Automated Well Test Analysis

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Outline

• What is well test analysis? What does it tell you?
• How do you do it? Instrumentation
• How do you automate it?
• What are the advantages/disadvantages to automated PTA?
• Other Automated Processes
• Examples
• Conclusions
What is Well Test Analysis?

• Looking at squiggly lines in pressure and/or rate data to divine what’s happening in the completion and/or reservoir
• A science?
• An art?

• Maybe it’s just a tool to aid in understanding the well/reservoir?
What is Well Testing?

**Definition:**
Anything you do actively or passively to the rate/choke of a well that helps you diagnose what’s going on in the well bore, completion and/or reservoir.
What is Well Test Analysis?

• Using Pressure and Rate Data to:
  – Short-Term: Completion & Rock Properties
    • \text{kh (perm-thickness)}, \text{skin/damage}
  – Long-Term: Reservoir Evaluation
    • Distance to boundaries
    • Boundary Types
    • \textbf{Reservoir Pressure}
    • Reservoir Volume
    • Drive Mechanism
What is Permeability?

• The ability of the rock to flow fluids
• A measure of the cross-sectional area of the connected pores in a rock.
• Permeability is a variable. It can change (especially in the deepwater)!
• It allows you to calculate what your well SHOULD be producing.
What is Skin?

• A reduction in POTENTIAL flowrate caused by ANYTHING, aka an additional resistance, or pressure drop, to overcome.
  – Damage
  – Non-Darcy effects
  – Partial perforation
• Fudge factor for the near wellbore region of excess pressure drop.
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
• **Two-Rate**: Change the rate enough to create a new transient; observe P & Q
What Can Well Testing Tell You?

• What kind of well problem do I have?
  – Skin/Damage (High)
  – Perm (Low)
  – Reservoir Pressure/Reserves

• More advanced schtuff:
  – Reservoir Volume
  – Reservoir Energy Map
How to “Bird-Dog” a Well Production problem

• Is it a wellbore problem?
  – Scale/Wax/Asphaltenes, Loading, Parted String
• Is it a completion problem?
  – Skin Accretion, Screen Plugging, Completion Failure
• 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!
A Word or Two of Warning

• **Nodal Analysis** only tells you if there’s a problem…it doesn’t tell you where it is!
• Looking at only PBUs or only DDs can lead to problems – especially in the deepwater GOM
• Do every type of analysis possible, not just your favorite
• **DIFFERENCES MEAN SOMETHING!!!**
Instrumentation Needs

Based on Well Type
Basics

• Way to get $Q_{gas}$, $Q_{oil}$ & $Q_{water}$
• Way to get 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 yield is above 30 bbl/MMcf – dhgs are recommended
Naturally 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)
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
Nat Gas, CO2 & Steam Injectors

• 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.
Conclusions - Instrumentation

• End User should have a say in:
  – What instruments are used
  – Sampling Frequency
  – Deadbanding/Filtering

PE’s need to have good general knowledge of the bits that go into their acquired data
Different well types require different kits
COMMON WELL TEST TYPES
Build-up PTA
Build-up Derivative Analysis

- $P_* = 11520$ psia
- $kh = 1090$ md-ft
- $perm = 191$ md
- $Sk_{in} (st) = 5.6$
- $DP_{skin}/Q = 15.7$ psi/MMcf-D

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Drawdown - PTA

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Drawdown PTA - Semilog Analysis

- $P_i = 4795 \text{ psi}$
- $k_h = 6930 \text{ md-ft}$
- $Perm = 110 \text{ md}$
- $Skin (sT) = 21$
- $DPI_{skin}/Q = 8.5 \text{ psi/MMcf-D}$
2-Rate Test (Esp. for Oil)
2-Rate Derivative (Oil)
2-Rate Oil Semilog

- $k = 80$ md
- $\text{Skin} = 2.3$
- $PT\text{ Eff} = 123\%$
- $p^* = 2660$ psia
Horner Plot – P* Determination

- **BHP**
- **P* (y = -184.51 * log(x) + 11626)**

- Valve Cycling Events
- Re-Injection
- Water Movement Below DHG
- Start of Valid BHPs

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RESERVOIR BOUNDARIES
Blind Energy Map

WAVEX Energy Map

SMI 109
No. A-1
Anomaly 508'-549'
622'
1,345'
1,736'
1,969'
2,784'

$R_{inv} = 3,215'$

Scale: 1" = 1,000'

154'

1-2-3-4 Limit Rotation

Energy Width 1,798'

Energy Map
OK...

...Now, let’s meet with the G&G team

This is the point to begin integration of Well Testing & Seismic.
WAVEX Energy Map

1-2-3-4 Limit Rotation

Energy Width 1,798'

SMI 109
No. A-1
Anomaly 508'-549'
622'
1,345'
1,736'
1,969'
2,784'

Rinv = 3,215'
Scale: 1" = 1,000'
OK...this might be useful...

How do you Automate it?
Transient and Regime Recognition

• 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

Oilfield Data Services Inc.
Date created: 8/13/2010 11:54 PM

The diagram shows a graph of pressure (psi) over time, with markers indicating specific dates and times, spanning from Jul 2008 to 22 Fri.
Transient Recognition
Regime Recognition
Regime Recognition
Well Test Automation Requirements

• Recognize Radial Flow (RF)
• Recognize Boundaries
• Recognize Steady-State Flow

• Calculate Fluid Properties
• Apply the right boundary Conditions
• Create Rules for the Computer to Follow
Advantages to Automation

• Every Possible Well Test Is Analyzed
  – Not just cherry picked tests
• Much faster for engineer to check the results than to analyze themselves
• Auto-Analysis is performed without bias, or with a known bias
• Cheaper & Faster (not necessarily better)
• PTA becomes more democratized
Disadvantages to Auto PTA

• Engineers become lackadaisical & forget how to do it themselves
  – Loose frame of reference
  – Start Trusting the computer
• “Experts” lose prestige
  – “Expert” definition: Someone who knows so much, they’ve stopped learning
• The Computer doesn’t know if it’s wrong, it just follows the rules
Other Things that Have Been Automated

- Gas Rate Calculations (need DHPG)
- Water Cut Calculations (need DHPG)
- Apparent HC volumes
- Mobile HC volumes
GOM Ex: Apparent Volumes
Strategies for Dealing with Automated 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 you decisions

If you know how much money you have left in the ground and understand the well history, you’ll make better decisions
Real-Time Examples
RTS Examples List

• North Sea #1
• HPHT GOM Gas-Condy
• Fizzy Oil – GOM
• NordZee – Gas
• Deepwater GOM Oil – Onset of Water?
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 WBD

![Diagram of North Sea #1 WBD](image)
North Sea #1 - Summary
# North Sea #1 - PBUs

![Graphs and tables related to North Sea #1 well performance](image-url)
North Sea #1 - DDs
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
HPHT GOM Gas-Condy
Extended Well Test

Set-up:
• Well Flowed-Back 6 months ago
• “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
DOT - Summary
DOT - Productivity
DOT – P/z and MBAL/EBAL
DOT - Conclusions

• 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 - WBD
Fizzy-1 Logs
Fizzy - Summary
Fizzy - Productivity
Fizzy – Flowing MBAL/EBAL
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
Nordzee #1

- Gas Well with Subsea Tree
- “Single Zone”? reservoir, but with possible baffles
  - MDTs match gas gradient
- Not fully cleaned-up during initial completion test

- Objectives:
  - Determine skin/perm
  - Determine in-place HCs
  - Estimate Recovery
Nordzee #1 - Logs
Nordzee #1 Full Logs
Nordzee Summary
Nordzee Productivity
Nordzee – Running MBAL/EBAL
Nordzee – P/z
Nordzee - Conclusion

• Early PBUs occurred when well was still cleaning up – accurate for what was flowing at the time, but not whole zone
• No good drawdowns
• PBU perms around 85 md, with a skin around 13
• Apparently 15 BCF hydraulically connected
• At least 11 BCF recoverable
Deepwater Oil Well (Water?)

- Start-up of New Deepwater Well (subsea)
  After just 3 months of Production, 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 – Allocated Rates

Where’d the water come from?
Deepwater Oil - WBS
Deepwater Oil – Interp. Log
Deepwater Well – Triple Combo
Deepwater Oil – RTS Summary
# Deepwater Oil – PBU Summary

## Summary Table

| Date/Time (dd/mm/yyyy) | End Date/Time (dd/mm/yyyy) | Start Length (Hours) | Test Type | WWIP (psia) | GHP (psia) | BHP (psia) | SKP (psia) | QIP (BBL/D) | QIP (STB/D) | Perm (md) | Skin | EIP Date | PI [STB/PRI] | PI [STB/STB] | PI [STB/PRI] | PI [STB/STB] | Report Link |
|------------------------|---------------------------|----------------------|-----------|-------------|------------|------------|------------|-------------|-------------|-----------|------|----------|--------------|--------------|--------------|--------------|-------------|-------------|
| 01/06/2012 10:00:00    | 01/06/2012 22:56:00       | 06/06/2012 10:24:00  | PBU        | 79.15       | 8063       | 11003      | 12011      | 12010       | 12221       | 4380      | 4380     | 447.2    | 0.8           | 21           | 12241        | 88           | 0           | R1Ref: 2012Jan5 10240 |
| 10/06/2012 10:44:00    | 10/06/2012 07:11:00       | 13/06/2012 10:46:00  | PBU        | 5923        | 8032       | 10769      | 11973      | 11027       | 12183       | 19003     | 19003    | 496      | 3.3           | 385          | 12283        | 65           | 0.02         | R1Ref: 2012Jan10 10440 |
| 18/06/2012 13:05:00    | 19/06/2012 04:11:00       | 15/06/2012 11:58:00  | PBU        | 6665        | 8032       | 11058      | 11890      | 11293       | 12095       | 13665     | 13665    | 234.2    | 1.6           | -220         | 12271        | 135          | 0.02         | R1Ref: 2012Jun1 13040 |
| 24/06/2012 07:37:00    | 27/06/2012 03:33:00       | 12/06/2012 10:28:00  | PBU        | 7189        | 8021       | 11290      | 11938      | 11504       | 12105       | 9070      | 9070     | 358.4    | 0.6           | 39           | 12245        | 91           | 0.02         | R1Ref: 2012Jun10 10440 |
| 06/07/2012 03:00:00    | 08/07/2012 23:54:00       | 12/07/2012 10:28:00  | PBU        | 6069        | 7917       | 10711      | 11777      | 10957       | 11983       | 15631     | 15631    | 522.6    | 5.6           | 426          | 12145        | 53           | 0.03         | R1Ref: 2012Jul10 13040 |
| 20/07/2012 19:59:30    | 21/07/2012 07:59:30       | 12/07/2012 10:28:00  | PBU        | 5532        | 7700       | 10906      | 11599      | 10500       | 11796       | 15579     | 15579    | 241.4    | 0.4           | 63           | 12004        | 94           | 0.02         | R1Ref: 2012Aug10 13040 |
| 25/08/2012 06:52:30    | 07/09/2012 13:44:30       | 09/08/2012 04:04:30  | PBU        | 4994        | 7805       | 5940       | 11731      | 10209       | 11940       | 18213     | 18213    | 614.6    | 13            | 981          | 11996        | 32           | 0.06         | R1Ref: 2012Sep10 13040 |
| 09/09/2012 15:10:30    | 10/09/2012 04:04:30       | 12/09/2012 10:28:00  | PBU        | 5043        | 7635       | 10044      | 16552      | 10310       | 11857       | 16157     | 16157    | 599.8    | 14.2          | 1008         | 12028        | 31           | 0.04         | R1Ref: 2012Sep10 13040 |
| 15/09/2012 15:23:30    | 16/09/2012 11:51:30       | 20/09/2012 10:28:00  | PBU        | 4852        | 7608       | 9903       | 11605      | 10172       | 11818       | 17270     | 17270    | 389.6    | 6.8           | 774          | 12005        | 48           | 0.04         | R1Ref: 2012Sep10 13040 |
# Deepwater Oil – DD Summary

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Deepwater Oil – MBAL/EBAL
Deepwater Oil – Calc Rates Summary
Deepwater Oil - Conclusions

- Err...no need to panic, it’s been making water since day 1
- In-place oil = 65 MM STB
- Apparent recoverable oil = 40-ish MM STB
- Enough Oil to justify work-over...but, the well doesn’t need a work-over
CONCLUSIONS
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: Well Test Automation

• This technology is already here!
• Production/Reservoir Engineers need to be Generalist
• 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”
Conclusions: Engineering Work Flow

• Check Results...if needed do the analysis manually
• Understand the system, not just your silo
• Understand how everything inter-relates
• Think about how what has happened will affect you Decisions!
• Don’t be a Technician...Be an Engineer!