Status of SPEE Monograph 4 &

The Importance of Transient Flow in Estimating Unconventional Reserves

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Or

How I became a modified Arps agnostic.
Status of SPEE Monograph 4 – Estimating Developed Reserves in Unconventional Reservoirs

• 6 of 10 chapters – final edits in progress
• 4 of 10 chapters – revised drafts due 1 November
• Final manuscript to SPEE 1 December?
• Sister society review?
• Publication 1Q 2016?
Developed Reserves Historically Estimated with Decline Curves

Decline curve assumptions

1. Constant bottomhole flowing pressure
2. Constant drainage area
3. Constant permeability and wellbore condition
4. Constant fluid properties
5. Well in boundary-dominated flow (BDF)
The Problem – Unconventional wells can take years to reach BDF

The Solution – Rate Transient Analysis (RTA)
The Problem – RTA requires rates and pressures

The Solution – Semi-empirical models
Current semi-empirical transient flow models

1. Arps
2. Modified Arps
3. Duong
4. Stretched Exponential Decline Model (SEDM)
These models can accurately forecast future well performance, even when the well is in transient flow.
Or can they?
DJ Niobrara horizontal well – four analyses

1. Full history – 4.7 years – The Truth
2. 6 months production data
3. 1 year production data
4. 3 years production data
Full history – production data

- Oil, Water, bpd - gas, mcf
- Time, months

Legend:
- Oil
- Gas
- Water
Full history – GOR & WOR plot
Full history – normalized rate vs material balance time plot

$q_o/(p_i-p_{wf})$, bpd/psia vs material balance time, days

- Data points
- Unit slope
- Half-slope

- 350 days
- 1150 days
Hyperbolic and exponential declines match boundary dominated flow

exponential decline = 22.7 %/yr
The Truth –
Estimated Ultimate Recovery = 157 mstb
6 months – production data

- oil, water, bpd - gas, mcf

- time, months

- oil, gas, water
6 months – GOR & WOR plot
6 months – normalized rate vs material balance time plot

Graph showing normalized rate against material balance time.
6 months – Arps match & forecast

- **Arps** match & forecast

- **Oil rate, bpd** vs **time, days**

- **b = 2**
- **De = 82.3 %/yr**
6 months – Arps & modified Arps forecast

De min = 8 %/yr
6 months – Duong plot

- \( a = 2.100 \text{ days}^{-1} \)
- \( m = 1.060 \)

- The plot shows the decay rate of a certain parameter over time.
- The Duong model is represented by a straight line on the plot.
- The parameters \( a \) and \( m \) are used to describe the rate of decay.

The plot is used to analyze and predict the behavior of a system over time, particularly in the early stages of oil production or similar processes.
6 months – Duong match & forecast

- Oil rate, bpd - cum oil, mstb
- Time, days

Graph showing oil rate and cumulative oil production over time with forecasts.
6 months – SEDM plot

\[ \ln\left(\frac{q_i}{q}\right) \]

vs.

\[ \text{time, days} \]

Graph showing the relationship between \( \ln\left(\frac{q_i}{q}\right) \) and time, days, with data points and a line representing SEDM.
6 months – SEDM match & forecast

![Graph showing oil production over time with labels for oil, cumulative oil, calculated gas, and calculated cumulative.](image-url)
6 months – all models – rate forecasts

![Graph showing oil production rate over time for different models.

- Data
- Arps exp
- Modified Arps
- Duong
- SEDM

The graph displays the oil production rate in barrels per day (bpd) against time in days. The different models are represented by various line styles and markers. The horizontal axis represents time in days, while the vertical axis shows the oil production rate in bpd. The curves indicate the predictive performance of each model over the 6-month period.]
6 months – all models – cumulative forecasts
6 months – EUR’s & lifetimes

<table>
<thead>
<tr>
<th>model</th>
<th>EUR, mstb</th>
<th>life, yrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arps</td>
<td>5,172</td>
<td>2,370</td>
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<tr>
<td>modified Arps</td>
<td>490</td>
<td>42</td>
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<tr>
<td>Duong</td>
<td>fails – rate inc</td>
<td>fails – rate inc</td>
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<tr>
<td>SEDM</td>
<td>43</td>
<td>1</td>
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<tr>
<td>hyperbolic</td>
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<td>19</td>
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<tr>
<td>exponential</td>
<td>151</td>
<td>14</td>
</tr>
</tbody>
</table>
1 yr – production data
1 yr – GOR & WOR plot

gor, scf/stb
wor, stb/stb
time, months

gor
wor
1 yr – normalized rate vs material balance time plot

- **Material balance time, days**
- **qo/(pi-pwf), bpd/psia**

Data points are plotted on a log-log scale, showing a decreasing trend with increasing material balance time. The dashed line represents the half-slope.
1 yr – Arps & modified Arps

- Arps
  - $b = 1.2$
  - $D_e = 76.9$

- Modified Arps
1 yr – Duong plot & match

- Left graph: 
  - y-axis: \( \frac{q_o}{N_p, \text{day-1}} \)
  - x-axis: time, days

- Right graph: 
  - y-axis: oil rate, bpd - cum oil, mstb
  - x-axis: time, days

Legend:
- Oil
- Cum oil
- Rate fcast
- Cum fcast
1 yr – SEDM plot & match

![Graph showing data and SEDM match.](image-url)
1 yr – all models – rate forecasts

- Arps exp
- modified Arps
- Duong
- SEDM

oil production rate, bpd

time, days

data
1 yr – all models – cumulative forecasts

cumulative oil, mstb vs. time, days

- data
- Arps exp
- modified Arps
- Duong
- SEDM
### 1 yr – EUR’s & lifetimes

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<td>35</td>
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<tr>
<td>Duong</td>
<td>365</td>
<td>57</td>
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<tr>
<td>SEDM</td>
<td>124</td>
<td>5</td>
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</table>
3 yrs – production data
3 yrs – GOR & WOR plot
3 yrs –
normalized rate vs material balance time plot
3 yrs – Arps & modified Arps

\[ b = 0.95 \]
\[ De = 86.5\% / \text{yr} \]
3 yrs – Duong plot & match
3 yrs – SEDM plot & match

- Left graph: Plot of \( \ln(q_i/q) \) against time in days, showing data points and SEDM model.
- Right graph: Plot of oil and cumulative oil against time in years, with data points, calculated oil, and calculated cumulative compared.
3 yrs – all models – rate forecasts

![Graph showing oil production rate (bpd) over time (days) for different models. The models include: data, Arps exp, modified Arps, Duong, and SEDM. The x-axis represents time in days, ranging from 0 to 6000, and the y-axis represents oil production rate in bpd, ranging from 1 to 10,000.](image-url)
3 yrs – all models – cumulative forecasts

![Graph showing cumulative oil production over time for different models: data, Arps exp, modified Arps, Duong, and SEDM. The x-axis represents time in days, and the y-axis represents cumulative oil production in mstb.]
3 yrs – EUR’s & lifetimes

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Summary

• Unconventional well rate forecasts often difficult because--
  o Multi-year transient flow – DCA problematic
  o Only rates, no pressures available – RTA problematic

• Solution - semi-empirical models & rates to predict performance

• Industry standard is modified Arps method
Summary - 2

• Mature DJ Niobrara well performance forecasted with—
  o Arps, modified Arps, Duong, and SEDM methods
  o 6 months, 1 year, and 3 years of production history

• None of the 4 methods considered--
  o Was clearly superior
  o Matched full history EUR
  o Only SEDM gives constant or increasing EUR with time
## Summary - 3

**Estimated Ultimate Recoveries (mstb) by method & history interval**

<table>
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<th>1 yr</th>
<th>3 yrs</th>
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EUR from current production = 157 mstb
Recommendations for Unconventional Wells in Transient Flow

• Continue to use modified Arps method to forecast future performance.

• Forecasts with modified Arps method are more accurate if constrained by offset and/or analogous wells—
  o Initial decline parameters – qi, b, Di
  o Terminal decline rate – De min
Thank you!

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