The Society of Petroleum Evaluation Engineers
SPEE Denver Chapter announces its July Luncheon Meeting.
(Members and Guests are cordially invited to attend.)

Thursday, July 27, 2017

Mr. Randy Freeborn
Chief Research Engineer, Energy Navigator, Inc.

Will be speaking on:
Production Rate Scaling Principles for use in Type Well Construction

LUNCHEON STARTS AT 11:30 A.M.
(A plate lunch will be served.)
PRESENTATION BEGINS AT NOON

The Denver Athletic Club
3rd Floor, The New Petroleum Club Room
1325 Glenarm Place (14th and Glenarm) Denver CO 80204
Parking flat rate $7.00 on space available basis

Cost: $25.00 per Person
Special pricing of $25 continued into 2017. Normally $35.

Please RSVP by Noon Tuesday, July 25, 2017

RSVP and simultaneously pay by credit card online at:
https://secure.spee.org/civicrm/event/info?reset=1&id=137
If the above link does not work, alternatively go to www.spee.org then select ‘Local Chapters’, then ‘Denver’, then ‘Register Now’.
Production Rate Scaling Principles for Use in Type Well Construction

Randy Freeborn, P. Eng.
July 2017
Topics

Sample Size Matters

Scaling to get more analogs
- Time to end of linear flow
- Well length
- Number of fractures
- Permeability

Diagnostics
- Estimate unknown parameters for a well
- Scale a well’s data to your planned drilling and completion design
Sample Size Matters
Sample Size Matters?

We bin to get representative wells
  • Drilling longer wells
  • More fractures, greater fracture density
  • Bigger fractures, both volume and proppant
  • Sweet spots are getting drilled up

How does sample size influence accuracy?
  • Each new bin halves the sample size
  • Scaling may provide representative wells without binning?
  • Trade off: scaling error vs error from small samples
Double the sample size, confidence improves two fold
Scale to get more analogs

Transform old wells to new wells

Reference: Freeborn et al, SPE 175967
Scaling

• Scale what you can, bin the rest

• Accuracy trade off: scaling vs small samples

• Logic is physics based intuition
  • Adjusting initial rate and $t_{elf}$
  • Based on Dr. Lee’s equation
    $$t_{elf} = \frac{1896 \phi \mu c_t d_i^2}{k}$$
  • Improvement possible from parametric simulation

• Create wells scaled to new drill/complete plan
  • Bin the scaled wells as necessary
  • For each bin, build type well from scaled wells
Scaling – End of Linear Flow

\[ t_{elf} = \frac{1896 \phi \mu C_t d_i^2}{k} \]
\[ t_{elf} \sim \frac{d_i^2}{k} \]

Time
viscosity
compressibility
inter-fracture distance
permeability

\[ t \quad \text{hours} \]
\[ \mu \quad \text{cp} \]
\[ c_t \quad \text{psi}^{-1} \]
\[ d_i \quad \text{ft} \]
\[ k \quad \text{md} \]

Dr. Lee, Reservoir Engineering Aspects of Unconventional Resources
SPE Course Oct 29, 2012
Scaling – Sweet spot

Intuition from physics

• Rate is proportional to permeability
• Proppant concentration may act as increase in perm
• For gas, $c_t \approx \frac{1}{p}$: pressure may act like k
• New permeability changes $t_{elf}$

Math and process

• Scale Factor = \( \frac{perm_{target}}{perm_{well}} \)
  \[ t_{elf} = \left( \frac{perm_{well}}{perm_{target}} \right) \]

• Remove history < $t_{elf}$ and multiply rates by the Scale Factor
• Forecast linear flow, transition at calculated $t_{elf}$
## Scaling – Sweet spot

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<td>k</td>
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Note: same rate increase as frac example where EUR decreased 9%

Montney: 02/11-13-077-15W6/0
Scaling – Sweet spot

67% increase in permeability (improved drainage)
EUR increases 28% (577 to 740 mcf/ft)
w-fracs, more time at high rate, shallow final decline
Scaling – Number of fractures (stage count)

Intuition from physics

• Prior to $t_{elf}$, each fracture behaves as vertical well
• $P_{wf}$ different at each frac; captured in the average
• New fracture spacing changes $t_{elf}$

Math and process

• Scale Factor = \( \frac{\# \text{frac}_{\text{target}}}{\# \text{frac}_{\text{well}}} \)

\[ t_{elf} = \left( \frac{d_{\text{target}}}{d_{\text{well}}} \right)^2 \]

• Remove history < $t_{elf}$ and multiply rates by the Scale Factor
• Forecast linear flow, transition at calculated $t_{elf}$
## Scaling – Number of fractures (stage count)

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<td>( t_{elf} )</td>
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<td>370</td>
<td>1134 (0.326)</td>
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<td>(471/825)^2 = 0.32</td>
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Montney: 02/11-13-077-15W6/0
Scaling – Number of fractures (stage count)

Increase from 9 fractures to 15
EUR decreases 9% (577 to 528 mcf/ft)
Earlier $t_{elf}$, less time at high rate, steeper final decline
Scaling – Why less EUR with more fracs?

- Rate - Base
- More perm
- More fracs

43% $D_{lim}$
23% $D_{lim}$
14% $D_{lim}$

Producing Days
Cumulative, bcf
Rate, mmcf/d

3esi • Enersight
Strategy • Planning • Asset Development • Capital Management • Economics • Reserves
Scaling – Well length

Intuition from physics

• Longer well with same \( d_i \) and \( t_{elf} \)
• Prior to \( t_{elf} \), each fracture behaves as vertical well
• More fracs, greater rate
• Rate improvement diminishes with length
  • Friction & liquid buildup in wellbore
  • Lower effective frac length and drawdown at the toe

Math and process

• \( \text{Scale Factor} = \left( \frac{\# \text{frac}_{\text{target}}}{\# \text{frac}_{\text{well}}} \right) \left( \frac{WLF_{\text{target}}}{WLF_{\text{well}}} \right) \)
• Multiply rates by the \( \text{Scale Factor} \)
• Forecast linear flow with no change to \( t_{elf} \)
Increase well length from 1 mile to 2 miles
IP 180 only increased by 60%
Convert the data to well length factor

Braun et. al., SPE 171658
## Scaling – Well Length

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<td>distance</td>
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<tr>
<td>wlf</td>
<td>0.743</td>
<td>0.550</td>
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Montney: 02/11-13-077-15W6/0
67% increase in length
Normalized EUR decreases 26% (577 to 425 mcf/ft)
Value is in drill cost reduction
Scaling – Combination of factors

Scenario

- Older wells that were drilled 3 or 4 years ago
- Technology and our understanding has changed
  - Previous 9 stage plug ‘n perf fractures
    Replaced with 30 stages of 2 perf clusters (60% efficient)
  - Longer wells: 11549 ft compared with prior 6559
  - Now drilling sweet spots with 25% greater $k$
  - 20% greater proppant volume per frac
Scaling – Combination

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| Length     | 6599   | 11549  |
| Fracs      | 9      | 36     |
| Distance   | 825    | 330    |
| $k$        | 1.00   | 1.50   |
| WLF        | 0.743  | 0.550  |

Montney: 02/11-13-077-15W6/0
Scaling – Combination

Only two adjustments required
• Rate multiple
• Revised $t_{elf}$
Scaling

• Other parameters suited to scaling
  • Frac size (proppant volume)
  • Frac quality $k_{eff}$ (proppant concentration)
  • Reservoir pressure (for gas $c_t \approx 1/p$)
  • Effective fracture length

• Examples of parameters suited to binning
  • Operator, vintage, cardinality, frac fluid

• Issues with scaling
  • Unknown or unavailable parameters
  • Assumes uniform reservoir drainable with completion
  • Scaling algorithm may not be developed
  • Flawed or incomplete intuition
Scaling – Summary

Confidence in probability distributions and type well profiles is roughly proportional to sample size.

Scaling has the potential to improve type well confidence

• Increase in analog well count
• Decrease in P10/P90 ratio – more similar wells

Less error results in more reliable type wells with more reliable reserve and economic assessments.
Diagnostics

Scaling to find completion unknowns and explain anomalies

Reference: Freeborn et al, SPE 175967
Diagnostic – Example 1

A well was cluster fractured. How many fractures?

- Control well: 9 fracs, plug and perf
  Estimate 900 tonnes placed
  horizontal length of 6599 ft

- Target well: 5 frac stages (16 perf intervals)
  1100 tonnes placed
  horizontal length of 6170 ft

- Result: 8 fractures (50% efficiency)

Control well 02/11-13-077-15W6/0
Target well 00/05-13-077-15W6/0
Diagnostic – Example 1

- Match with fracs – 12 is best, but $t_{elf}$ wrong
- Match with perm – $t_{elf}$ still wrong
- Trade fracs for perm – match with 8 fracs, 40% more perm
- With 8 fracs, the target well had 37% more sand/frac
Diagnostic – Example 2

Conflicting results

• Control well: 9 fracs, plug and perf
  Estimate 900 tonnes placed
  horizontal length of 6599 ft

• Target well: 16 fracs, plug and perf
  1600 tonnes placed (same/frac)
  horizontal length of 7375 ft

• Result: 7 fractures
  connecting behind pipe

Control well 02/11-13-077-15W6/0
Target well 00/10-13-077-15W6/0
Diagnostic – Example 2

- Rates too low, even with sand volume adjusted perm
- Best scaling is with 7 fracs and 2.75 x k
  - Perm increase has 2 factors: 2.3 fold proppant, 20% k
  - Fractures must be connecting behind pipe
Diagnostic – Summary

• Diagnostics are a useful tool for understanding what really happened with your completions.

• Diagnostics pay permit determining the completion parameters needed for scaling when they are unknown.

• When a source well is not available, it could come from RTA or simulation.

• Scaling / diagnostics combined with economics are useful for reducing the number of completion optimization alternatives.
Thank you

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