Webinars

Creating KPI Dashboards and Threat Arrays from Surveillance Data

Chris Fair, Oilfield Data Services, Inc. (ODSI)

April 14, 2023

1

Webinars

SPE Webinars are Sponsored by:

SPE Foundation

2

Outline – Creating Surveillance Dashboards

Webinars

- Intro to RE/PE Surveillance – Timing and Tools
- Rates and BHPs!
- What is Your Job as a Surveillance Engineer?
- What can go Wrong with Your Well? How Can You Tell?
  - Using Auto-PTA to Recognize Trends
  - Using Mobility-Thickness to Predict Catastrophic Shear Failure Pressure
- Example: Managing a Trainwreck
- Tracking KPI's & Presenting Results to Management
  - Oil Well Example and Gas Well Example
  - Dashboards, Spreadsheets, Bubble Maps and Commentary
- Concluding Remarks

SPE International

3

3

Surveillance: How to Play the Game!

Two Big Ideas to Focus on NPV!	• **Well Performance**: Maximizing well performance and rates while maintaining completion and well integrity • **Reserves Recovery:** Confidence band in reserves and how it changes over time • Maximizing reserves recovery
Initial Surveillance (Evaluation)	• What do I have? (Current well performance conditions and reserves) • Are there any problems? (Perm, skin, small reserve volumes?) • If there are currently no problems, am I expecting any near-term and/or long-term problems?
Day-to-Day Surveillance	• What are the current oil/gas/water rates? Are they in line with expectations for this well? • Is anything changing with the well performance? • What is changing? Why is it changing?
Long-Term Surveillance	• Is anything changing with reserves? How are they changing? Why are they changing? • Are there any infill, sidetrack, and development opportunities? • How historical producers behaved can inform on the type of projects and locations for capturing remaining reserves

Most Critical Data for Surveillance: Rates & BHPs

Oil/Gas/Water Rates

- Flow Meters
- Well Tests
- Allocations
- Virtual Metering
  - DPwb
  - DP across choke (very dodgy)
  - Temperature based
  - Choke Setting
  - Glorified Curve Fitting

Valid Bottomhole Pressures

- How do you get valid BHPs?
  - Correlations
  - Mechanistic Models
  - Empirical Models
  - Gradient Models
  - P.I. back-calculation from Allocations

Where did your rate come from?

Note: All Rate 'Measurements' are subject to Error!
- Know how your 'measurements' work; know how they break

Is the error in the flow rate consistent?
- The implications could affect surveillance analyses (skin, perm, P.I., etc.)

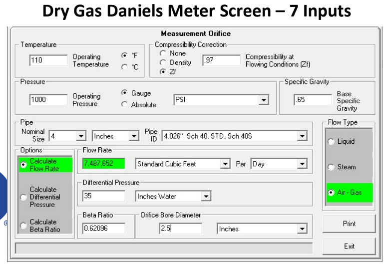
What Can Go wrong w/ Rate Measurements?

Where did your rate come from?

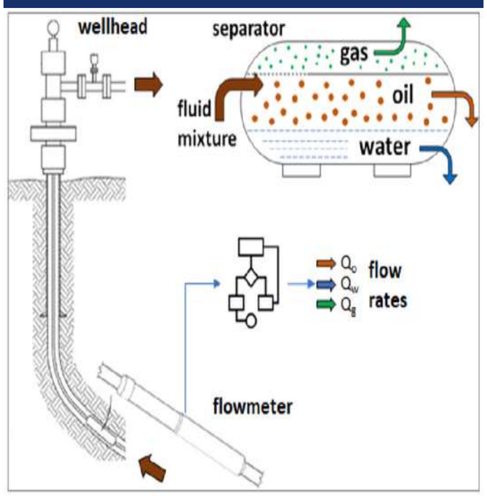
- Dedicated Separator (corrected to STB/s.c.?)
- Meter (right meter for the phases?)
- Virtual Meter
  - DPwb
  - Temperatures
  - Choke Setting
  - Glorified Curve Fitting
- Production Universe-Like System (P.I.)
- Back-Allocation
- SWAG?

Example – How is Rate "Measured"

Dry Gas Daniels Meter Screen – 7 Inputs



Rate measurements along the way



6

What Can Go Wrong w/ Rate Measurements?

Webinars

Test Separator	D/P Meters	Multi-phase Flow Meters	Virtual Metering

• Plugged Sensing Lines
• Wrong Orifice Size (Input for calcs; Outside of Sweet Spot)
• Wrong Turbine Meter Counts
• Dump Valve Blocked
• Previous Well's Fluids still in separator/lines
• Wrong Time Interval
• Wrong Well in Test
• Wrong Shrink Factor
• Boiler plating
• Fat Fingering/Numbers Backward/Human Error in Inputs
• Inefficient Separation (Emulsion, Flooding, Sand in Sep)
	• Scale/Fouling (diameter decrease/friction increase)
	• Wrong Orifice Diameter
	• Wrong/Changing PVT
	• Plugged Lines
	• Wrong Inputs for Calculations
		• **Actual Multi-phase Flow (especially free gas)**
		• Incorrect/Changing PVT
		• Solids
		• Scale/Deposition
		• Improper Calibration/Re-calibration
		• Fixed GOR-based Calculations
		• Wrong Conversion to STB/s.c.
			• What is it really doing?
			  • Is PVT included? (Pressure, Temperature?)
			  • Just an Analog?
			  • Just a Type Curve?
			  • Just a Choke Position?
			  • Just an Input?
			  • Just based on P.I. and your last well test?
			  • Just the number your boss wants to see?
			• VM Technology has really progressed! Sometimes, it's better than metered rates!

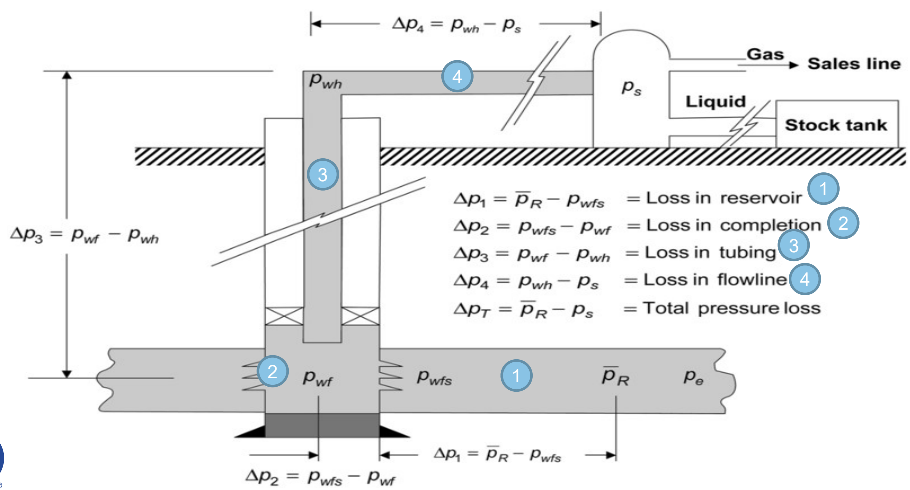
SPE International

7

7

The Parts of the System You can Evaluate

Find the pressure drop that shouldn't be there (and get rid of it)!



What Engineering Tools do we have?

Webinars

- Nodal (VLP & IPR)
- PTA/TTA Well Test Analysis (PBU, DD; 2-Rate Tests)
- Automated PTA/RTA
- Static & Flowing MBAL
- Boundary Volumetrics
- Conventional Decline
- TTA/RTA Decline
- Reservoir Simulation

SPE International

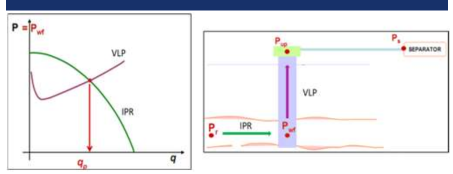
9

NODAL Analysis – IPR + VLP

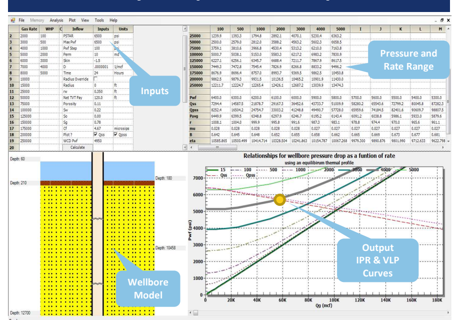
NODAL Description

- **NODAL Analysis is a combination of Reservoir deliverability (Inflow Performance Relationship) and Wellbore deliverability (Vertical Lift Performance)**
- **<u>Benefits of NODAL:</u>**
  - Prediction of DP to achieve a Rate (vice versa)
  - Prediction of Liquid Loading Scenarios
  - Optimization of Tubular Design
- **<u>Problems with NODAL:</u>**
  - **Doesn't Decouple Skin & Perm!**
  - **Infinite # of combos of skin and perm to calculate the same rate (can't use NODAL to determine skin or perm)**
  - Reservoir Pressure can change too!!!
  - User has to pick the right inflow model and right VLP/PVT correlations
  - User has to choose the right drive mechanism (Watch Out! It can change!)
  - Doesn't handle transient situations well – may match your well today, but not next month

IPR and VLP Curves

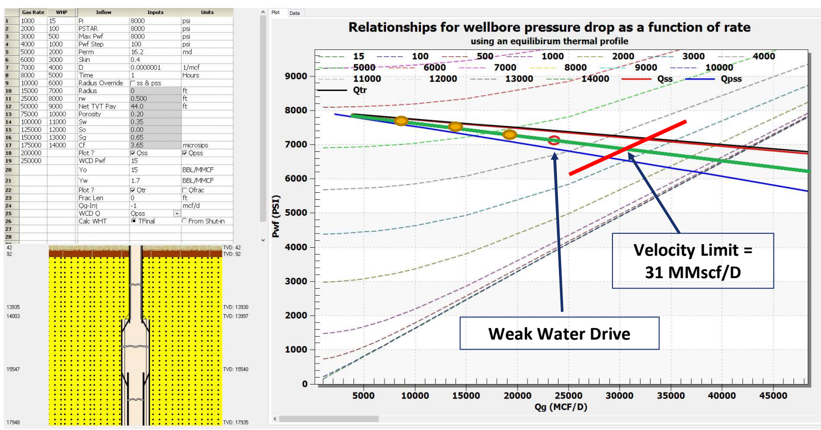


Analysis Inputs and Outputs



Rate After Rate Matches – Drive Mech (Nodal)

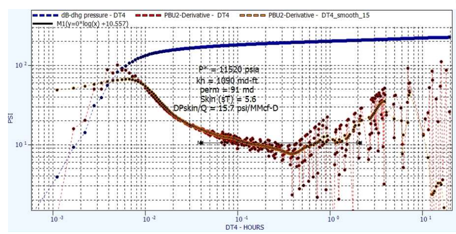
If Drive Components Aren't Changing – Projected Rates & DDs

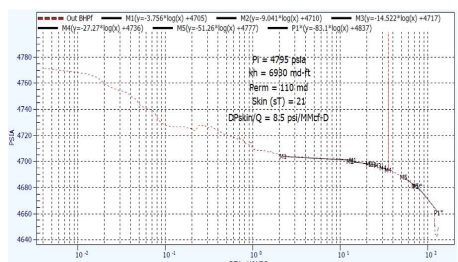


Pressure Transient Analysis (PTA)

PTA Description

- **Pressure Transient Analysis uses changes in pressure to determine reservoir parameters such as productivity, average reservoir pressure, reservoir size, boundary locations, types of boundaries, etc.**
- Build-up: After flowing the well for awhile, shut it in and observe the pressure response
  - If long enough, the build-up can provide valid P*
- Drawdown: After shutting in the well for awhile, flow the well on a constant choke and observe the pressure and rate response
- 2-rate: Change the rate enough to create a new transient; observe the pressure and rate
- Multi-Rate: Change the rates and compare Delta Pressure (DP) vs. Rate
- Communication: Shut-in a well and see if a neighboring well causes the pressure to drop





12

Static Material Balance (MBAL)

MBAL Description

- **Used to determine original fluids-in-place based on production and static pressure data**
- **MBAL equations considered assume tank-type behavior at any given datum depth – the reservoir is considered to have the same pressure and fluid properties at any location in the reservoir**
- A P/z for gas wells or a Static Material Balance for oil wells provide a means to evaluate the **total elastic energy in a reservoir**
- This volume is then translated into an HC volume to find the in-place volume and with an abandonment pressure to determine the maximum recoverable volume under a likely economic limit
- The biggest challenge with these calculations - they are counting EVERYTHING…gas, oil, water, and elastic energy in the rock, i.e. anything that can move, wiggle or expand
- This is why it is considered bad practice to use a P/z plot on gas wells with known water drive
- By applying another extreme case – that of Straight-Line Depletion (SLD), with hydrocarbons being pushed by an infinite aquifer – a minimum in-place hydrocarbon volume can be obtained
  - Assumption: no hydrocarbon expansion
  - These two cases then provide the bookends to the range of possible hydrocarbon volume in-place

General Equation

$$\underbrace{G_{fgi}E_g}_{\text{free-gas expansion}} + \underbrace{N_{foi}E_o}_{\text{free-oil expansion}} + \underbrace{WE_w}_{\text{free-water expansion}} + \underbrace{V_{pi}E_f}_{\text{pore-volume contraction}} + \underbrace{W_e}_{\text{water influx}}$$

$$= \underbrace{\left(G_p - G_I\right)\left(\frac{B_g - B_oR_v}{1 - R_vR_s}\right)}_{\text{net gas withdrawal}} + \underbrace{N_p\left(\frac{B_o - B_gR_s}{1 - R_vR_s}\right)}_{\text{oil withdrawal}} + \underbrace{\left(W_p - W_I\right)B_w}_{\text{net water withdrawal}},$$

<u>A P/z for gas wells or a Static Material Balance for oil wells provide a means to evaluate the total elastic energy in a reservoir.</u>

<u>A drawback of the Static MBAL is that the well needs to produce a meaningful amount for the volumes to be valid… But… Why???</u>

Volume – Working Equations

1-phase Oil

<u>Depletion Drive</u>

Static MBAL Vc $= \frac{N_p \times Bo}{Bo - Boi}$

<u>Infinite Water Drive</u>

Static MBAL SLD = $N_p \ x \ \frac{P_i}{P_i - P^*}$

1-phase Gas

<u>Depletion Drive</u>

Static MBAL Vc $= \frac{G_p \times Bg}{Bg - Bgi}$

<u>Infinite Water Drive</u>

Static MBAL SLD = $G_p \ x \ \frac{P_i}{P_i - P^*}$

Correction Factor to account for formation compressibility: Cpp/Ct, where Cpp is the compressibility of the primary phase.

SPE International

Static Material Balance (MBAL) – P* (Pres)

MBAL – Estimating P* (Preservoir)

- **There are two ways to estimate P*/Pres**

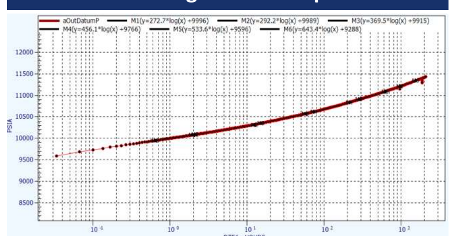
Semi-log (MDH)

- Usually the P* line is extrapolated to 1,000 hours (or DT at the edge of the hydrocarbons); may change based on different well scenarios
- Why extrapolate to 1,000 hours? Because you are likely not going to recover any hydrocarbons beyond that point (DT ~ Distance)

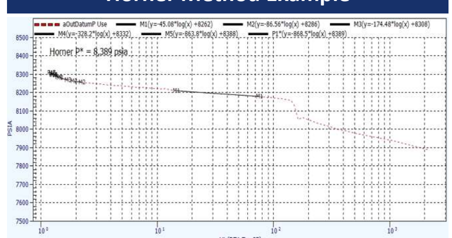
Horner Method

- Used when the well has not been producing for a long time, usually less than 3 to 4 months, or when the build-up is significantly longer than the flow period
- Horner Time Ratio = $\frac{t_p + \Delta t}{\Delta t}$
- Extrapolate P* line to a Horner Time of 1.0 (10^0)

Semi-log MDH Example



Horner Method Example



14

14

Boundary Volumetrics (BV)

BV Description

- Boundary volumetrics is an in-place volume calculation dependent on reservoir properties such as volume, porosity, and fluid saturations
- Preferably, this should be done 'blind', without seeing the reservoir map first
- Should be based solely on fluid & rock properties, as well as pressure & rate data
- Use two bookends to provide a range of volumes:
  - Constant Pay Thickness (h)
  - Pyramid Rule (h/3)
- Better understanding of reservoir when the 'blind' reservoir boundary evaluation is compared to the geological map

Original Oil/Gas In-Place Equations

OOIP = $\frac{A\ h\ \emptyset\ S_o}{B_{oi} \times 5.615\ \frac{cu\ ft}{bbl}}$ *in STB*

OGIP = $\frac{A\ h\ \emptyset\ S_g}{B_{gi} \times 5.615\ \frac{cu\ ft}{bbl} \times 1000000}$ *in BCF*

The Area (A) is determined from the boundaries from PTAs

Working Equations

- To get the area, you'll need to calculate the distance
  - Distance to a boundary = $2\sqrt{\eta * \Delta t}$ *in ft*
- To get the distance, you'll need to calculate the hydraulic diffusivity
  - Hydraulic Diffusivity: $\eta = \frac{0.0002637 * k}{\phi \mu C_t}$ *in ft2/hr*

Boundary Volumetrics (BV)

Webinars

Identifying Boundary Contact Types

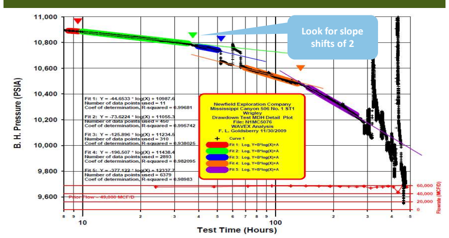
- No Flow Boundary (Stratigraphic or Fault)
  - Slope ratio ~ 2
- Gas/Water Contact
  - Pressure curve bounces and exhibits a slope ratio of 1.6
- Oil/Water Contact
  - Pressure curve flattens if the water mobility is higher than oil
  - Pressure curve bounces if water mobility is lower than oil (like gas, just with a different slope ratio)

Each of these boundary contacts exhibit a specific pressure response on a Semi-log plot.

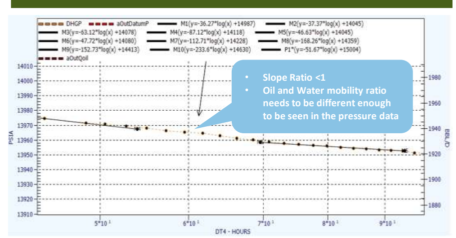
In a high formation compressibility environment, it is highly recommended to use drawdowns to find boundaries – build-ups are suppressed due to rock relaxation

SPE International

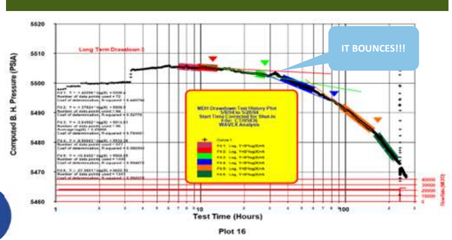
Stratigraphic and Faults



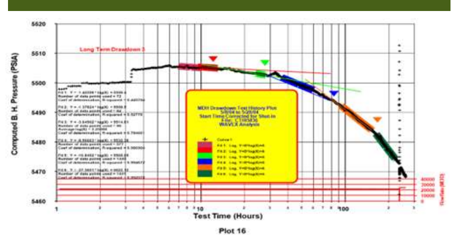
Oil/Water Contacts



Gas/Water Contact



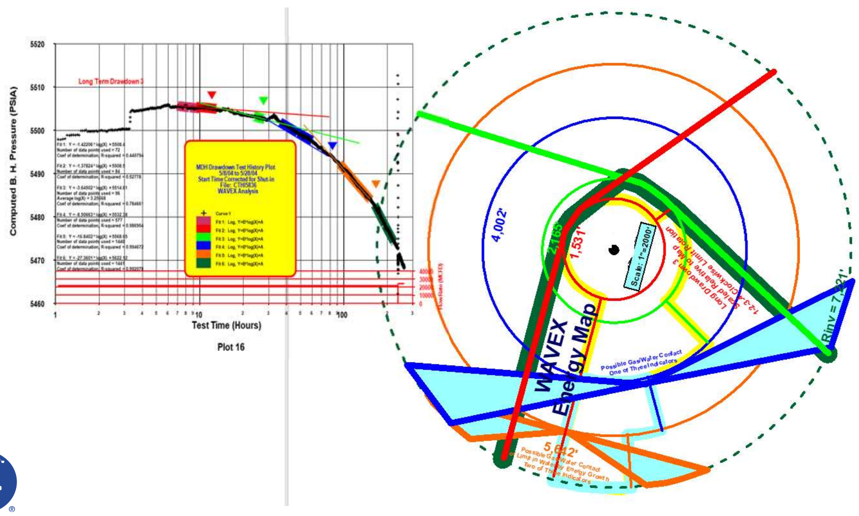
More Complicated Geometries



Boundary Volumetrics (BV) – Blind Mapping

Webinars

“Blind” Reservoir Image



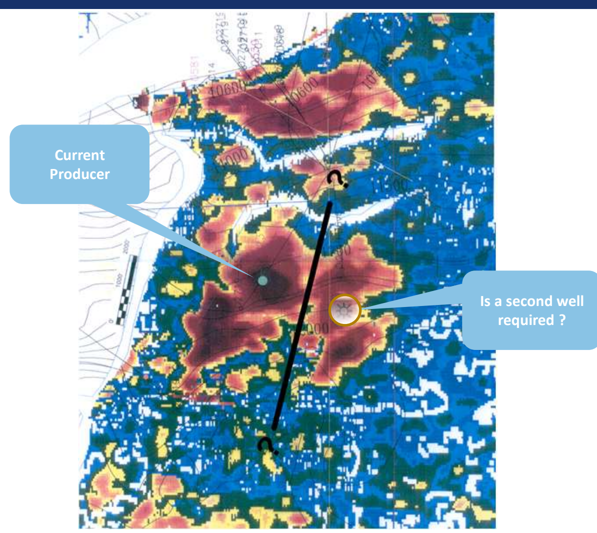
SPE International

18

Blind Mapping – Geo Image

Webinars

Geo-Blob Map

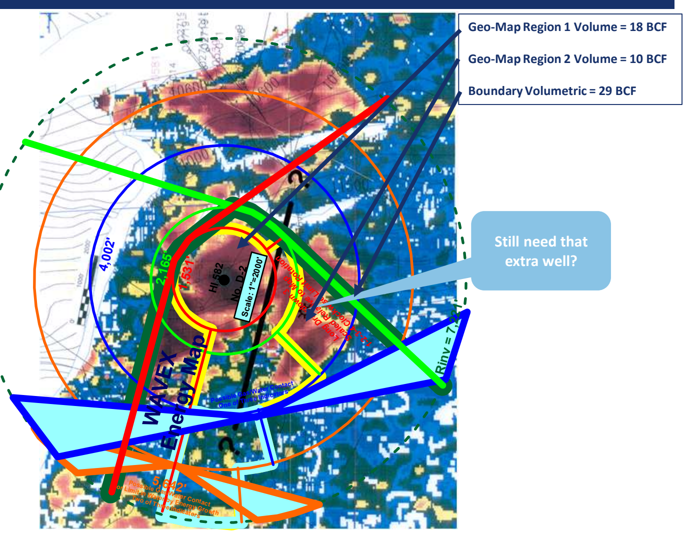


SPE International

Boundary Volumetrics (BV) – Blind Mapping

Webinars

Boundary-Geo Overlay and Volume Comparison



SPE International

Decline Analysis

Webinars

Decline Analysis Description

- **Decline Analysis should not be confused with Decline CURVE Analysis**
- **Conventional Decline Analysis = Hydraulically Connected Volumes**
  - The compressibility volume is determined using the rate of decay with pressure per unit time (i.e. PSI/day) on a Cartesian plot
  - If a reservoir is in a closed system and once all of the boundaries of the reservoir are encountered, the well will then transition to some sort of steady-state flow (usually PSS)
- **Thermodynamic Transient Analysis (TTA) = Mobile volumes**
  - Thermodynamic Transient Analysis, TTA refers to any technique of analysis that applies the constant driving force solution of the diffusivity equation.
  - Mobile Volume are hydrocarbons that are not only connected but also currently moving towards the well
- It's easier to think in terms of energy…
- Conventional Decline Analysis is hydraulically connected energy….
- TTA Decline Analysis is mobile energy…
- How do we know what type of energy it is? That's where the engineering comes in!
- One important concept to remember is that the mobile volumes should be equal or less than the connected volumes
  - If the mobile volumes are greater than the connected volumes, then that should be a red flag!!!

Working Equation Matrix

	Connected Volume	Mobile Volume
Depletion via Compressibility	$Conv.\,V_c = \frac{Q_{avg}}{Slope_{DP-DT}} * \frac{1}{C_t}$	$TTA\,V_c = \frac{1}{Slope_{DTTA-DT}} * \frac{1}{C_t}$
Straight Line Depletion via Displacement	$Conv.\,V_{SLD} = \frac{Q_{avg}}{Slope_{DP-DT}} * P_{res.}$	$TTA\,V_{SLD} = \frac{1}{Slope_{DTTA-DT}} * P_{res.}$

Thermodynamic Transient Analysis (TTA)

- TTA is the inverse of relative productivity, so as TTA function increases, productivity decreases and vice versa
  - Units are (PSI/STB/DAY)/DAY
- Pi is initial reservoir pressure - constant
- TTA is a tool used to monitor apparent productivity and how it changes with various reservoir/non-reservoir events
- It is also used to estimate reservoir volumes and for well testing purposes and for modeling rates
- RTA allows Pi to 'float' in order to 'game' reserves

SPE International

Decline Analysis Definitions

Acronyms

- **Vc** – Compressibility Volume (apparent energy from oil or gas expansion)
- **SLD** – Straight-Line Depletion (apparent energy not related to oil or gas expansion)
- **TTA** – Thermodynamic Transient Analysis (coupled term of rate and pressure drop in reservoir: DPreservoir/Rate)
- **DP/DT** – Change in pressure per unit time (psi/day)
- **DTTA/DT** – Change in the TTA function per unit time (psi/rate per day)

Four Flowing MBAL/EBAL Calcs

- **Two Simple Bookends:**
  - Vc =Expansion Drive Only (Compressibility Volume)
  - Vsld=Infinite Water Drive Only (Pushed Volume)
  - These two bookends are applied for min and max number
  - In reality, the real answer is somewhere in-between, but this a very useful tool when you're trying to make decisions
- **Conventional SLD**: Hydraulically Connected Potential Elastic Energy, assuming infinite water drive
- **Conventional Vc**: Hydraulically Connected Potential Elastic Energy, assuming expansion drive
- **TTA-SLD**: Mobile Connected Apparent HC Volume, assuming infinite water drive
- **TTA-Vc**: Mobile Connected Apparent HC Volume, assuming expansion drive

22

22

Decline Analysis – Types of Flow Regimes

Conventional Wells

- **Transient Flow** — The pressure transient migrates outward from the well without encountering any boundaries
- **Boundary-Dominated Flow** — The pressure transient has reached one or more boundaries (but not all) and the static pressure is not declining uniformly across the reservoir
- **Pseudo-Steady State Flow** — The pressure transient has reached all of the boundaries and the static pressure is declining at the boundary and declining uniformly throughout the reservoir
- **Steady State Flow** — The pressure transient has reached all of the boundaries but the static pressure at the boundary does not decline
- **Linear Flow/Channel Flow** – Cartesian Linear Pressure decline (flow occurs in long, narrow reservoirs) after hitting two parallel boundaries
- **Hybrids Flow Systems**
  - Channel-Levy (Beware of Re-injection)
  - High-Perm Fairway/Blob – Low Perm Feed (HPF-LPF)
  - Weak Water Drive
- **Horizontal Conventional Wells (additional regimes)**
  - 1st Radial
  - Linear Horizontal
  - 2nd Radial

Unconventional Wells

- **Frac** – Flow from just the fracture network itself
- **Linear Frac (FDR)** – Flow within the fracture and from the fracture-affected matrix to the wellbore without much contribution from the unfractured matrix
- **Linear Matrix (Hybrid)** – Flow travels from the formation perpendicular to the length of the wellbore and dominates the fracture response (assumes that the fracture conductivity is high enough that the ROI travels quickly through the fractures)
- **Matrix-Dominated** – The pressure transient has stabilized and behaves as a single equivalent between the fracture and matrix.
- **Quasi-PSS** – When there is significant contribution, the Linear Frac acts as if it is in PSS, while the matrix is in transient flow. This is similar to a HPF-LPF conventional reservoir.

Decline Analysis Workflow

Workflow	Basic Concepts

Workflow

- Identify straight-line sections in the DP-DT and the TTA Plots, draw slopes
- Only slopes during PSS/SS or Channel-Linear Flow considered
- Determine Produced Volumes at the point of the slopes
- Calculate Remaining and Total Apparent Volumes for the 4 Decline Analysis Methods

Basic Concepts

Reservoir Behavior

- Transient Flow: Connected and Mobile Volumes are increasing
- PSS: Connected and Mobile Volumes stabilizes to a number

Any increase energy/volume after PSS could be due to:

1. Water: ConVc increases but the TTAVc stay the same
2. Water mobilizes: ConVc trend stays the same but the TTAVc starts the increase.
   - In some cases, TTA Vc > ConVc or ConVc (PSS) = TTASLD or TTA slope of zero (indicating infinite volume)
3. Low perm feed: ConVc gradually increasing with TTAVc staying the same or ConVc and TTAVc gradually increasing…

24

24

Decline Analysis Workflow

Webinars

Hydraulically Connected Volume - Pressure On Left Axis

Mobile HC Volume - TTA on Left Axis

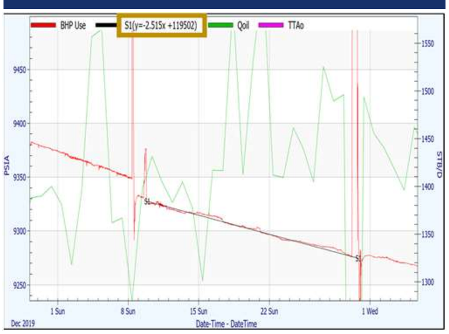
The analysis is used to determine Hydraulically Connected and Mobile HC volumes and how they are changing with time.

SPE International

Decline Analysis Workflow

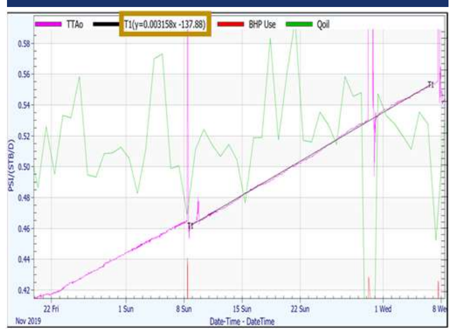
Webinars

Drawing Slopes on Pressure (DP/DT) Cartesian



- Find straight lines on the pressure function, where the period is longer than 1.5 days
- Select the same period as the TTA but on a constant choke (stabilized Qavg rates)
- Qavg = 1,425 STB/d
- Pressure = 9,300 psia
- DP/DT Slope = 2.515 psi/d

Drawing Slopes on TTA Cartesian



- Find straight lines on the TTA function, where the period is longer than 1.5 days
- Once the slope is drawn with the best fit, note the TTA slope and period of time it covered
- TTA Slope = 0.003158 psi/stb/d per day

SPE International

Decline Analysis Workflow

Gathering Other Important Parameters

- Total Compressibility (Ct) is based upon the compressibility of the rock/formation (Cf) and compressibility of all the fluids that are in the reservoir such as oil (Co), gas (Cg) and water (Cw)

- The fluid compressibility must also be corrected with saturation values

- Total Compressibility can be calculated using this formula:

$$C_t = (C_o * S_o) + (C_g * S_g) + (C_w * S_w) + C_f$$

- The default value for Cw is 0.000003 Sips or 3 MicroSips (3 e-6 per psi)

Decline Analysis Workflow

Total compressibility (Ct) Calculation Example

- Calculating Ct using the following properties:
  - Oil compressibility of 0.00001 Sips with saturation of 0.8
  - Water Compressibility of 0.000003 Sips
  - No gas
  - Formation Compressibility of 25 microsips

$$C_t = (C_o * S_o) + (C_g * S_g) + (C_w * S_w) + C_f$$

$$C_t = (10 * 0.8) + 0 + (3 * 0.2) + 25$$

$$C_t = 33.6\ microSips\ or\ 33.6x10^{-6}\ per\ psi$$

Decline Analysis Workflow

Webinars

Decline Analysis Calculation Example

- Based on the previous slides, we have the following parameters:
  - DP-DT Slope = 2.515 PSI/D
  - TTA Slope = 0.003158 PSI/(STB/D)/D
  - Pressure = 9,300 PSIA
  - Qavg = 1,425 STB/D
  - Ct = 33.6 microsips

- We can now Calculate Connected and Mobile Volumes for this specific period

SPE International

Decline Analysis Workflow

DP/DT Calculation

$$Conv.\ V_c = \frac{Q_{avg}}{Slope_{DP-DT}} * \frac{1}{C_t} = \frac{1425\ \frac{STB}{D}}{2.515\ \frac{PSIA}{D}} * \frac{1}{33.6 * 10^{-6}\ \frac{1}{PSIA}}$$

$$\boxed{= 16.86\ MM\ STB}$$

$$Conv.\ V_{SLD} = \frac{Q_{avg}}{Slope_{DP-DT}} * P = \frac{1425\ \frac{STB}{D}}{2.515\ \frac{PSIA}{D}} * 9300\ PSIA$$

$$\boxed{= 5.27\ MM\ STB}$$

TTA Calculation

$$TTA\ V_c = \frac{1}{Slope_{DTTA-DT}} * \frac{1}{C_t} = \frac{1}{0.003158 \frac{\frac{PSI}{STB}}{\frac{D}{D}}} * \frac{1}{33.6 * 10^{-6}\ \frac{1}{PSI}}$$

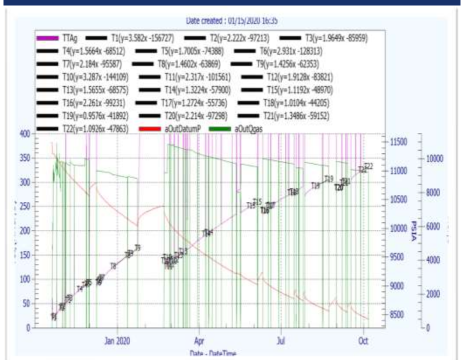
$$\boxed{= 9.43\ MM\ STB}$$

$$TTA\ V_{SLD} = \frac{1}{Slope_{DTTA-DT}} * P = \frac{1}{0.003158 \frac{\frac{PSI}{STB}}{\frac{D}{D}}} * 9300\ PSIA$$

$$\boxed{= 2.95\ MM\ STB}$$

Decline Analysis Workflow

Slopes Drawn Throughout the Prod. History



- Drawn Slopes are tracked throughout the well's production history
    - Done for both the DP/DT and TTA
- Each slope represents the time period with the calculated connected and mobile volumes

Calculation Table

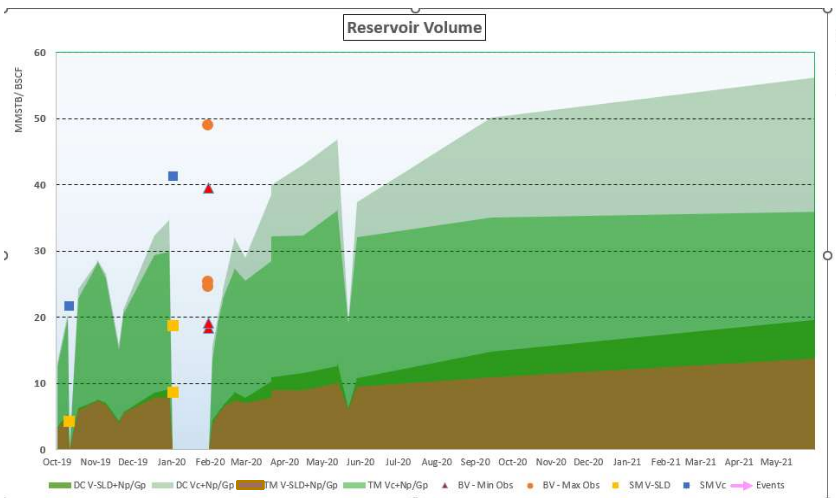
Conventional Decline/Connected Volumes												
Slope	**Date**	**Pres/Pavg**	**Bg**	**DP/DT**	**Qgas(avg)**	**Ct**	**V-SLD**	**Vc**	**Incr Gp**	**Gp**	**VSLD + Gp**	**Vc + Gp**
#	mm/dd/yyyy	PSIA	BBL/MCF	PSIA/D	MMCF/D	msips	**BCF**	**BCF**	**BCF**	**BCF**	**BCF**	**BCF**
S1	10/22/2019	11473	0.578	30.82	9.131	22.368	**3.4**	**13.2**	**0.020**	**0.020**	**3.42**	**13.27**
S2	10/31/2019	11390	0.579	21.07	9.825	22.469	**5.3**	**20.8**	**0.086**	**0.106**	**5.42**	**20.86**
S3	11/08/2019	11322	0.580	17.758	9.624	22.553	**6.1**	**24.0**	**0.073**	**0.179**	**6.32**	**24.21**
S4	11/23/2019	11222	0.581	14.913	9.605	22.679	**7.2**	**28.4**	**0.143**	**0.323**	**7.55**	**28.72**
Long Shut-in (11/30/2019 - 12/08/219)/Restart												
S9	12/11/19	11086	0.582	25.83	9.283	22.854	**4.0**	**15.7**	**0.090**	**0.413**	**4.40**	**16.14**
S5	12/14/2019	11054	0.583	19.56	9.259	22.897	**5.2**	**20.7**	**0.030**	**0.442**	**5.68**	**21.12**
S7	01/20/2020	10769	0.586	10.89	8.874	23.286	**8.8**	**35.0**	**0.335**	**0.777**	**9.55**	**35.78**
Long Shut-in (01/23/2020 - 02/21/2020)/Restart												
S10	02/24/2020	10480	0.589	28.42	9.168	23.707	**3.38**	**13.61**	**0.058**	**0.835**	**4.22**	**14.44**
S11	02/28/2020	10431	0.589	23.59	10.851	23.782	**4.80**	**19.34**	**0.033**	**0.867**	**5.67**	**20.21**
S12	03/03/2020	10360	0.590	18.40	10.208	23.891	**5.75**	**23.22**	**0.058**	**0.926**	**6.67**	**24.15**
S13	03/12/2020	10243	0.591	14.12	10.626	24.075	**7.71**	**31.26**	**0.081**	**1.007**	**8.72**	**32.27**
S14	04/11/2020	10118	0.593	10.54	10.135	24.278	**9.73**	**39.62**	**0.302**	**1.309**	**11.04**	**40.93**
S15	06/03/2020	9694	0.598	8.12	9.524	25.017	**11.37**	**46.87**	**0.513**	**1.821**	**13.19**	**48.69**
Long Shut-in (06/05/2020 - 06/10/2020)/Restart												
S16	06/12/2020	9617	0.599	20.78	9.983	25.161	**4.62**	**19.09**	**0.037**	**1.858**	**6.48**	**20.95**
S17	06/19/2020	9570	0.600	10.78	9.940	25.249	**8.82**	**36.51**	**0.059**	**1.917**	**10.74**	**38.43**
S19	10/05/2020	8699	0.612	6.72	9.239	27.128	**11.96**	**50.68**	**0.885**	**2.803**	**14.76**	**53.48**

TTA Decline/Mobile Volumes											
Slope	**Date**	**P*/Pavg**	**Bg**	**DTTA/DT**	**Ct**	**V-SLD**	**Vc**	**Incr Gp**	**cum Gp**	**TTA VSLD + Gp**	**TTA Vc + Gp**
#	mm/dd/yyyy	PSIA	BBL/MCF	PSIA/D	MMCF/D	msips	Bcf	Bcf	Bcf	Bcf	Bcf
T1	10/22/2019	11473	0.578	3.582	22.37	**3.2**	**12.5**	**0.020**	**0.020**	**3.223**	**12.50**
T2	10/31/2019	11390	0.579	2.222	22.47	**5.1**	**20.0**	**0.086**	**0.106**	**5.232**	**20.14**
T3	11/08/2019	11322	0.580	1.965	22.55	**5.8**	**22.6**	**0.073**	**0.179**	**5.942**	**22.75**
T4	11/23/2019	11222	0.581	1.566	22.68	**7.2**	**28.2**	**0.143**	**0.323**	**7.489**	**28.48**
Long Shut-in (11/30/2019 - 12/08/219)/Restart											
T5	12/11/19	11086	0.582	2.931	22.85	**3.8**	**14.9**	**0.090**	**0.413**	**4.195**	**15.34**
T6	12/14/2019	11054	0.583	2.184	22.90	**5.1**	**20.0**	**0.030**	**0.442**	**5.504**	**20.44**
T7	1/20/20	10769	0.586	1.4256	23.29	**7.6**	**30.1**	**0.335**	**0.777**	**8.331**	**30.90**
Long Shut-in (01/23/2020 - 02/21/2020)/Restart											
T8	02/24/2020	10480	0.589	3.287	23.71	**3.2**	**12.8**	**0.058**	**0.835**	**4.023**	**13.67**
T9	02/28/2020	10431	0.589	2.317	23.78	**4.5**	**18.1**	**0.033**	**0.867**	**5.369**	**19.02**
T10	03/03/2020	10360	0.590	1.9128	23.89	**5.4**	**21.9**	**0.058**	**0.926**	**6.342**	**22.81**
T11	03/12/2020	10243	0.591	1.5655	24.08	**6.5**	**26.5**	**0.081**	**1.007**	**7.550**	**27.54**
T12	04/11/2020	10118	0.593	1.3224	24.28	**7.7**	**31.1**	**0.302**	**1.309**	**8.960**	**32.46**
T13	06/03/2020	9694	0.598	1.1192	25.02	**8.7**	**35.7**	**0.513**	**1.821**	**10.483**	**37.54**
Long Shut-in (06/05/2020 - 06/10/2020)/Restart											
T14	06/12/2020	9617	0.599	2.261	25.16	**4.3**	**17.6**	**0.037**	**1.858**	**6.112**	**19.44**
T15	06/19/2020	9570	0.600	1.2724	25.25	**7.5**	**31.1**	**0.059**	**1.917**	**9.439**	**33.04**
T17	10/05/2020	8699	0.612	1.0681	27.13	**8.1**	**34.5**	**0.885**	**2.803**	**10.947**	**37.32**

- **Tracking the volumes from initial production provides valuable insight to the changes in volumes**
- Observing the trend in the connected volume and mobile volume can help identify
    - Gain or loss in connected energy?
    - Mobilization/movement of any energy?
    - Any changes within the reservoir or fluids?

31

Tracking the Decline Volume Functions

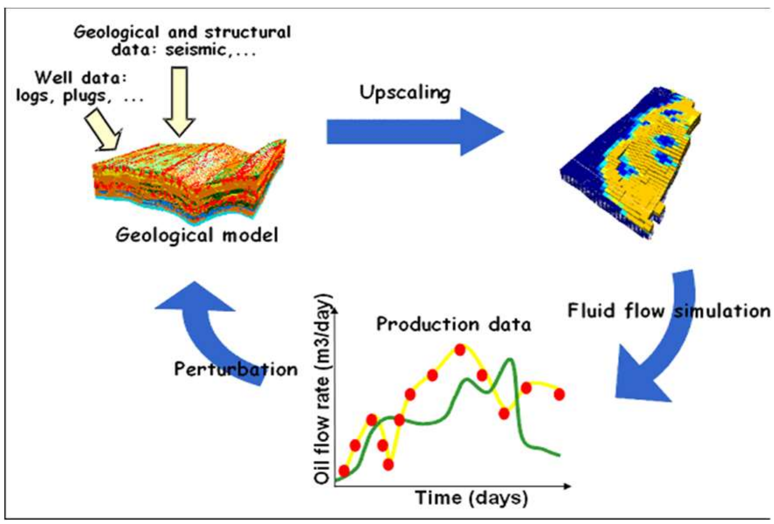


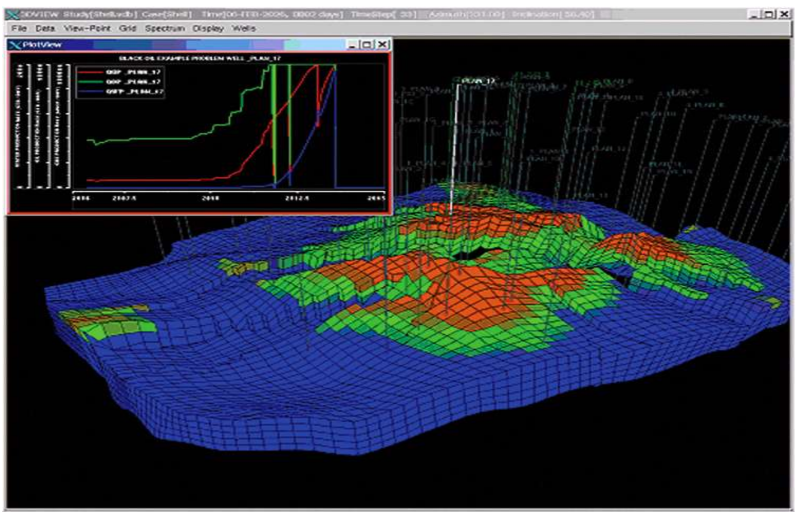
Webinars

SPE International

32

Reservoir Simulation Cycle





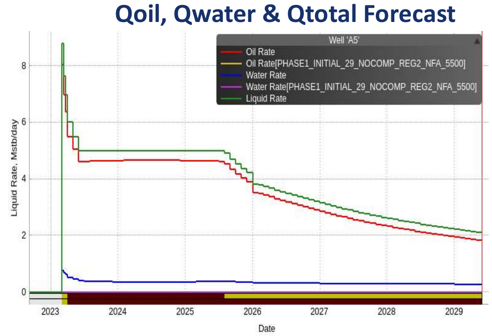
34

34

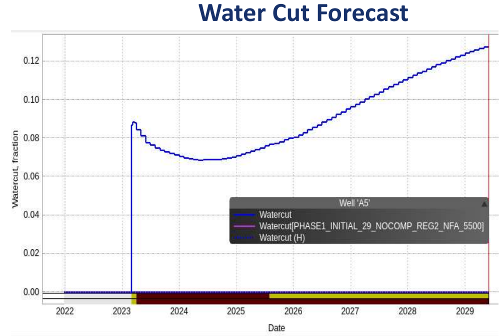
Long-Term Forecast from Res. Sim.

Webinars

Qoil, Qwater & Qtotal Forecast



Water Cut Forecast



SPE International

Reservoir & Production Engineering Surveillance

Webinars

Tools That Have Been Automated

- Pressure Transient Analysis – PBUs, DDs and Multi-Rate Tests
- Wellbore Regime Recognition
- Nodal & Transient Nodal Analysis
- BHP Conversion
- Static & Flowing Material Balance
- Decline Analysis (Conventional & TTA)
- Auto-Feed to Reservoir Simulation Models

SPE International

Reservoir Volume Calculation Summary

Webinars

Methods for Calculating Reservoir Volumes		
Method	**Type of Volume**	**Comment**
Boundary Volumetric	In-Place	Boxcar or Pyramid Rule
Static MBAL	In-Place	SLD & Vc Bookends (no TTA)
Conventional Decline	Connected	Pressure Decay
Flowing MBAL	Connected	SLD & Vc Bookends (no TTA)
TTA Decline	Mobile	TTA (Pi-Pwf/Q) Decay

- Note: Methodology and Equations used to calculate the volume vary based on phase behavior in the reservoir and drive mechanism
- Use **Nodal** for Short-Term Forecasts
- Use **Simulation** for Long-Term Forecasts

SPE International

37

37

What's Your Job as a Surveillance Engineer?

Webinars

Surveillance Engineer Duties

- All of the tools in the earlier slides have already been (or are in the process of being) automated
- You need to check the automation to make sure it's correct
- You still need to know how to analyze the data manually
- Your Job is to ***think about what it means***…

…and What to Do About it!

…and How to Use the Results to Make Your Company More Money!

But…Don't Get Caught Up in Automation Bias!

SPE International

38

38

Well Performance Impairments

What Can Go Wrong With Your Well?

Keep Track of Changes in Well Performance:

a. Skin Increase (or initially higher than you thought it would be)
b. Perm Decrease (or initially lower than you thought it would be)
c. Res. Pressure Decrease (or initially lower than you thought it would be)
d. Lifting/Wellbore issues (Water Head, scale, asphaltenes, wax, obstruction, tubing leak, parted string, bad packer seal)
e. High Flow Line back-pressure (flowline impairment/waxing/obstruction)
f. Flapper partially closed
g. Coning Gas and/or Water (High DD/High Skin)
h. Inefficient GLG/bad GLG design/Multi-porting
i. Non-Optimal Pump Design/Operation
j. Flow behind pipe (esp. water)
k. Choke plugging
l. Choke & Pipe Erosion (Solids)

Reserve Recovery/EUR/NPV Impairments

What Can Go Wrong With Your Well?

Keep Track of Changes in Reserve Recovery:

Are You Sure Your Reserves were Right in the first place?
- Will Throwing Money at the Problem Change That?
- Saving Money by Not Spending it on a Dog Well is Really Making Money!

a. Value Destruction Just to Get a High 1st Month's IP
b. Falling in Love with a Rate or Opening the Choke until it sands up (Proppant Fluidization & Catastrophic Shear Failure)
c. Unexpected Change in produced fluids (flow behind pipe, early break-through)
d. Shifting to the wrong ICV/SS position
e. Fault Activation/Baffle Jumping
f. Drilling Development Wells You Don't Really Need
g. Frac Hits
h. Asphaltene Plugging
i. Screen Cutting (Sand + Velocity)

The Short List of Big Trouble!

Well Performance/Recovery: Prevent These!

- Ripping the completion out of the ground
- Tearing up your tubing/flow lines/chokes
- Gunking-up your well bore or completion with scale, wax or asphaltenes
- Cutting out your screens
- Coning water and/or gas
- Flowing the Wrong Zone (Check your ICVs!)
- Burning up/Breaking your pump

41

41

Working in Teams
to Prevent Problems and Enhance Production

How Do you Tell?

- Figure out what catastrophe looks like
  - Which Failure Modes are Likely/Possible/Unlikely
- Train your system and your engineers to look for it and try to prevent it (without catastrophizing)
- Work Out Decision Trees with Ops/Production/Reservoir/MGMT to know what to do when something bad happens
- Recognize when you have a problem you can't fix economically
- Look for ways to Make or Save you company More Money!

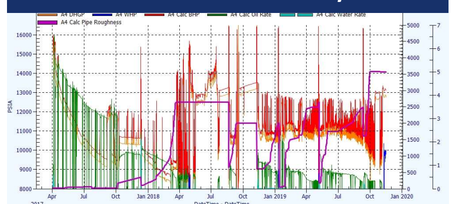
Example of Recognizing a Problem that Cannot be Fixed

Webinars

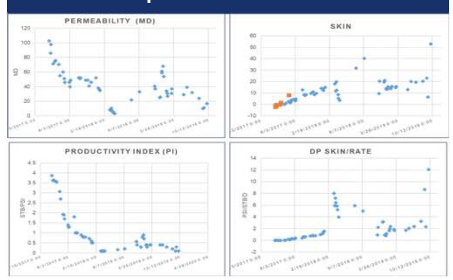
Case Study Description

- **Situation Overview:** Small to mid sized GoM Operator – observed a reduction in well's performance soon after the well came online
- **Instrumentation and Data Acquisition:** WHP/T and DHGP/T data available with a test separator on the platform
- **Surveillance Program Thesis:** To monitor and evaluate day to day the reservoir, completion, and wellbore performance, identify root cause of performance impairment and suggest remedial actions
    - PVT and AOP Modeling
    - Rate Determination (Spot & Allocation) and BHP calculation
    - Well Performance Evaluation (skin, perm. P.I, etc.)
    - Reservoir Volume Determination
    - Wellbore Lift Efficiency
- **Results:** Recognized AOP at the initial reservoir conditions and asphaltene deposition on the screens soon after the startup. Manage the Failure!
- **Is it worth a $5MM stim job to recover $3MM worth of oil?**

Well Production History



Time-Lapse Auto PTA Dashboard



SPE International

43

43

Putting it All Together

Webinars

- Understand as much as you can about your well/reservoir performance and failure modes
  - Skin, Perm, Completion Efficiency
  - Reservoir Volumes
  - Formation Strength & Stress
  - Sanding Potential
  - Hydraulics (Efficient Lift)
  - Compaction
  - Screen and Wellbore Velocities
- Turn that Knowledge into a Dashboard that Everyone Can Understand (and Can Use to Make More Money!)

SPE International

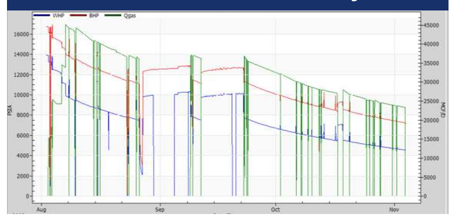
Real-Life Surveillance Example: Gas Well

Webinars

Case Study Description

- **Situation Overview:** Supermajor GoM Operator wanted support on best reservoir and production practices on one of the early Deep Miocene shelf gas well
- **Instrumentation and Data Acquisition:** WHP/T and data available with a test separator on the platform
- **Fluid Description and Reservoir Strength:**
  - Gas condensate with a yield of 15 BBL/MMcf
  - Strong reservoir rock with a Cf of 8 microsips
- **Surveillance Program Thesis:** To monitor and evaluate the reservoir and completion performance and determine how to maximize NPV against the aquifer front
  - Rate Determination (Spot & Allocation) and BHP calculation
  - Well Performance Evaluation (skin, perm. P.I, etc.)
  - Reservoir Volume Determination
  - Water contact (edge) tagged with PTA/BV
- **Results:** Provided high-frequency BHP conversion based on WHP and gas rates to be able to use the surveillance tools and came up with the production strategy to outrun the water by producing at maximum rates until the water hits, then R/C to next zone up

Well Production History



Reservoir Volume Summary

- **In-Place Gas: 7.5 – 9.5 Bcf**
- **Connected Gas: 7.5 Bcf**
- **Mobile Gas: 5.0 Bcf**
- **Likely EUR: 4.5 Bcf**
- **Water Volume: 6 MM STB**

The well will likely make about 4-5 Bcf, then load up and die…

SPE International®

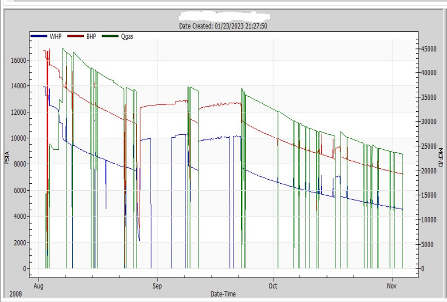
Real-Life Surveillance Example: Gas Well

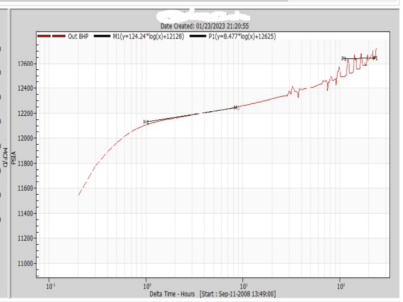
Webinars

Auto PTA Checks

Summary | PBU | DD | Derivative | Daily Values | PTA/ Productivity | HC Volumes | P/z | Yields | Analysis Events | Analysis

	Start D/T ddMmmyyyy hh:mm:ss	End D/T ddMmmyyyy hh:mm:ss	Test Length Hours	Test Type	WHPi psia	WHPf psia	DHGPi psia	DHGPf psia	BHPi psia	BHPf psia	QGasi Mcf/D	QGas Mcf/D	Perm md	Skin	DPskin psi	PStar psia	PI Eff %	DPs/Q psi/MMcf	kh/mu md-ft/cp	Mid Slope psi/cycle	P* Slope psi/cycle	Report Link
1	15Aug2008 09:37:00	15Aug2008 16:49:00	7.2	PBU	8641	11313	-99999	-99999	12508	13913	40557	40557	16.3	1.4	233	14343	82	5.74	16271	1[illegible]5.1	189.433	ODSIRTRep_2008Aug15_093
2	23Aug2008 09:31:00	23Aug2008 18:19:00	8.8	PBU	7755	9330	-99999	-99999	11372	11770	36506	36506	NaN	NaN	NaN	13021	NaN	NaN	0	0	198.842	ODSIRTRep_2008Aug23_093
3	26Aug2008 13:37:00	08Sep2008 20:01:00	318.4	PBU	7477	10277	-99999	-99999	11070	12852	36012	36012	NaN	NaN	NaN	13324	NaN	NaN	0	0	887.146	ODSIRTRep_2008Aug26_133
4	11Sep2008 13:49:00	22Sep2008 17:01:00	267.2	PBU	7504	10128	-99999	-99999	11110	12691	36205	36205	22.5	3.3	351	12812	66	9.71	24037	124.235	269.841	ODSIRTRep_2008Sep11_134
5	17Oct2008 03:07:00	18Oct2008 12:37:00	33.5	PBU	5448	7046	-99999	-99999	8423	9272	27000	27000	16.2	0.4	47	9692	93	1.75	20429	1[illegible]4.685	227.934	ODSIRTRep_2008Oct17_030



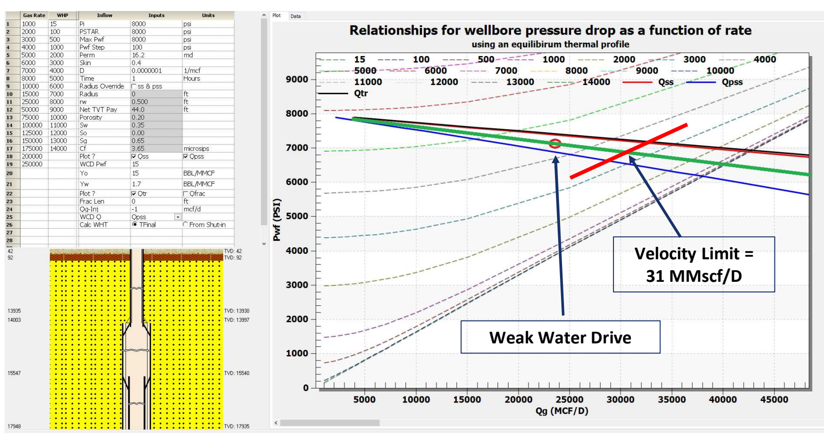


SPE International

Real-Life Surveillance Example: Gas Well

Webinars

Check Match on NODAL – Are We Operating the Well Safely?



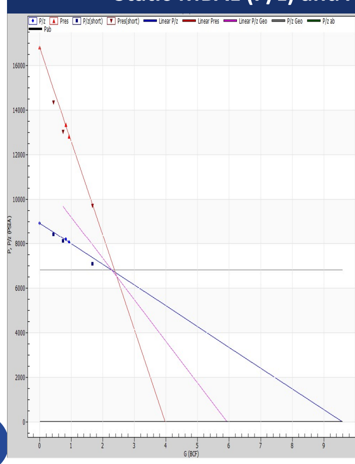
SPE International

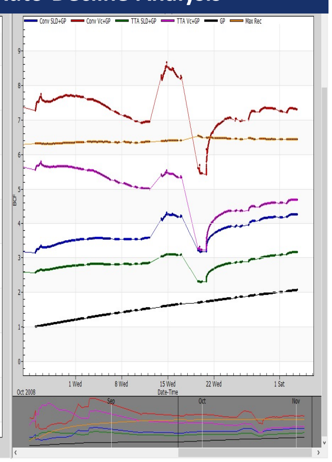
Real-Life Surveillance Example: Gas Well

Webinars

Reservoir Volume Determination

Static MBAL (P/z) and Auto-Decline Analysis





Res. Vol. Summary

- In-Place Gas: 7.5 – 9.5 Bcf
- Connected Gas: 7.5 Bcf
- Mobile Gas: 5.0 Bcf
- Likely EUR: 4.5 Bcf
- Water Volume: 6 MM STB

The well will likely make about 4-5 Bcf, then load up and die…

SPE International

48

Real-Life Surveillance Example: Gas Well

Webinars

Gas Example: Big Problem Checklist

Potential Issue	Good/Bad/Ugly?	Comment
Compaction/Shear	Good	No Issues – Competent Rock…May need to reduce rate once water hits the well and compaction is evident
Completion Velocity	Potential Issues	Velocity issues with free water production, limiting the gas rate to 20 MMcf/D after water breakthrough
Scale	Possible	Unknown until water arrives; reserves likely don't justify a stim job if scale creates skin
Tubing Erosion	Possible (Don't Get Greedy!)	Limiting Velocity to avoid this issue
Flow Behind Pipe	Potential Issues	Lots of stacked pays and water sands…reserves don't justify a work-over if it happens

SPE International

49

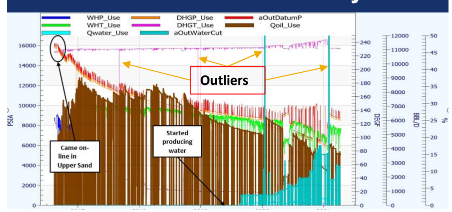
49

Real-Life Surveillance Example: Oil Well

Case Study Description

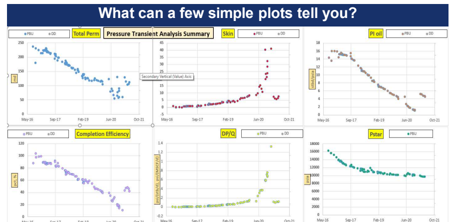
- **Situation Overview:** Mid-sized GoM Operator needed a detailed reservoir description on their first well in a newly discovered Deepwater Mid-Miocene field
- **Instrumentation and Data Acquisition:** WHP/T and DHGP/T data available with a test separator on the platform
- **Fluid Description and Reservoir Strength:**
  - Slightly heavy black oil (25° API) with a GOR of 700 scf/stb
  - Moderately strong reservoir rock with a Cf of 15 microsips
- **Surveillance Program Thesis:** To monitor and evaluate day to day the reservoir, completion, and wellbore performance, and propose projects to maximize the assets NPV
  - Rate Determination (Spot & Allocation) and BHP calculation
  - Well Performance Evaluation (skin, perm. P.I, etc.)
  - Reservoir Volume Determination
  - Water Contact (edge) tagged with PTA/BV
  - Wellbore Lift Efficiency
- **<u>Results</u>: Safely maximized NPV; Recognized a sudden decrease in permeability due to asphaltenes and proposed a xylene treatment to restore the well's performance**

Well Production History



Time-Lapse Auto PTA Dashboard

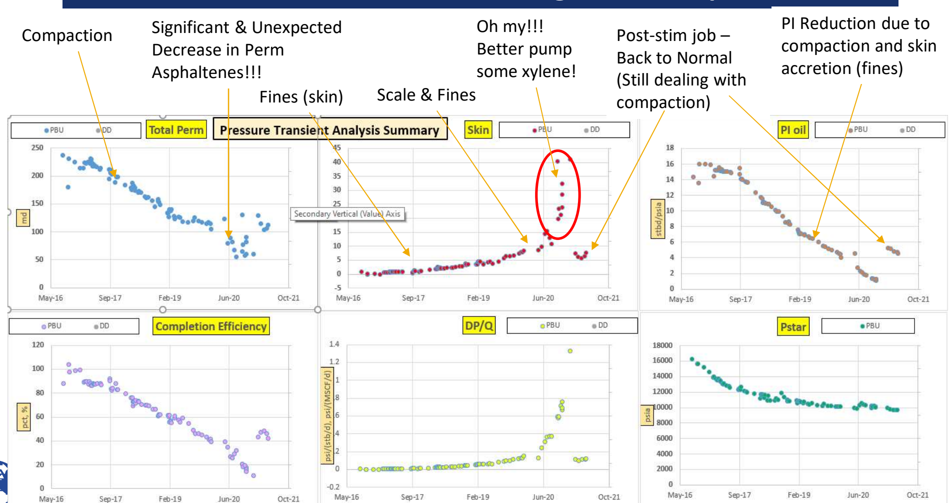
What can a few simple plots tell you?



50

Real-Life Surveillance Example: Oil Well

PTA Dashboard – Accreting Skin Example



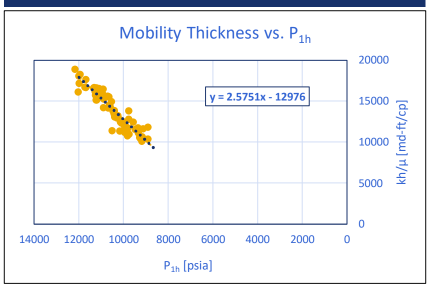
51

Real-Life Surveillance Example: Oil Well

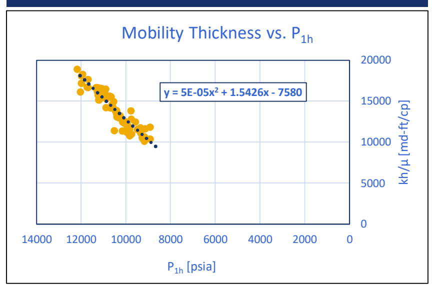
Webinars

Reservoir Failure Pressure – Estimation

Linear Decline	Quadratic Decline



Following a linear decline from the trendline gives us a failure pressure of ~5040 psia



Following a quadratic decline from the trendline gives us a failure pressure of ~6130 psia

The possible range of failure for the reservoir is 5100-6200 psia
(Likely Pfailure = 5500 psia)

SPE International

Field Level – Spare Capacity Dashboard

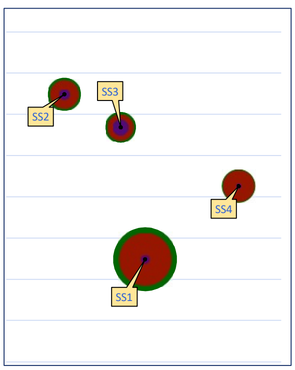
Safely Maximizing Well Performance and Reserve Recovery

Well	ODSI Current Rate (Oil) [stb/d]	Current WC [%]	Operator Current WC (%)	Operator DPR Oil [stb/d]	Operator ΔOil [stb/d]	Excess Capacity (Oil) [stb/d]	FDHGP [psia]	Minimum DHGP [psia]	Min DHGP Rationale	FBHP/Compaction Flag?	Screen Velocity Issues
SS01	10,630	16	15	10,807	-177	2,800	9,953	**8,500**	**Bad Ju-Ju Asphaltenes**	No	No
SS02	2,475	18	26	2,356	119	550	9,500	8,500	Asphaltenes	No	No
SS03	5,194	53	56	4,851	343	0	10,100	8,500	Asphaltenes	No	yes, at higher rates
SS04	5,396	12	14	5,294	102	550	8,650	6,200	Compaction / Sand Failure	Some, not critical yet	No
Sum =	23,695			23,308	387	3,900	<--Excess Potential Oil Rate				

Field Level – How Much is Left?

Proactive Surveillance keeps you well informed of your current NPV

GOM Subsea Wells



Well				Remaining EUR, MMSTBo			
	Cum Oil Prod, MMSTB	Cum Gas Prod, BSCF	Cum Water Prod, MMSTB	P90	P50	P10	Comments / Recommendations
SS01	23.5	16.3	1.8	6.80	9.97	14.45	Maintain current Ck setting, plan stim job if skin exceeds 20
SS02	6.2	4.7	0.7	1.60	2.62	3.12	Maintain current Ck setting
SS03	5.3	4.0	1.5	3.00	5.40	6.10	Flow the well as hard as possible for as long as possible to keep water away from the SS1
SS04	6.2	5.8	0.4	0.80	1.60	2.20	Ok to increase choke but monitor closely

Real-Life Surveillance Example: Oil Well

SS01 Oil Example: Big Problem Checklist		
Potential Issue	**Good/Bad/Ugly?**	**Comment**
Compaction/Shear	Manageable	The well shouldn't get below 5500 psia unless it develops a large skin
Completion Velocity/ Screen Cutting	Possible Issues	Screen Cutting is possible if we try to flow the well at high rates with a high skin
Scale	Treatable	Drop Acetic/HCl if the skin gets above 20
Fines	Manageable	Normal Fines accretion…any stimulation/solvent treatment will push them back
Asphaltenes	**HFS!!!**	**Stay above 8500 psia!!!** **Potential Asphaltene Death Spiral!**
Flow Behind Pipe	Possible	That Water Sand about 100' up the hole looks ornery…if it breaks through, the reserves justify a R/C Squeeze
Early Water Front Arrival	Possible	Trying to balance withdrawal rate from SS03 and SS01 decay to shape the water front/Maximize EUR & Stay Above AOP

55

55

Webinars

Concluding Remarks

SPE International

56

56

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/Volume issue – See MY Nodal!!
- Geology/Exp: It HAS to be big! Must be someone else's **fault**!
- Petro-physics: The interpreted log says it's HC bearing – the water must be coming from somewhere else

57

57

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

58

58

It’s Everybody’s Problem

Webinars

- Understand what happened in the Past
- Understand what’s happing Now
- Get an idea of what’s going to happen in the Future

Need a Non-Biased (non-bullying) way to sort things out

Get a Cross-Disciplinary Team Together to Perform Pro-Active Surveillance: How Do We Make More Money?

SPE International

Conclusions

Webinars

- Democratization of data and results within the organization and asset teams is critical for a proactive and effective surveillance program
  - Encourages a multi-disciplinary approach to problem solving
- Automated surveillance and visual dashboards allows engineers to focus on what the results mean to improve production and EUR, which maximizes NPV
  - Analyze ALL of the data, not just the data you have time to look at manually
- Early detection of problems can be bucketed into short- and long-term problems to provide guidance on planning and scheduling
  - Capture opportunistic times for well remediation jobs to prevent prolonged downtime due to scheduling conflicts
  - Get ahead of problems and avoid trainwrecks

SPE International

60