(… applications)*
(2018) PTA/RTA model for a multi-fracture horizontal well in a fractal reservoir. *(… proxy)*

Future:

(????) Have we taken time-rate-pressure diagnostics to the limit? *(… I have to ask)*

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Tom + PTA
(Anybody can analyze short-time events, right?)

History:

- (1983) First PTA course. *(not exactly love at first sight)*
- (1984) Graduate PTA course. *(the love affair began)*
- (1989) SPE 018799 ("pressure integral" method) *(thought it was genius, it wasn't)*
- (1989) SPE 019099 ("direct" deconvolution method) *(hint: material balance time for PTA)*
- (1991) SPE 021826 ("semi-analytic" solution for WBS) *(thought it would change the world)*
- (1993) SPE 026424 ("semi-analytic" solution for a finite-conductivity fracture) *(… cheated)*
- (1994) SPE 027685 (case history on injection/fall-off analysis) *(just though I'd mention it)*
- (1995) SPE 029584 (V_p from PBU — pressure derivative) *(clever, but impractical?)*
- (1997) SPE 038725 (p_{avg} from PBU — pressure derivative) *(proof of Muskat-Arps method)*
- (1999) SPE 056487 (case history on PTA at Arun Field) *(applied everything I knew)*
- (2003) SPE 084374 (variable mobility for gas condensates) *(heavy math/practical result)*
- (2003) SPE 084475 (co-application of *PTA* and *RTA*) *(RTA in tight gas reservoirs)*
- (2005) SPE 095571 (deconvolution using regularization) *(full credit to Ilk and Valko)*
- (2006) SPE 100578 (fracture injection/falloff model) *(full credit to Craig)*
- (2006) SPE 103204 (β-pressure derivative) *(simple — but unique for power-law regimes)*
- (2006) SPE 103216 (direct WBS deconvolution) *(simple — but too "approximate")*
- (2015-) Several "consultations" on well interference in shales. *(… sorry, confidential)*
- (2020) PTA in shales ... *(several efforts, all roads lead to WBS + power-law regimes)*
- (2024) PTA for injection *(PTA applications/methodologies for water and CO_2 injection)*

Future: (all comments for unconventional reservoirs)

- (????) What other data can we incorporate in PTA? *(… temperature?)*
- (????) Can we "pulse test" the reservoir (and what does it mean)? (SPE 191407 [PXD])
- (????) Can we quantify well interference and/or "frac-hits" *(… keeps me up at night)*

Tom + DCA
(It's just rate versus time, don't overthink it.)

History:

- (1986) SPE 015018 (DCA → reservoir engineering) *(hey, it was my first paper)*
- (1996) SPE 035268 (semi-analytic gas flow relation) *(very accurate result)*
- (2002) SPE 077550 (application semi-analytic gas flow relation) *(… for reserves)*
- (2005) SPE 098042 (direct solution of Arps relations) *(full derivation of Arps)*
- (2008) CIM 2008-108 (DCA — "Power-Law Exponential") *(origin/application)*
- (2009) SPE 123298 (direct estimation of reserves) *(simple approach)*
- (2009) CIM 2009-202 (DCA — power-law $b(t)$ relations) *(extension of PLE)*
- (2010) SPE 132352 (continuous EUR approach) *(computation of EUR(t))*
- (2010) SPE 135616 (DCA — "hybrid" DCA relations) *(Ilk DCA relations)*
- (2012) Student work (Askabe [MS] Duong and LGM models) *(added terminal decline)*
- (2013) SPE 167242 (DCA — "Transient Hyperbolic") *(2-part hyperbolic relation)*
- (2014) SPE-170945 (DCA — variable Δp case) *(robust methodology)*
- (2016) URTeC 2461766 ("Time Cumulative" DCA relations) *(family of Q(t) relations)*
- (2017) URTeC 2698457 ("well clean-up" model) *(more of a concept model)*
- (2019) URTeC 2019-178 (hybrid $q(t)$ and $p_{wf}(t)$ DCA approach) *(clever and effective)*
- (2020) Student work (PETE 648 [assigned to create a DCA model]) *(very innovative)*
- (2021) URTeC 2021-5519 ("rate-integral" DCA) *(data smoothing/interpretation)*
- (2023) URTeC 2023-3870942 (DCA — "Lognormal Cumulative Distribution") *(statistical model)*

Future:

- (????) Try to derive "mechanistic" DCA models? *(… may not conform to observations)*
- (????) Consider other data transforms for DCA applications? *(… longshot, but maybe)*
- (????) Continue to incorporate pressure into DCA? *(… $p_{wf}(t)$ model requires calibration)*
- (????) More "new DCA models?" *(… need some element of rigor/rationale)*

Tom + data analytics
("a love[-hate] story")

History:

- (1983) First course in Numerical Methods. *(Hoped it was my last, it wasn't)*
- (1984) Programmed decline curve analysis in Basic language. *(Don't ask)*
- (1986) (spring) "Optimization" Course. *(Worst teacher (+ grade) in grad school)*
- (1986) (summer) Taught myself non-linear optimization. *(best experience, ever)*
- (1986) (summer/fall) Application of non-linear optimization. *(deconvolution)*
- (1988) Non-linear optimization for Laplace transform inversion. *(reinvented the wheel)*
- (1988) Non-linear optimization for pressure transient analysis. *(believe it or not)*
- (1991) Non-linear optimization for approximate fracture model. *(kind of clever)*
- (1995) (black oil) PVT correlations. *(updates to industry standard models)*
- (1997) Non-parametric regression. *(I was along for the ride, but very important work)*
- (2002) (natural gas) PVT correlations. *(massive database + new correlations)*
- (2005) Non-linear least squares + regularization (for deconvolution). *(… student work)*
- (2005) (and 2016) p_c correlations. *(large database + new correlations)*
- (2006-) Petrophysical correlations. *(k, ϕ, S_{wi}, V_{sh}, F, etc.)*
- (2010-) (numerous projects) New DCA relations. *(… student work)*
- (2018) Tikhonov Regularization in transient derivative analysis. *(… student work)*
- (2019) Use of the numerical Laplace transform for data smoothing. *(… student work)*
- (2020) Deconvolution and derivatives and noise reduction. *(… student work)*

Future:

- (????) Learn something other than Fortran or Excel. *(old dog + new tricks?)*
- (????) Be a "Data Analytics" expert. (… *instead of a data diagnostics expert*) *(… nope)*
- (????) Create new data models and interpretation schemes. *(old dog + old tricks)*
- (????) Truly understand non-parametric data correlations. *(I wish I had the brains)*

2024 SPE-GCS Reservoir Study Group
[14 November 2024 — Houston, TX]

Perspectives on the Reservoir Engineering Aspects of Unconventional Reservoirs and Thoughts on Petroleum Engineering Education

End of Presentation

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