Using Automated Reservoir and Production Engineering Tools to Make Quicker & Better Decisions

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SPE – Perth

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Based on SPE Paper 171512
Outline

- Bias! & “INMP”
- Surveillance & Visualization
- Instrumentation
- Background Physics
- Analysis Techniques/Tools
- Case Studies
- Conclusions
Bias in Decisions

• **Confirmation/Expectation Bias**
  • Decision Already Made
  • Answer Already “given”

• The Inside View
• Risk Compensation
• Gambler’s Fallacy
• Ownership/Sunk Cost Bias
• Unintended Consequences - Incentives
• Gotta Spend it...(budgets)
The Turds in the Pool

• The “Expert”
• The “Smartest Guy in the Room”
• The Information Hoarder
• The Bully
• The Amateur Epidemiologist
• Mister Minutia
• “NIH” Disease
• The Investment Banker
Whose Problem is it?

• Drilling: We got the hole down – it’s not my problem
• Completions: The well flowed – it’s not my problem
• Frac’ing: We pumped all the sand – INMP
• Facilities: I designed it for what you told me the rate was going to be - INMP
• Production: Not a wellbore or skin problem – See my Nodal!
• Reservoir: It’s not a perm/Vc issue – See MY Nodal
• Geology/Exp: It HAS to be big! Must be someone else’s fault/problem
• Petro-physics: The interpreted log says it’s HC bearing – the water must be coming from somewhere else
Well...

- Drilling: Fluid Type/Losses can induce damage
- Completions: Fluid Type/Losses, Completion Type and Execution can affect performance
- Frac’ing: If you frac out of zone or the proppant gets crushed, your frac may not be any good
- Facilities: Do the best you can with what you have
- Production/Reservoir: Find the pressure drop that shouldn’t be there!
- Geology/Exp: Communicate with RE – How big is it? Do the perms make sense!
- Petro-physics: Try digging up the ‘raw” *.las data; don’t assume that the service co. “interpreted” it correctly
• Understand what happened in the Past
• Understand what’s happening Now
• Get an idea of what’s going to happen in the Future

Need Non-Biased (non-bullying) way to sort things out
What is Good Surveillance?

• Always have a handle on:
  • How much oil or gas is in the ground
  • How much of it is likely to be recovered
  • What is the current well performance? Can anything be done to improve the performance?
  • Are there problems developing in the well bore?
  • Are there problems developing in the completion?
  • Are there problems developing in the reservoir?

• Is anything changing?

• If something happens, what is the current NPV of the asset?
What is Bad Surveillance?

• Only accept information about the well/reservoir that fits your or the company’s beliefs- ignoring data!

• Change the “static” or geologic and/or simulation model until you get the answer you want- doesn’t fit the data!

• Wait until something bad happens:
  • Call it bad luck & move on
  • Say it’s too late to fix it & move on
  • Call in a technical expert & move on
  • Use Nodal Analysis or Simulation to muddy the waters

• Be reactive...or just do nothing
Drowning in Data?

- Engineers doing surveillance work spend over half their time just looking for data
- Many data systems are still designed as if computer storage/memory were expensive
- Many software packages cannot handle multi-million point data sets

- Need a common framework that engineers and managers can use and understand & visualize!
Build-up in B7
Forcing open SCSSV on B6
Valid PBU on B7
Common Framework – Basics

• Easy Access to Data
• Ability to do diagnostic graphs, with annotations
• Links to Email
• Process Alarms

• Ability to Plug & Play with other software packages, not just the Framework’s software

This forms the basics for Automated Real-Time Analysis!
NOTE: This Technology is 15+ years old!

Where do we go from here?
How do we Use this Technology to make Faster & Better Decisions?
Reservoir & Production Engineering
Analysis/Evaluation Tools

What they are and what they tell you
Analysis Types and Their Objectives

- PTA (Pressure Transient Analysis)
  - Skin, Perm, Deliverability, Communication, Productivity, Reservoir Boundaries, Reserves, Reservoir Pressure (P*)
- RTA (Rate Transient Analysis)
  - Same as PTA, but with less reliability on boundaries
- P/z Plots (gas) & Static MBAL Plots (oil)
  - Oil and/or Gas in Place
- Decline Analysis: Flowing BHP or IP vs Time
  - Apparent HC Volumes – Running MBAL/EBAL
- Nodal Analysis: Interaction of WB/Comp/Res
  - Changes in well performance; short-term rate predictions
- Reservoir Simulation: Cell/Gridblock disposition of Saturations, Pressures (Energy)
  - Field Optimization; longer-term rate/withdrawal predictions
How to ‘Bird-Dog’ a Well Production Problem

• Is it a wellbore problem?
  • Scale/Salt/Wax/Asphaltenes?, Slugging? Loading?
• Is it a completion problem?
  • Skin Accretion?, Screen Plugging?, Completion Obstruction?
• Is it a reservoir problem?
  • Perm?
  • Reserves?
  • Water Encroachment?

• Is it a combination of two or more of the above?

FIND THE PRESSURE DROP THAT SHOULDN’T BE THERE!
In Order for any of this to work, you have to have:
Valid Rates & Valid Mid-Completion BHPs!!!
Failure to perform an analysis on mid-completion BHP leads to:

- Overestimation of Permeability
- Overestimation of Skin
- Underestimation of $P^*/$Reservoir Pressure

To show the importance of mid-completion BHP and that the well is not a stimulation candidate, pressure transient analysis was performed on:

- WHP
- Upper Downhole gauge pressure
- Lower Downhole gauge pressure
- Calculated mid-completion BHP
Pressure conversion can be performed at any point along the wellbore. Pressures were calculated at every gauge depth and plotted for comparison purposes.
‘BHP’ Conversion Example
Importance of mid-completion BHP

Note: Wellbore Cooling Effect causes the difference in mid-time slope values. Temperature changes affect the density, hence the head.
Skin = 20.8; permeability = 361 md

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Skin = 10.5; permeability = 222 md
Skin = 6.4; permeability = 175 md
Semi-log PBU Analysis – Calculated Mid-Completion BHP

Skin = 3.6; permeability = 154 md
Semi-log PBU Analysis Summary

<table>
<thead>
<tr>
<th></th>
<th>Slope (psi/cycle)</th>
<th>Skin</th>
<th>DP Skin (psi)</th>
<th>DP Skin/Q (psi/MMCF/D)</th>
<th>Permeability-thickness (md-ft)</th>
<th>Perm (md)</th>
<th>ROI (ft)</th>
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<tbody>
<tr>
<td>WHP</td>
<td>13.33</td>
<td>20.8</td>
<td>242</td>
<td>2.14</td>
<td>27318</td>
<td>361</td>
<td>4007</td>
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<td>U-DHGP</td>
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<td>10.5</td>
<td>194</td>
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<td>222</td>
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<td>L-DHGP</td>
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<td>13264</td>
<td>175</td>
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<tr>
<td>BHP</td>
<td>29.85</td>
<td>3.6</td>
<td>93</td>
<td>0.82</td>
<td>11616</td>
<td>154</td>
<td>2746</td>
</tr>
</tbody>
</table>

It is important to calculate mid-completion BHP. Failure to do so leads to overestimating skin and permeability and underestimating reservoir pressure/P*.
A Brief History of How We Lost the Plot

• Start with the Fundamental Physics
• No Computers → Make Assumptions & Develop Correlations so the math is easier
  • VLP correlations, No Initial Shear, No Inertia
• Build Lab Experiments/Tests based on Assumptions
• Create “Models”
• Match data to models (remove the bits that don’t fit)
• Apply Computing Power to iterate between data and models

Note: We forgot we made a lot of BAD Assumptions First!
• Most software is designed to eliminate or “smooth” data that doesn’t fit “The Model”
  • This is OK if you’re dealing with outliers or impossible data (i.e. DHGP = -259 psia)
• This is known as **Imposing a Model on the Data**
  • Data that is being filtered by comparison with a model is a recipe for “Get what you Guess”
  • You’ve already introduced BIAS!!!
  • Err...What if “The Model” is wrong?
Maybe, There’s a better way….

• Start with the Fundamental Physics
• Apply Computing Power to Solve the Equations
  • Make only valid assumptions
  • Don’t use correlations
• Don’t “doctor” the data
• Don’t impose a model on the well!!
• Let the well tell you what it’s doing!
Components of a Real-Time Well Evaluation Package

Take all the bits and Bolt them together
What Do We Already Have? (Batch Process)

- Hopefully...adequate data frequency and quality
- PTA/RTA Package
- “Snapshot” VLP
- “Snapshot” Inflow
- Reservoir Simulation Tool
- Wellbore Model
- Geologic/Geo-Physical Model
- Enough Well History?
What Do We Need to Make it Real-Time?

- Link to RT Data (w/Validation of Data, esp. rates)
- Wellbore Flow Model (w/Thermal & PVT Modeling)
- Completion Geometry & Flow Correction
- Reservoir Parameters
- Transient Recognition
- Boundary Recognition
- Reservoir Flow Regime Recognition
- Prediction vs. Actual Comparison
- Engineering by Difference (Did anything Change?)
The Bits...

- Scada/DCS Interface
- Model Creation and Validation
- Wellbore Modeling
- Reservoir Simulator
- Transient Nodal Analysis
- Real-Time Comparison to Overall System & Components of System

Integrated System Model
Wellbore↔Completion↔Reservoir

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Methodology

- Start with most valid pressure measurement point
- Use Measured, Calculated or Inferred Rate
- Work the Mech NRG solution to WHP and mid-completion BHP
- Employ Complex Completion Model if Required
- Use Banded Energy Solution, along with Transient/Regime Recognition to determine Reservoir Inflow in both Transient and Steady-State Flow
- Bob & Weave – incorporate changes in Reservoir Model as it changes (i.e. Moving Water Contact)
- Keep track of the important stuff & Warn PE’s when something goes wrong!
Present the Results in a way that folks are used to:

- Well Test Analysis Results (skin, perm, P*)
- Productivity Tracking
- In-Place, Hydraulically Connected, and Mobile Hydrocarbon Volumes
- Reservoir Map (Energy Equivalent Map)
- Nodal Plots (Snapshots as a function of time)
  - Includes Dynamic WBM & Res Inflow Model
Automated Processing
Case Studies
(Done on-the-fly)

How do you use this technology to make better decisions?
Strategies for Dealing with RT Data/Analysis

- Make sure that predictions match actual well behavior
- Look for changes!
  - Perm
  - Skin
  - Apparent Volumes
- Let the well tell you – don’t impose models on the well!
- Look for changes in the rate of change
Real-Time Data Strategies

• Spend time looking for results, not just digging for data
• Validate the results; only analyze manually if you disagree...or if it’s important enough to spend time on
• Think about what the results mean
• Think about how this meaning affects your decisions

If you know how much money you have left in the ground and understand the well history, you’ll make better decisions
At no time was the pressure data “smoothed”
At no time was the data forced to fit a model
At no time was the “answer” provided ahead of time

If you let it, the well will tell you what it’s made of and what it can produce

**Analyze the Data Without Imposing Bias!**
Thoughts, Musings & Conclusions
What is Good Oilfield Management?

- Maximize NPV
- Maximize Recoverable Reserves
- Avoid waste (time/money/resources)
- Mitigate/minimize risk (Ops/Reserves/HSE)
- Learn from your mistakes (and successes)

- MAKE BETTER DECISIONS IN A TIMELY FASHION
What is BAD Oilfield Management?

• Maximize bonus
• Maximize ‘booked’ reserves
• The INSIDE View – eliminate/ignore contrary data
• Falling in love with a rate
• Wait until a problem is obvious (and expensive to fix)
• Hope no one notices (until you’ve moved on) – make sure no one takes ownership
• Shoot the messenger
  - Make the decision that’s best for you, not the company
What are the Consequences of Automated Monitoring/Surveillance?

• Democratized information/results
  • Can spend time discussing what it means
  • Easier to translate to other departments/silos
  • Less finger pointing and more inclusive work processes

• Quicker Decisions
  • Reach conclusions on what it means
  • Easier to focus on NPV of Decisions

• Quicker Actions/Inactions
Conclusions: RT Well Evaluation

• Proper Instrumentation and Visualization Software are the 1\textsuperscript{st} Step (Don’t Drop Bits!)
• Closed-Loop Solutions for the Wellbore and Reservoir make it possible to quickly check system model
• Do NOT impose a “static” model on the well
• Warning an Engineer when (or before) something bad happens is more important than being accurate to the 9\textsuperscript{th} decimal place
• Checking the results of an Automated Calculation is a lot easier and more timely than doing it yourself
Final Thoughts

- This technology is already here!
- Understand the physics – not just the software package
- Always know:
  - How much is in the ground?
  - How fast can I get it out (safely)
  - Is the performance changing?
- Compare NPV remaining vs. Cost of a “fix”
- Seek out non-biased results
Supplemental Material
Current Surveillance Programs

• Some Operators STILL don’t even have Scada
• Some have Scada, but no data visualization
• Some have Scada & Visualization, but only for some departments
• Some have alarms, triggers, automatic PBU recognition
• Some have links to internal & external software packages
• Possible Instrumentation (Upstream of Facilities)

• Instrumentation based on well type:
  • Natural Flow – Gas & Gas/Condy
  • Natural Flow – Oil
  • Artificial Lift – Oil
  • Annular Flow Wells (CBM/CSM)
  • Water Injection
  • Nat Gas injection
  • CO2 injection
  • Steam Injection
Pressure/Temperature Measurement

What do I really need to measure accurately?

• Wellhead Pressure
• Wellhead Temperature (Thermowell)
• Downhole Pressure
• Downhole Temperature
• Distributed Temperature (multi-zone wells)
• Line Pressure/Temperature
• Annular Pressures
Rates and Valve/CK Status

- Flow Rates of Oil, Gas & Water
  - Multiphase Meters, Venturi Meters, Turbine Meters, d/p meters (Daniels), Coriolis meters, Ultrasonic Flowmeter
  - Dedicated Test Separator
  - Meter Prover
  - Virtual Rate Measurement (VRM)…based on what?

- Other bits
  - Choke Setting
  - SCSSV, MV, Control Valves
  - Injection lines
Instrumentation Needs
Based on Well Type
• Way to calculate/validate Qgas, Qoil & Qwater
• Way to calculate Mid-Completion BHP
• Temperatures, Choke & Valve Settings are nice too!
Gas & Gas/Condy Wells

• Need at least one pressure and continuously measured Rates...OR
• Two pressures in/on well (can be used to calculate gas rate)
• Choke Setting
• Valve Status
• MPFM?

Note: If well is expected to make significant water or if the Condy yield is above 30 bbl/MMcf – DHG’s are recommended
Natural Flowing Oil Wells

- Tree & DHG (Pressure & Temperature)
  - Can be used to calculate water cut
- Mass Flowmeter, Turbine Meter, MPFM, Integrated Tank Level flow indicator
- Choke Setting
- Valve Status
Artificial Lift Oil Wells

• Same as natural flow, but DHPG must be below the artificial lift system (and Tree pressure may be irrelevant)
  • Below pump for PCP, ESP or jet pump (in communication with reservoir)
  • Below standing valve for sucker-rod
  • Below mandrel for gas lift (+gas injection pressure)
Typical Coal Seam Gas Production Well Diagram

Methane gas Produced through Annulus between tubing and casing

Water Produced through Tubing to Holding pond

Tubing

Pump

Coal Beds

As gas bubbles and water enter the well bore the gas will flow up the annulus, and the water be drawn into the pump and pumped through the tubing to a flow line to a holding pond.
Annular Flow (CSM)

- Annulus Pressure/Temperature
- WHT/WHP
- Pump torque & rpm
- DHG (below pump)
- Liquid Level indicator (avoid running pump dry)
- Water Rate (tubing) – tank level meter
- Gas Rate (annulus)
Water Injectors

- DHG – Pressure/Temperature
- Can use WHP if well doesn’t go on vacuum during fall-off
- Qwater (turbine meter)
- Ways to measure/infer water gravity
  - Capacitance
  - Salinity
  - Density
• If composition is constant, can get by with just WHP and Qgas-inj and Tinj
• If composition is variable or well is a recycler, need WHP, WHT, DHGP, DHGT and Qgas (mass flow)
• Valve Status
• Choke Status
• For CO2 Injectors: DHG and Tree gauge required
  • PVT tuning & rate validation
• For Steam Injectors: Same as nat gas inj.
Comments on Instrumentation

- Instrumentation is relatively cheap
  - Price difference between good and crap equipment is small
  - Cable (TEC) and Rig Time are not
- Don’t drop bits!
  - Most transmitters are 18-24 bit
  - Don’t lose resolution over a $30 vs. a $50 I/O card
- **Let the end users spec the equipment!**
- Don’t let IT run the show!
Make sure the data can tell you something
• Before it gets to you, Your Data is likely to pass through:
  • One or two A/D converters
  • An I/O card on the Control Panel
  • Dead-band filters
  • Signal filters
  • Archive filters

• You can lose sampling resolution (frequency) and instrument resolution at any point along the way
How Do We Make Use of Automated Surveillance?

... may have to change the way we work and assign responsibility
Automation Bias!
Analysis Type Examples

- Build-up PTA Derivative
- Drawdown PTA Semilog
- Horner – \( P^* \)
- Proper RTA (Rate Transient Analysis)
- MBAL/EBAL “bookends”
- \( P/z \) (gas) or Static MBAL (oil)
- Conventional Decline Analysis (Running MBAL)
- TTA/IPA (Running EBAL)
- NODAL ANALYSIS
- Simulated Rates/Pressure vs. Actual
Analysis/Evaluation Tools: PTA

• Build-up: After flowing the well for a while, shut it in and observe the pressure response
  • If Long Enough, Valid P*

• Drawdown: After shutting in the well for a while, flow it on a constant choke and observe the pressure and rate response

• 2-rate: Change the rate enough to create a new transient; observe P & Q

• Multi-rate: Change the rates and compare DP vs Q

• Communication: Shut-in a well and see if a neighboring well causes the Pressure to drop
Build-up PTA
Build-up Derivative Analysis

Date created: 6/29/2010 5:31 PM

- $P^c = 61520$ psia
- $kh = 1090$ md-ft
- $perm = 91$ md
- $Sk(h;Sf) = 5.6$
- $DPskin/Q = 15.7$ psi/MMcf-D
Drawdown PTA – Semi-log Analysis

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Date created: 5/15/2010 12:13 AM

\[ P_l = 4795 \text{ psia} \]
\[ k_h = 6930 \text{ md-ft} \]
\[ R_{erm} = 110 \text{ md} \]
\[ \text{Skin (sT)} = 21 \]
\[ DP_{skin}/Q = 8.5 \text{ psi/MMcf/D} \]
Horner Plot – P* Determination

P* = 11626 psia
2-Rate Test (Esp. for Oil)
2-Rate Test Oil Semi-log

Date created: 11/3/2010 9:54 PM

$k = 80 \text{ md}$

$\text{Skin} = -2.3$

$\text{PTF Eff} = 123\%$

$P^* = 2660 \text{ psia}$
RTA Example – Cartesian

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RTA – Semi-log Analysis

Date created: 8/14/2010 6:11 PM

Output Qgas
M1(y=-805.9*\log(x) +9301)

kh = 850 md-ft
Perm = 8.5 md
Skin (sT) = 9.5
DPskin/Qavg = 30 psi/MMcf-D

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Two Simple Bookends: Applied to Static and Dynamic MBAL/EBAL

• Expansion Drive Only (Compressibility Volume)
  • $V_c$

• Infinite Water Drive Only (Pushed Volume)
  • $V_{SLD}$
  • Also known as “straight line depletion”
P/z & Static MBAL

- **Static MBAL for Oil – Conventional & SLD**
  - Conventional: \( N = N_p \times \frac{B_o}{B_o|N_p - B_o} \)
  - SLD: \( N = N_p \times \frac{P_i}{P_i - P|N_p} \)

- **Static MBAL for Gas – Conventional & SLD**
  - Conventional: \( G = G_p \times \frac{B_g}{B_g|G_p - B_g} \)
  - SLD: \( G = G_p \times \frac{P_i}{P_i - P|G_p} \)

- **P/z for Gas: Plot** \( P^* \) vs \( G_p \) and \( P^*/z \) vs \( G_p \)
  - SLD In-place = Intercept of \( P^* \) slope at 15 psia
  - \( P^*/z \) In-place = Intercept of \( P^*/z \) slope at 15 psia

Where \( B_o|N_p \) or \( B_g|G_p \) are FVF at current reservoir coincident with the produced hydrocarbon volume and \( P|N_p \) or \( P|G_p \) are the current reservoir pressure.
Conventional & TTA Decline

• Conventional Decline Relates to Hydraulically Connected Volume
  • DP/DT Slope is the Conventional decline slope

• TTA Decline Relates to Mobile Volume
  • The TTA function is simply the relative inverse productivity: \((P_{initial} - P_{wf})/Q_{spot}\)
  • \textit{Slope is the TTA-slope}
Conventional Decline Analysis

- $\text{ConV}_c = \frac{Q_{avg}}{(\Delta P/\Delta T \text{-slope} \times Ct)}$

- $\text{ConV}_{SLD} = \frac{Q_{avg} \times \text{Reservoir}}{(\Delta P/\Delta T \text{-slope})}$

$V_{SLD}$ and $V_c =$ volume in units compatible with $Q_{avg}$ & $DT$, $Q_{avg} =$ average flow rate over the period where the $\Delta P/\Delta T$-slope is selected, $\Delta P/\Delta T$-slope is the decline in pressure per unit time $[\text{psi/day}]$, and $Ct$ is total system compressibility $(1/\text{psi})$. 
TTA Decline Analysis

- \( TTA|V_c = \frac{1}{(TTA\text{-Slope} \times Ct)} \)

- \( TTA|V_{SLD} = \frac{\text{Preservoir}}{TTA\text{-Slope}} \)

TTA-Slope has units consistent with the stock-tank or standard condition rate units and pressures
Six Values:

• Static MBAL (expansion) – In-place Energy
• Static MBAL (SLD) - Pushed In-Place Energy
• Conventional Vc – Hydraulically Connected Energy
• Conventional SLD – Pushed Hyd. Conn. NRG
• TTA Vc – Mobile Energy
• TTA SLD – Pushed Mobile Energy

Changes in these values Mean Something!!!
Production History for P/z

Date created: 11/12/2008 4:42 PM

PBU long enough for valid P* but not long enough for P*
Conventional Decline Evaluation

Apparent Reserves = 18.1 Bcf

Pushed Reserves = 8.3 BCF
TTA ‘Decline’ Analysis

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Apparent Reserves = 13.3 BCF
Pushed Mobile Gas = 5.6 Bcf
‘Static’ Nodal Analysis

• Compares Reservoir Inflow (IPC) with Wellbore Performance (VLP)
  • Allows Prediction of DP to achieve a Rate (vice versa)
  • Allows Prediction of Liquid Loading Scenarios
  • Allows Optimization of Tubular Design

• Problems with Nodal
  • Infinite # of combos of skin & perm calculate the same rate (Can’t use nodal to determine skin or perm)
  • User has to pick the right inflow model and right VLP correlation
  • Doesn’t handle transient situations well – may match your well today, but not next month
Nodal – IPC + VLP

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Nodal VLP – IPC Plot

Relationships for wellbore pressure drop as a function of rate using an equilibrium thermal profile

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Transient Nodal Analysis Tool

- Keep track of changing produced fluid composition
- Update skin & perm from last valid PTA
- Update P* from last valid PBU
- Keep track of pressure decay during drawdown
  - Adjust Reservoir while producing
  - Use Transient Inflow model when in transient flow
  - Use Appropriate Steady State Inflow model when in SS Flow
- Link Reservoir Simulator to Wellbore Model
Transient Nodal Initiation

- Preservoir, Treservoir
- Skin (s & D) & Perm from Flowback PTA
- Wellbore Radius and Net TVT pay
- Fluid PVT
- Well Configuration/Geometry
- Petro-physical inputs
  - Sw, porosity, formation compressibility
- Forced Fixed Reservoir Volume or Floating Reservoir Volume
- Production Time Since last Valid P*/Pres
Inflow and VLP for $T_p = 1$ hour
Inflow and VLP for Tp = 24 hours

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Inflow and VLP for Tp = 168 hrs
Reservoir Simulation

• Tracks behavior (esp. Pressure and Saturation) in the reservoir
• Incorporates Multiple Wells/Multiple Zones
• Matches History and Attempts to Predict Future Performance
• Coupled with a Wellbore Simulator, can do amazing things

• Drawback: It takes a while to run...but they’re getting faster
Simulation Gist...

Geological and structural data: seismic,…
Well data: logs, plugs,…
Geological model

Upscaling

Perturbation

Oil flow rate (m³/day)
Production data
Fluid flow simulation

Time (days)
Simulation: Well Grid
Simulator Prediction vs Actual

Date created: 8/15/2010 12:00 AM

PSIA

13500 13400 13300 13200 13100 13000 12900 12800 12700 12600 12500 12400

Oct 2008 1 Wed 8 Wed 15 Wed 22 Wed 1 Sat

Corr Date-Time - DateTime

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Simulator Prediction vs Actual – Semi-log
Simulation Drawbacks

• Treats system as a tank model
  • OK for High-perm, not so good for low-perm
• Works best in SS or PSS flow (poor for transient)
• Doesn’t handle discontinuities very well
• Subject to “gaming”

• Best Case Scenario: The History Match Quality is the BEST the future predictions will be...
Closed-Loop WB Components

- Wellbore Thermal Modeling (Warming/Cooling)
- Liquid Drop Out (Build-ups)
- Liquid Surge (Start-up)
- Phase Behaviour EOS Calcs
  - Use SRK or PR w/Peneloux
- Rate Modeling
  - Residence Time
  - Rate Surging & Decay
- Coupled Effects (Rate-Thermal-Phase)
Developing Thermal/PVT Models

• Run Static Temp/Pressure Survey
• Run Flowing Temp/Pressure Survey
  • Multiple Rates
• Develop Heat Transfer Model – Account for:
  • Heat Capacity of Fluids/Tubulars/Annuli/Sinks
  • Heat X-fer via Conduction
  • Heat X-fer via Convection
  • Heat X-fer via Forced Convection
• Can Tune PVT using same data...just get a good sample first
Bernoulli Solution Process

Build Parametric Models & Well Configuration

Assume Continuity

Solve Bernoulli (MEB)

Check Continuity

Note: If Continuity Doesn’t Hold, the Well is Loading–up (which is important to know)
Continuity Equation

\[ \frac{\partial \rho}{\partial t} = - (\nabla \cdot (\rho v)) \]

- Rate of Change in Density Caused by Changes in Mass Flux
\[ \Delta \frac{1}{2} (v)^2 + g \Delta h + \int_{p_1}^{p_2} \frac{dp}{\rho} + Ws + \sum_i \left( \frac{1}{2} v_i^2 \frac{L}{R_h} f_i \right) + \sum_i \left( \frac{1}{2} v_i^2 e_{v_i} \right) = 0 \]
For Single-Phase Gas Flow in Pipes, the MEB reduces to:

\[
\frac{dp}{\rho} = -(g \sin \theta/g_c + 2f_f u^2/g_c D) \, dL
\]

• Basis for CS, Gray & A-C
Bernoulli for Single Phase Oil
Incompressible Conditions

\[
\frac{dp}{d\rho} + \frac{v dv}{g_c} + \frac{g}{g_c} \, dz + \frac{2 f_f v^2 dL}{g_c D} + dW_s = 0
\]

• Basis for Hagedorn-Brown & Beggs/Brill
Simplification of Flow-in-Pipe Eqns.

- Conceptually, these Equations are simply:

\[ \text{BHP} = \text{Gauge P} + \Delta P(\text{gravity}) + \Delta P(\text{friction}) \]
Using a Direct Bernoulli Solution for WB

• Works for Oil, Gas or Water (Continuity)
• Gas
  • Have DP, solve for rate & BHP
  • Have Rate, solve for DP & BHP
• Oil
  • Have DP, solve for Water cut & BHP
  • Sometimes possible to solve for rate (high rate)
• Much Easier to Apply Parametric Models Continuously:
  • Thermal Transients
  • Rate Transients
  • Phase Transients
  • Coupled Rate & Thermal Transients
Completion Modeling

• Reconcile Well Geometry (frac, horizontal, etc.) with base inflow
  • Build Dual Perm Model
  • Build “skin” model (easiest way if it works)

• Reconcile Completion/Reservoir Interaction
  • Partial Perforation/Penetration
  • Pay Loss/Growth
  • Near Well Stresses – Elasto-Plastic Rock

• True “Afterflow” vs. Terminal Velocity Flow
Closed-Loop Reservoir Solution

• Use “Static Reservoir Model” as input
• Use Transient Reservoir model when in transient flow
• Use Steady-State Reservoir model in SS flow
• Use Transient Recognition to “bob & weave”

• Objective: Run very quickly & get close
• Recognize if there’s a problem with the “static” model
Locate New Transients

- Rate goes to zero, Rate stops being zero
- Rate changes enough to start new transient
- Pressure Methods
  - Wavelets
  - De-convolution Variance
  - DP Logic

Banded Response Recognition

- Transient vs. Steady-State
- Boundary Recognition
- Transition Recognition
Transient Recognition

Date created: 8/13/2010 11:54 PM

WHP

psi

Date - DateTime

Jul 2008
Transient Recognition

Date created: 8/13/2010 11:54 PM

Chris Fair-SPE Perth
Boundary/Regime Recognition

RF
B1
B2, Linear Flow
B3, Linear
B3, Transient
B4, Transient
PSS Flow

Date created: 8/14/2010 3:47 AM
The Bits...

Integrated System Model
Wellbore ↔ Completion ↔ Reservoir

- Model Creation and Validation
- Wellbore Modeling
- Reservoir Simulator
- Transient Nodal Analysis
- Real-Time Comparison to Overall System & Components of System

Scada/DCS Interface
Automated Processing
Case Studies
(Done on-the-fly)

How do you use this technology to make better decisions?
Case Studies List

• North Sea #1 – Rate Calculations
• HPHT GOM Well Test Gas-Condy (DOT)
• Fizzy Oil – GOM Oil well Start-up
• Offshore Oz – Gas Condy Start-up
• Deepwater GOM Oil – Onset of Water?
  • Calculated Oil-Water Splits
• HPHT GOM Shelf Start-up
North Sea #1 – Gas Well

• Start-up of new gas field (Subsea Trees)
• Well Tests have a lot of variance
• MDTs and PVT indicate same fluid in all zones

• Objectives:
  • Explain differences in the well test analyses
  • Confirm that calculated rates match measured rates
North Sea #1 Logs
## North Sea #1 – PTA Summary: PBU’s

### Summary Table

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### Graphs

- **Left Graph**: Date Created: 11/26/2013 7:46:33 AM
- **Right Graph**: Date Created: 11/26/2013 7:46:14 AM

---

**Chris Fair**
SPE Perth
North Sea #1 Rate Check

Green – measured gas rate, purple – calculated gas rate

Chris Fair-SPE Perth
North Sea #1 – Conclusions

• Rates (measured vs. calculated) appear valid
• Build-ups are consistent – perm of 10md, skin of 3-ish
• Drawdowns are all over the place
  • Maybe related to zonal flow?
  • No consistent explanation
• Ignore DD’s – use PBUs for evaluations of change
Set-up:
- Well flowed-back 6 months before
- "Discredited" Well Test/Reservoir Engineer said it depleted on test
- Supposed to be upwards of 1 TCF of reserves in field
- Temporary MOPU on location
- Rock could be ‘squishy’
- Good CBL
- Packer could be a weak point

Objective: Determine if reserves justify a platform
Whaddaya Think?
DOT – PTA Summary

Chris Fair - SPE Perth
DOT-PTA Summary: PBU’s

Chris Fair - SPE Perth
DOT – Productivity

Chris Fair-SPE Perth
DOT – P/z and MBAL/EBAL
• It’s WEE!

• Gosh, we wasted a lot of rig time...
GOM Volatile Oil Well

• Start-up: Objectives
  • Figure Out kh & skin
  • Determine Productivity
  • Determine Oil-in-Place
  • Estimate Recovery

Objective: Does an injection well make sense?
# Fizzy – PTA Summary

| Start B/T | Std B/T | Text Length | Text Type | Work pass | Work pass | Swag pass | Swag pass | BHP pass | BHP pass | Quill BHP | Quill BHP | Perm md | Node | Sampled | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | Fat Eff | 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Fizzy – Flowing MBAL/EBAL

Chris Fair - SPE Perth
Fizzy - Conclusions

• Only about 450,000 STB in place
• Around 100,000 recoverable by natural drive
• Maybe 200,000 more recoverable with water injection

• Don’t drill $30 MM injector
Oz Gas-Condy

- Offshore Australia
- Gas Condensate well
  - Tree Gauge
  - Downhole Gauge
  - Gas Rate is occasionally measured from the test separator
  - Potentially changing condensate yield

**Objectives:**
- Validate Test Separator Rates
- Calculate Gas Rate Continuously
- Calculate Condensate Yield and Sales Oil Rate
Gas-Condy
Provided Data/Inputs
The well model was created/tuned:

- PVT
- Phase-thermal behavior
- Frictional component

Using the pressure drop in the wellbore i.e. pressure difference between the tubing head and the downhole gauges, the gas rate was calculated.

Condensate Yield was re-calculated/re-calibrated during every shut-in period.

With the calculated condensate yield and gas rate, oil rate was calculated.
Using the d/p wellbore, the gas rate was calculated accurately. The calculated gas rate closely matched valid separator rates.
## Oz Gas-Condy

### Measured vs Calculated Rates

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**Note:** The highlighted values in the table (Tests #4 & #8) did not match the calculated rates because the rates were changed during the well test.
• It is important to account for fluid’s changing composition
• Every time there is a short shut-in, re-calibrate PVT (the density portion of EOS)
Every time there is a short shut-in, re-calculate the changing condensate yield and adjust further calculations accordingly.

Chris Fair-SPE Perth
Oz Gas-Condy
Final Calculated Oil and Gas Rates

Chris Fair-SPE Perth
PTA Summary:
Even though it is highly deviated/horizontal wellbore, it is treated as vertical to observe changes in skin and perm with time
- High perm & Low skin
Hyperbolic behavior in the Productivity (PI) plot indicates that the well is likely to be in a channel/horizontal or frac’ed system. The above plots are good diagnostic tool to evaluate if:

• Well lost/gained pay?
• Improved/increased skin?
• Did anything happen to the completion?
The well is in a linear system. Its drainage is still growing, but it is possible to quantify minimum connected and mobile volumes

- If expansion drive
  - Min connected/mobile volume ~ Z BCF
- If water drive
  - Min connected/mobile volume ~ 0.64 Z BCF
Using the pressure drop between 2 gauges, gas rate can be accurately calculated
- Calculated gas rate matched occasionally measured separator gas rates
- Invalid test separator rates were detected; rates were changed during the well test
- During the Build-ups, the Condensate Yield can be determined, and applied to interim sales oil rate calculations

Once the rate is calculated, the mid-completion BHP can be calculated accurately and pressure transient analysis, reservoir volume calculations can be performed
Automated PTA
  • High k
  • Low skin

Relative PI and Inverse Plots
  • The well is likely to be in a linear system, the drainage volume is still growing

Minimum Reservoir Volume
  • Min Connected Volume ~ Z BCF
  • Min Mobile Volume ~ 0.64 Z BCF
Deepwater Oil Well (Water?)

• Start-up of New Deepwater Well (subsea)
  After just 3 months of Production, the well started making 4000 STB/D of WATER!

Objectives:
1) Find out where the water’s coming from
2) See if it justifies a work-over
Deepwater Oil – WBS
Cash Money #2 – Deepwater & BHP’s

Chris Fair-SPE Perth
Where did Water Production Begin???
YES...ALLOCATIONS REALLY ARE THIS BAD!!
## Deepwater Oil – PTA Summary: PBU

### Graph 1

- **Oil**, **Gas**, and **Water** production rates over time.
- Data: 11/26/2013 7:43 AM.

### Graph 2

- **关井** and **GSP** comparison.
- Data: 11/26/2013 11:47 AM.

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**Chris Fair**

SPE Perth
How Much Oil Should it Produce?

Chris Fair - SPE Perth
Deepwater Oil – Conclusions

• Err…no need to panic, it’s been making water since Day One
• Min In-place oil = 65 MM STB
• Max In-place oil = 260 MM STB
• Min recoverable oil = 40-ish MM STB

• Enough Oil to justify work-over…but, the well doesn’t need a work-over
Deep GOM Shelf – Gas/Condensate

- 18,000 psia $P_{\text{initial}}$; 330 degF
- Initial Flowback – 20 MMscf/D; 400 BOPD

Objectives:
- Can we pull it harder?
- How big is it?
- No, really...how big is it? How much is water?
- What’s up with the perms being all over the place?
GOM Shelf IPT

- Gulf Of Mexico Gas Condensate Well
- Has SCADA WHP Gauge + Instant Separator Gas and Periodic Liquid Rates
- Have To Apply Liquid Residence Time
  
- Objectives:
  - Calculate Liquid Rates
  - Analyze Build-up Tests
  - Split Apparent Reserves into Components
Logs – GOM Shelf
Permeability ~ 15 md, Skin Is Low And Remains Constant
Reservoir Pressure Drops 6000 psia
Reservoir Appears To Be In Depletion Drive
• No Major Shifts In Productivity (No Shifts In Scalar Value Or Slope)
• Inverse Productivity indicates Pseudo Steady-State Response
• P/Z Calculation and SLD-P Calculation Gives Us 4-10 BCF
Running Energy And Material Balances
LHS: Remaining Apparent Gas Volume
RHS: Total Gas Volume
This can be Compared With P/Z Results
GOM Shelf – Static and Flowing MBALS
GOM Shelf

- **LHS:**
  - SLD/Straight Line Depletion *(Red)*
  - P/Z Expansion/Depletion: *(Blue)*

- **RHS:**
  - Conventional Expansion: *(Red)*
  - Conventional SLD: *(Blue)*
  - TTA Compressibility: *(Purple)*
  - TTA SLD: *(Green)*
  - Gp: Black
  - Static MBAL To The Gas/Water Contact: *(Orange)*
Skin & Perm are fluctuating due to crossflow and differential depletion in high-perm zones

- Moderate Perm with Low Skin
- Gas on top of dead-leg water

Reservoir Volume: 10 BCF of potential elastic energy

- 3 BCF of water (dead leg)
- 1.5 BCF of rock compaction
- 5.5 BCF of Mobile Gas
- 1.0 BCF of “Tight” Gas
Chris Fair

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July 14, 2016

SPE – Perth