Reserves Management:
A Concerted Effort

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ConocoPhillips
Introduction

• Proposed Workflow
• Importance of “b” in DCA (Decline Curve Analysis)
• DCA used to evaluate & book reserves
• “b” used for:
  – Well performance evaluation
  – Decline curve analysis
  – Reserves evaluation
  – Identification of Layered-no-crossflow

• Decline Curve Analysis - DCA:
  – Graphical method to analyze production decline
  – Used also to forecast future performance of oil and gas wells

\[ q = \frac{q_i}{(1 + bD_i t)^{\frac{1}{b}}} \]
“4 in 1” plot

- Method proposed by Fetkovich in 1990 to visualize not only well performance, but also mechanical/operational effects. Consists of:
  - Log (Qg) vs. time (semi-log, understand operational changes)
  - P/Z vs. Cum.Prod (cartesian, material balance)
  - Log (Qg) vs. Log (Dt) (flow regime analysis)
  - Deliverability plot, Log (DP^2) vs. Log (Qg)
Workflow

Lease Review DB
- Production data
- Well Schematics
- Comments from previous Lease Reviews

Reserves DB
- Production data
- Reserve Type
- Reserves and forecast
- Decline Curve Analysis

Evaluate logs
- Number of completions
- Volumetrics

Generate 4 in 1 plot
- Evaluate slopes
- Generate b factor

P/Z vs. Gp review
- Validate extrapolation
- Interpret shape

Review logs and completion
- Homogeneous layer?
- Hydraulically Fractured?

Update DB’s
- Lease Review & Reserves
- Perform Economics
- Feedback to Operations & LRP
- Prepare Documentation

Is “b” realistic for the actual completion?
- NO
- Y

Update “b” and re-do Decline Curve Analysis

Gather and validate Economic Parameters
• Hyperbolic decline, “b” should be:
  – $0 < b < 0.5$, for single layer completions
  – $0.5 < b < 1$, for multi-layer completions

• Possible actions after evaluating “b”:
  – Completion limited: Frac or re-frac candidate
  – Difficult to define due to liquid loading: candidate for artificial lift
  – Differential depletion: evaluate different completion strategies
Typical “4 in 1” plot

Understand the production history

Transient

Slope “n”

b=(2n-1)/2n

Extrapolation shows OGIP
Example 1 (4 in 1)

**Homogeneous?**

**Smooth history**

**Slope=-1/2 (transient)**

**Slope=-1 (depletion)**

**n=1.0**

**b=0.5**
Example 1 (completion)

Example 1, Wellbore schematic and Logs
Example 1 (Fetkovich)

Remaining resource 650 MMcf using Fetkovich Type-curve

Example 1 (Fetkovich)

Gas Rate (Dimensionless) vs. Time (Dimensionless)

- b=0
- b=0.5
- b=1

Working Forecast Parameters
Phase: Gas
Case Name: Remedial
b: 0.494943
Di: 0 A.n.
qi: 110.9 Mcf/d
ti: 07/31/2010
te: 04/30/2048
Final Rate: 19.9522 Mcf/d
Cum. Prod.: 4126.49 MMcf
Cum. Date: 07/31/2010
Reserves: 649.375 MMcf
Reserves Date: 04/30/2048
EUR: 4775.86 MMcf
Forecast Ended By: Rate
Initial Date: 07/31/1999
DB Forecast Date: 08/02/2010
Example 1 (Hyperbolic Decline)

Remaining reserves 642 MMcf using Hyperbolic decline with b=0.5

<table>
<thead>
<tr>
<th>Working Forecast</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase</td>
<td>Gas</td>
</tr>
<tr>
<td>Case Name</td>
<td>Remedial</td>
</tr>
<tr>
<td>b</td>
<td>0.5</td>
</tr>
<tr>
<td>Di</td>
<td>0.07422 A.n.</td>
</tr>
<tr>
<td>qi</td>
<td>112.706 Mcf/d</td>
</tr>
<tr>
<td>ti</td>
<td>07/31/2010</td>
</tr>
<tr>
<td>te</td>
<td>08/31/2047</td>
</tr>
<tr>
<td>Final Rate</td>
<td>19.9611 Mcf/d</td>
</tr>
<tr>
<td>Cum. Prod.</td>
<td>4126.49 MMcf</td>
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<tr>
<td>Cum. Date</td>
<td>07/31/2010</td>
</tr>
<tr>
<td>Reserves</td>
<td>642.457 MMcf</td>
</tr>
<tr>
<td>Reserves Date</td>
<td>08/31/2047</td>
</tr>
<tr>
<td>EUR</td>
<td>4768.95 MMcf</td>
</tr>
<tr>
<td>Forecast Ended By</td>
<td>Rate</td>
</tr>
<tr>
<td>DB Forecast Date</td>
<td>09/02/2010</td>
</tr>
</tbody>
</table>

Current Gas Cum. : 4126.5 MMcf
Example 2 (4 in 1)

- **Date**: Represents the timeline for the gas production data.
- **Gas Rate (Cal. Day) (Mcf/d)**: The gas rate data is plotted on a logarithmic scale.
- **(DeltaP)^2**: The square of the pressure drop is also plotted.
- **P/Z**: The ratio of pressure to the compressibility factor is shown.
- **Days Since 1st Prod (Mdays)**: Indicates the time since the initial production.
- **Cum. Gas at Test (MMcf)**: Cumulative gas production data.
- **Gas per Day (Mcf/d)**: Daily gas production rate.
- **Slope=-1**: Indicates a linear relationship with a slope of -1, typical for depletion cases.
- **n=1**: The exponent n is set to 1 for certain calculations.
- **b=0.5**: The exponent b is set to 0.5 for others.

The graphs illustrate the decline in gas rate over time, with a focus on high-pressure line behavior and the calculation of depletion slopes.
Example 2 (completion)

Wellbore schematic

Sand in wellbore

Example 2 Wellbore schematic
Example 2 (Fetkovich)

Remaining resource 3.8 Bcf using Fetkovich Type-curve
Example 2 (Hyperbolic Decline)

Remaining reserves 3.7 Bcf using Hyperbolic decline with b=0.5

Working Forecast Parameters
Phase : Gas
Case Name : MWD
b : 0.5
Di : 0.0576698 A.n.
qi : 631.613 Mcf/d
ti : 07/31/2010
te : 06/30/2040
Final Rate : 182.051 Mcf/d
Cum. Prod. : 27537.5 MMcf
Cum. Date : 07/31/2010
Reserves : 3705.3 MMcf
Reserves Date : 06/30/2040
EUR : 31242.8 MMcf
Forecast Ended By : Time
DB Forecast Date : 09/02/2010

Current Gas Cum. : 27537.5 MMcf
Example 3 (completion)

Des: Breakdown Test, Depth (MD): 8,104-8,360, Date: 1/16/2003, Com: 2475 SITP. MIRU Halliburton Services frac equipment & test treating line to 10044 psi & set pop-off at 8559 psi, test ann. line to 4000 psi & set pop-offs at 2520 & 2525 psi. Break down the Lobo 6 zone from 8104.121, 8176.186, 8246-263, 8352-360 w/ 2% KCL water at 5 bpm at 2749 psi, load well w/ 141 bbls. SLP at 1279 psi, W/ .592 psi/ft FG. Leak-off first 5 mins= 131 psi/min, 10 mins= 65 psi/min, 15 mins= 44 psi/min, 30 mins= 23 psi/min, SI w/ 620 psi. Load ball injector w/ 70-7/8" Bio-Balls and open well at 620 psi. Run ball-job at 12.5 bpm and ball-out to 4301 psi w/ good break backs. Pumped 344 bbls clean fluids w/ avg. pump rate of 12 bpm, avg. pump pressure at 1919 psi. RDMO frac equipment.

Des: FILL, OD:4, Depth (MD): 8,619-8,700, Date: 2/25/2009
Des: CTCO 9/22/06, OD:4, Depth (MD): 8,699-8,700, Date: 9/22/2006

Production, 4 1/2, 3.920, 22, 6,771.9, 12/17/2002
### Example 3 (Prod.Logs)

Production logs show how the contribution from different intervals changed with time, this is a good example of "differential depletion", depletion in the lower intervals allowed the upper zones to increase production.

<table>
<thead>
<tr>
<th>Perf.Interval (ft)</th>
<th>2003</th>
<th>2009</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gas (%)</td>
<td>Gas (mcsfd)</td>
</tr>
<tr>
<td>8104-8121</td>
<td>4.1</td>
<td>25 (mcsfd)</td>
</tr>
<tr>
<td>8178-8188</td>
<td>4.9</td>
<td>30 (mcsfd)</td>
</tr>
<tr>
<td>8246-8263</td>
<td>65.5</td>
<td>397 (mcsfd)</td>
</tr>
<tr>
<td>8350-8360</td>
<td>25.5</td>
<td>153 (mcsfd)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>100</td>
<td>605 (mcsfd)</td>
</tr>
</tbody>
</table>
Example 3 (4 in 1)

Slope = $-\frac{1}{4}$ (transient)

More than one zone?

$n = 1.35$

$b = 0.62$
Example 3 (Fetkovich)

Flat portion indicates no stimulation

Remaining Reserves = 1.96 Bcf
Example 3 (Hyperbolic Decline)

Remaining Reserves = 1.93 Bcf
Example-4 (frac candidate, no depletion flow in the Log-Log plot)

(Slope=$-\frac{1}{4}$)

(Slope=$-\frac{1}{2}$)

Transient flow only

$n=4$

$b=0.5$
Fetkovich Analysis Plot (actual data showing no stimulation)

Actual data (red) flat at the beginning showing no stimulation.
Example 4 (Frac Candidate)

Proposed rate uplift = 500 mcf/d, incremental reserves approx. 1 Bcf
Example 4 (Results)

Stabilized production @ 830 mcf/d after hydraulic fracture job
Example 5 (Holes in tubing)

Slope = -1/2, transient

Operation/Mechanical?
Example 5 (Results)

New tubing, optimizing plunger lift at this point in time
Example 6 (Capstring installation)

- $n = 0.7$
- $b = 0.3$

Slope = -1
Example 6 (Lower perfs uncovered)

<table>
<thead>
<tr>
<th>ftKB (MD)</th>
<th>Schematic - Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
</tr>
<tr>
<td>5,090</td>
<td></td>
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<tr>
<td>7,408</td>
<td></td>
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<td>9,771</td>
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<td>9,804</td>
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<td>9,805</td>
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<td>9,807</td>
<td></td>
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<td>9,811</td>
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<td>9,819</td>
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<td>9,851</td>
<td></td>
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<td>9,911</td>
<td></td>
</tr>
<tr>
<td>9,919</td>
<td></td>
</tr>
<tr>
<td>9,922</td>
<td></td>
</tr>
<tr>
<td>10,038</td>
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<td>10,800</td>
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<td>10,824</td>
<td></td>
</tr>
<tr>
<td>10,994</td>
<td></td>
</tr>
<tr>
<td>11,075</td>
<td></td>
</tr>
</tbody>
</table>

**Jet Perforation, 9,900-9,922, 1/22/1994, 3 SPF, 9 SHOTS, 90 DEG. SPIRAL PHASING**

**Jet Perforation, 9,985-10,038, 1/22/1994, ESTIMATED DATE ENTERED**

**Jet Perforation, 10,800-10,826, 1/8/1994, 2 SPF 53 SHOTS 90 DEG. SPIRAL PHASING**

**Jet Perforation, 10,994-11,000, 1/8/1994, ESTIMATED DATE ENTERED**

**Fracture, Depth (MD) 10,900-9,822, 1/22/1994, Com. (SF) SPF FAC'D W/COD W/144, 080 guns gal & 384,000 lbs. + (-) SF 5/244, 020 lbs. 20 lbs.**

**Des. 1/22/1994, 11,075, prod. casing, 1/12/1994, 9,11, 200's, 12,25/93**
Example 6 (Results)

Optimizing chemical injection
Summary

• Consistent and common approach across disciplines

• This is a way to identify remedial candidates to maintain base production

• It is also a way to identify opportunities for long term planning

• Evaluation of production optimization practices

• Evaluation of completion strategy
Conclusions

• Proposed Workflow
  – Successful and consistent evaluation approach

• Importance of “b” in DCA
  – Forces the engineer to consider operational/mechanical influences on forecast

• DCA used to evaluate & book reserves
  – Limits subjectivity in the analysis

• “b” used for:
  – Well performance evaluation
  – Decline curve analysis
  – Reserves evaluation
  – Identification of layered no-crossflow effects
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