

The Whitson logo, consisting of the word "whitson" in a bold, lowercase, blue sans-serif font, is positioned in the upper right quadrant of the slide. It is set against a white rectangular background that is partially overlaid by a dark blue vertical bar on the right edge of the slide.

whitson

The "whitson+" logo, featuring the word "whitson" in a bold, lowercase, blue sans-serif font followed by a plus sign, is located on the left side of the slide. It is set against a dark blue background that forms a diagonal shape across the slide.

whitson+

# Well Test Techniques CPG, DQI & DFITs

Venkata "Teja" Chavali

[chavali@whitson.com](mailto:chavali@whitson.com) | whitson+ Virtual Half-Day Course

16 October 2024



# Agenda

- whitson+ fundamentals

- Fields
- Projects
- Wells
- Scenarios
- Main Data & Models ^
- PVT
- Production Data
- Production Data Analysis ^
- Decline Curve Analysis
- Bottomhole Pressure
- Flowing Material Balance
- Analytical RTA
- Numerical RTA
- Numerical Model
- Nodal Analysis
- Multi-Well Analysis ^
- Auto-Forecast
- Type Well
- Comparison Plot
- Multi-well Numerical Model
- Well Testing ^
- Chow Pressure Group
- DFIT
- DQI
- Advanced PVT & Phase Beha... ^
- Virtual PVT Lab v
- Gas EOR PVT v

- **Part 1 – CPG**

- CPG What and Why
- CPG How (Workflow, Options)
- CPG Exercise

- **Part 2 – DQI**

- DQI What and Why
- DQI How (Underlying Models, Sensitivities)
- DQI Exercise

- **Part 3 – DFIT**

- DFIT What and Why
- DFIT How (Stress, Pressure and Permeability calculations)
- DFIT Exercise

# Software Basics


# Access to whitson+

**whitson**

Welcome

Log in to whitson+ to continue to courses.whitson.com.


Username or email address\*


Password\* 

[Forgot password?](#)

Continue

OR

 Continue with Whitson Office 365

 Continue with Support



<https://courses.whitson.com/>



Username is your email



Password: [WellTest2024](#)

\*Send an e-mail to [support@whitson.com](mailto:support@whitson.com) if you need help to login.  
Need to use Google Chrome, Firefox or Microsoft Edge. Internet Explorer won't work.

# whitson+: Set Zoom to 70-80%

The screenshot displays the whitson+ web application interface. The browser address bar shows the URL: <https://internal.whitson.com/fields/2/projects/49/wells/241/pvt/fluid-definition>. The application header includes navigation menus for Field (Bakken), Project (Stian-PhD-Project), Well (Volatile-Oil), and Analysis (Main). The main content area is titled "FLUID DEFINITION" and contains two panels: "Reservoir Fluid Composition" and "Surface Process".

The "Reservoir Fluid Composition" panel shows the following data:

| Method:                      | API and GOR |
|------------------------------|-------------|
| T <sub>reservoir</sub>       | 200 F       |
| P <sub>reservoir, int.</sub> | 8000 psia   |

The "Surface Process" panel shows the following data:

| Process: | Well Specific Process |
|----------|-----------------------|
| Stage 1: | 300 psia 100 F        |
| Stage 2: | 14.7 psia 60 F        |

The "Phase Envelope" plot shows Pressure (psia) on the y-axis (0 to 8000) and Temperature (F) on the x-axis (0 to 700). The plot includes a legend with the following items:

- Initial Reservoir Conditions (diamond symbol)
- Separator Conditions (square symbol)
- Critical Point (circle symbol)
- Bubblepoint (green line)
- Dewpoint (red line)

The plot shows a bubblepoint curve (green) and a dewpoint curve (red) forming a closed loop. The Initial Reservoir Conditions are marked at approximately 200 F and 8000 psia. The Separator Conditions are marked at approximately 100 F and 500 psia. The Critical Point is marked at approximately 380 F and 4000 psia.

A blue callout box with the text "Click here (Alternatively, CTRL + '-' on keyboard)" points to the Zoom menu item in the browser's context menu. The Zoom menu is open, showing the current zoom level at 50% and a zoom in (+) button.

The Windows taskbar at the bottom shows the system tray with the date and time: ENG NO 5:35 PM 3/1/2023.

# whitson+: Maximize Screen by "F11"

whitson+  
Field: Bakken, Project: Stian-PhD-Project, Well: Volatile-Oil, Analysis: Main

Click F11

Pressure (psia)

Temperature (F)

Initial Reservoir Pressure

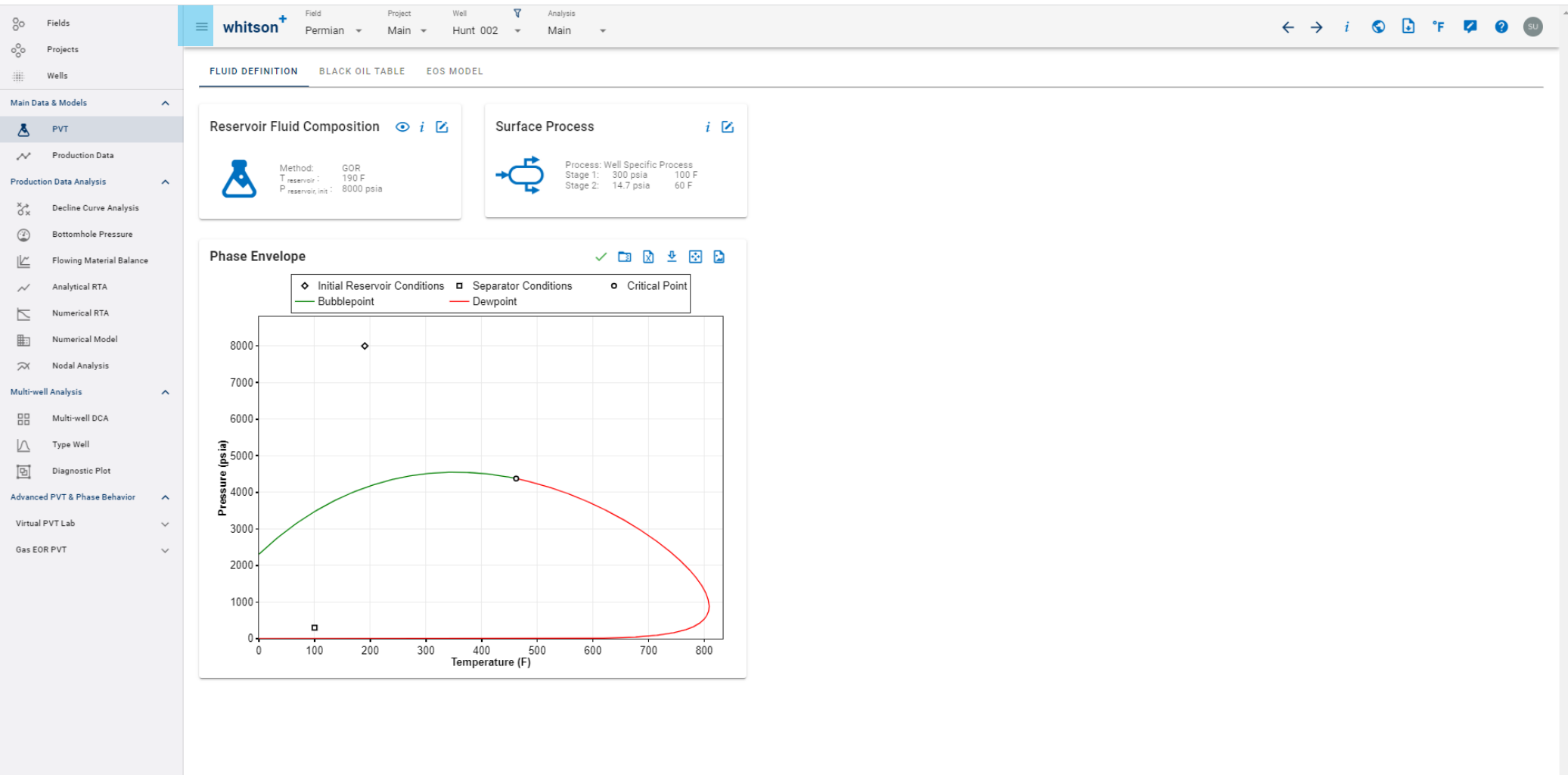
Bubblepoint

© 2023 - Whitson AS. All rights reserved

Type here to search

ENG NO 5:37 PM 3/1/2023

# whitson+: More Screen Real Estate



# whitson+: Navigation Panel

The screenshot displays the whitson+ software interface. On the left is a navigation panel with a tree view of modules. The main area shows a 'Phase Envelope' plot. A blue callout box with white text points to the navigation panel.

**Navigation Panel Overview of all modules**

**Phase Envelope**

Legend:

- ◆ Initial Reservoir Conditions
- ◻ Separator Conditions
- Critical Point
- Bubblepoint
- Dewpoint

The plot shows Pressure (psia) on the y-axis (0 to 8000) and Temperature (F) on the x-axis (0 to 800). The bubblepoint curve (green) starts at approximately 2000 psia at 0 F, peaks at about 4500 psia around 350 F, and ends at the critical point (black circle) at approximately 4500 psia and 450 F. The dewpoint curve (red) starts at the critical point and descends to about 1000 psia at 800 F. A diamond marker (Initial Reservoir Conditions) is located at approximately 8000 psia and 180 F. A square marker (Separator Conditions) is located at approximately 200 psia and 100 F.

© 2023 - Whitson AS. All rights reserved



# whitson+: Software Hierarchy

The screenshot displays the whitson+ software interface. The top navigation bar includes 'whitson+' and dropdown menus for 'Field' (Permian), 'Project' (Main), 'Well' (Hunt 002), and 'Analysis' (Main). A toolbar on the right contains navigation icons, with the 'Next / Previous Well' icons highlighted by a red dashed circle. A blue callout box points to these icons with the text 'Next / Previous Well in a project'. A large blue callout box in the center of the interface reads 'Software Hierarchy Fields → Projects → Wells'. The main content area shows a 'Phase Envelope' plot with 'Pressure (psia)' on the y-axis (0 to 8000) and 'Temperature (F)' on the x-axis (0 to 800). The plot includes a green bubblepoint curve and a red dewpoint curve. A legend indicates 'Initial Reservoir' (diamond) and 'Bubblepoint' (line). A small square marker is visible at approximately (100, 200) on the plot. The left sidebar lists various analysis modules such as 'PVT', 'Production Data', 'Decline Curve Analysis', and 'Multi-well Analysis'.

© 2023 - Whitson AS. All rights reserved

# whitson+: Create Multiple Analyses for a Well

The screenshot displays the whitson+ software interface. The top navigation bar includes 'Field' (Permian), 'Project' (Main), 'Well' (Hunt 002), and 'Analysis' (Main). A dropdown menu is open under 'Analysis', showing options: 'Add new analysis', 'View all analyses', and 'Main'. A blue callout box points to the 'Add new analysis' option with the text: 'Save an analysis (or interpretation) for a given well'. The main workspace shows two analysis cards: 'Reservoir Fluid Composition' (Method: GOR, T<sub>reservoir</sub>: 190 F, P<sub>reservoir, int</sub>: 8000 psia) and 'Surface' (Process: Well Specific Process, Stage 1: 300 psia, 100 F, Stage 2: 14.7 psia, 60 F). Below these is a 'Phase Envelope' plot with Pressure (psia) on the y-axis (0 to 8000) and Temperature (F) on the x-axis (0 to 800). The plot shows a bubblepoint curve (green), a dewpoint curve (red), and a critical point (black circle). Initial Reservoir Conditions (black diamond) are at approximately (190 F, 8000 psia). Separator Conditions (black square) are at approximately (100 F, 300 psia).

© 2023 - Whitson AS. All rights reserved

# whitson+: Create Multiple Analyses for a Well

The screenshot shows the whitson+ software interface. On the left is a navigation sidebar with categories like 'Main Data & Models', 'Production Data Analysis', 'Multi-well Analysis', and 'Advanced PVT & Phase Behavior'. The main area displays analysis settings for 'Reservoir Fluid Composition' and 'Surface'. A dropdown menu is open over the 'Main' analysis, showing options: 'Add new analysis', 'View all analyses', and 'Main'. A blue callout box points to the 'View all analyses' option with the text: 'Click here and it will bring you to the well overview page'. Below the analysis settings is a 'Phase Envelope' plot showing Pressure (psia) vs. Temperature (F). The plot includes a green bubblepoint curve, a red dewpoint curve, and a critical point. Key data points are marked: Initial Reservoir Conditions (diamond at ~180 F, 8000 psia) and Separator Conditions (square at ~100 F, 200 psia).

Click here and it will bring you to the well overview page

## Well Overview page

The screenshot shows the 'Well Overview' page in whitson+. It displays a detailed view of the well analysis, including well information, reservoir properties, completion metrics, and well data. The page is organized into several sections: Well Information, Reservoir Properties, Completion Metrics, and Well Data. A table at the bottom shows the analysis results for the 'Main' analysis.

| Analysis Name | Analysis Type  | Owner   | Created           | View             |
|---------------|----------------|---------|-------------------|------------------|
| Main          | Reservoir Data | Default | 23 Feb 2023 15:55 | View & Edit Data |

# whitson+: Change Units

The screenshot displays the whitson+ software interface. At the top, the 'Change Unit System' dropdown menu is open, showing options for 'Field' (selected), 'SI/Metric', and 'SI/Metric'. A blue callout box with the text 'Change Units' is positioned over the dropdown. The main interface shows the 'FLUID DEFINITION' tab with sub-tabs for 'BLACK OIL TABLE' and 'EOS MODEL'. The 'Reservoir Fluid Composition' panel displays: Method: GOR, T<sub>reservoir</sub>: 190 F, P<sub>reservoir,init</sub>: 8000 psia. The 'Surface Process' panel displays: Process: Well Specific Process, Stage 1: 300 psia, 100 F, Stage 2: 14.7 psia, 60 F. The 'Phase Envelope' plot shows Pressure (psia) on the y-axis (0 to 8000) and Temperature (F) on the x-axis (0 to 800). The plot includes a green bubblepoint curve, a red dewpoint curve, a black diamond for Initial Reservoir Conditions at approximately (190, 8000), a black square for Separator Conditions at approximately (100, 300), and a black circle for Critical Point at approximately (450, 4500).

© 2023 - Whitson AS. All rights reserved

# whitson+: Input Card

The screenshot displays the whitson+ software interface. The top navigation bar includes 'whitson+', 'Field' (Permian), 'Project' (Main), 'Well' (Hunt 002), and 'Analysis' (Main). Below this, there are tabs for 'FLUID DEFINITION', 'BLACK OIL TABLE', and 'EOS MODEL'. The 'FLUID DEFINITION' tab is active, showing two cards: 'Reservoir Fluid Composition' and 'Surface Process'. The 'Reservoir Fluid Composition' card is highlighted with a blue callout box that says 'Open by clicking here', pointing to an edit icon. A larger blue callout box on the left explains that these cards are 'Input Cards' containing input information for different features. Below the cards is a graph showing 'Separator Conditions' and 'Dewpoint' curves. The x-axis is 'Temperature (F)' from 0 to 800, and the y-axis is pressure from 0 to 2000. A red curve represents the dewpoint, and a green curve represents the separator conditions. A small black square marker is visible on the x-axis at approximately 100 F.

These “Cards” is what we call an “Input Card” and they contain input information for the different features-

Open by clicking here

© 2023 - Whitson AS. All rights reserved

# whitson+: Support Ticket

The screenshot displays the whitson+ software interface. The top navigation bar includes 'whitson+', 'Field' (Permian), 'Project' (Main), 'Well' (Hunt 002), and 'Analysis' (Main). The main content area is divided into 'FLUID DEFINITION', 'BLACK OIL TABLE', and 'EOS MODEL'. The 'Reservoir Fluid Composition' panel shows 'Method: GOR', 'T<sub>reservoir</sub>: 190 F', and 'P<sub>reservoir, int</sub>: 8000 psia'. The 'Surface Process' panel shows 'Process: Well Specific Process'. The 'Phase Envelope' plot shows Pressure (psia) vs. Temperature (F) with 'Initial Reservoir Conditions' (diamond), 'Separator Conditions' (square), 'Bubblepoint' (green line), and 'Dewpoint' (red line). A 'Feedback / Question' modal window is open, containing the following fields:

- Title
- Type (dropdown)
- Module (optional) Fluid Definition (dropdown)
- Field (optional) (dropdown)
- Project (optional) (dropdown)
- Well (optional) (dropdown)
- Calculation ID: cc3a482e-a74d-42ce-8740-93d3ac5f7116 (copy icon)
- Description (text area)
- Attachment (optional) (upload icon)

Buttons at the bottom of the modal are HIDE, DISCARD, and SAVE.

**You can also e-mail support@whitson.com**

© 2023 - Whitson AS. All rights reserved

# whitson+: Manual

- Fields
- Projects
- Wells
- Main Data & Models
  - PVT
  - Production Data
  - Production Data Analysis
    - Decline Curve Analysis
    - Bottomhole Pressure
    - Flowing Material Balance
    - Analytical RTA
    - Numerical RTA
    - Numerical Model
    - Nodal Analysis
  - Multi-well Analysis
    - Multi-well DCA
    - Type Well
    - Diagnostic Plot
  - Advanced PVT & Phase Behavior
    - Virtual PVT Lab
    - Gas EOR PVT

whitson+ Field: Permian Project: Main Well: Hunt 002 Analysis: Main

User Manual ?

FLUID DEFINITION BLACK OIL TABLE EOS MODEL

### Reservoir Fluid Composition

Method: GOR  
T<sub>reservoir</sub>: 190 F  
P<sub>reservoir,init</sub>: 8000 psia

### Surface Process

Process: Well Specific Process  
Stage 1: 300 psia 100 F  
Stage 2: 14.7 psia 60 F

### Phase Envelope

Initial Reservoir Conditions Separator Conditions Critical Point  
Bubblepoint Dewpoint

| Point                        | Temperature (F) | Pressure (psia) |
|------------------------------|-----------------|-----------------|
| Initial Reservoir Conditions | ~190            | 8000            |
| Separator Conditions         | ~100            | ~300            |
| Critical Point               | ~470            | ~4500           |

User manual

# Important Shortcut: Refresh

- Refresh shortcut: “CTRL + R”
- Use if you experience
  - Bad connection
  - The browser is “stuck”

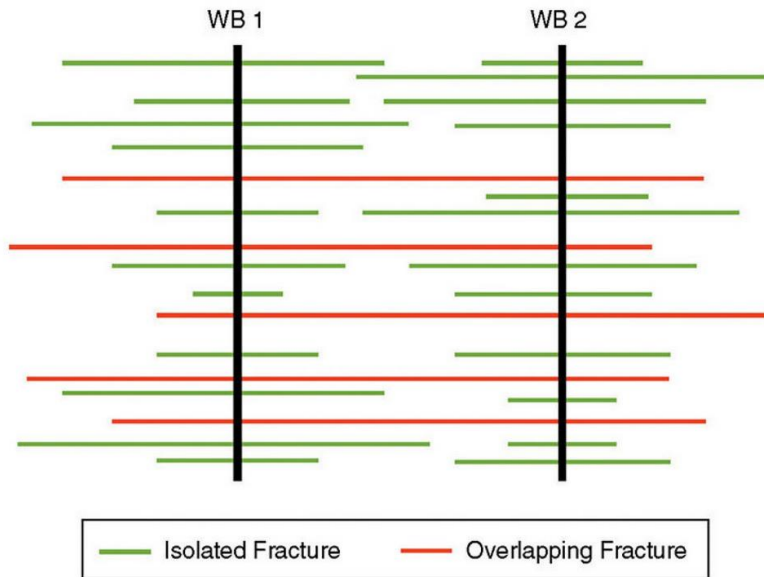




# Part 1 - CPG

**Why**

# CPG Meaning



| CPG value | Level of Interference    |
|-----------|--------------------------|
| 0         | No pressure interference |
| 0-0.5     | Weak                     |
| 0.5-0.8   | Moderate                 |
| 0.8-1     | Strong                   |

- We assume CPG is an index that goes from 0 to 1.
- Higher the fracture overlap, the impact of shut in and drawdown felt at the monitoring well is higher.
- Higher the CPG values or MPI, higher the magnitude of pressure interference

**What**

# Chow Pressure Group - CPG

- The CPG analysis is used to detect and quantify pressure interference between offset and monitoring well pairs.
- CPG considers the BHP trend in the monitoring well before and after the offset well POP (Put on Production) to establish the magnitude of pressure interference (MPI)
- It is simply the pressure change with time over the corresponding derivative slope after the offset well comes online, given as –

$$MPI \approx \text{Stabilized mean of CPG} = \frac{\Delta p}{2 * \Delta p'}$$

- Chu et al (2017, 2018) integrated CPG analysis into the well interference test program at Pioneer to guide well spacing, completion volumes and its grading of the results of stacked and staggered well patterns.

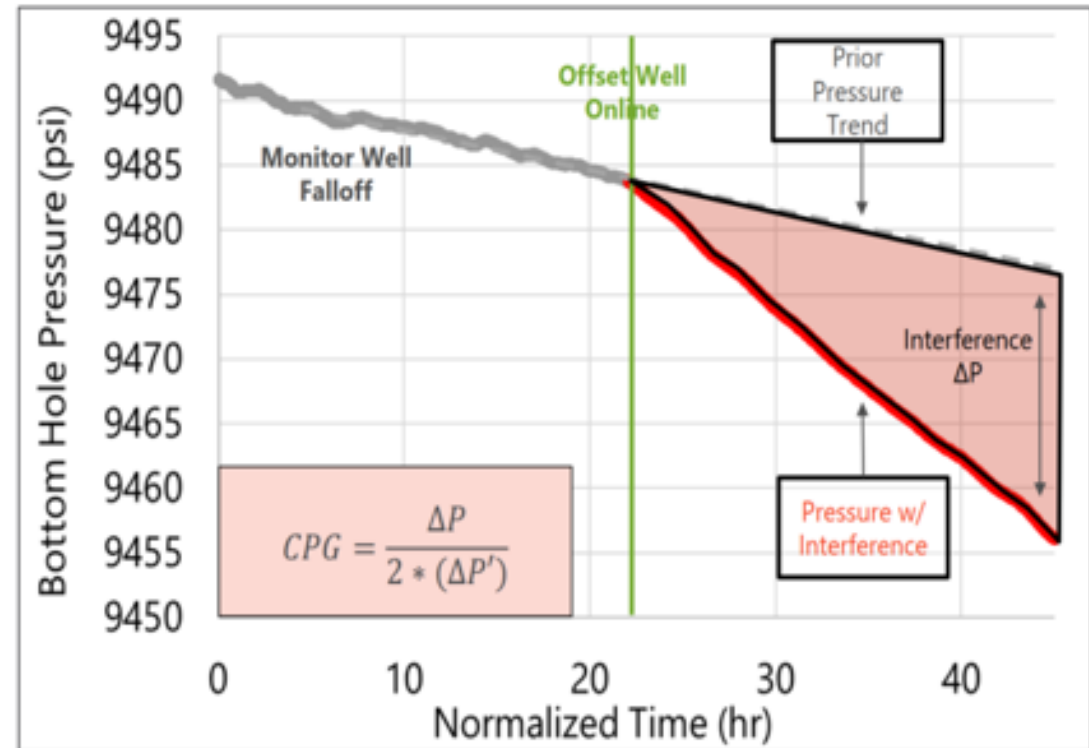
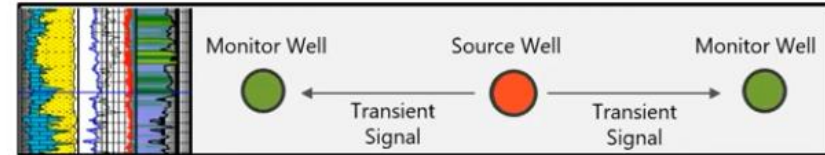
How

# Drawdown CPG Example – RTA

## Testing Design

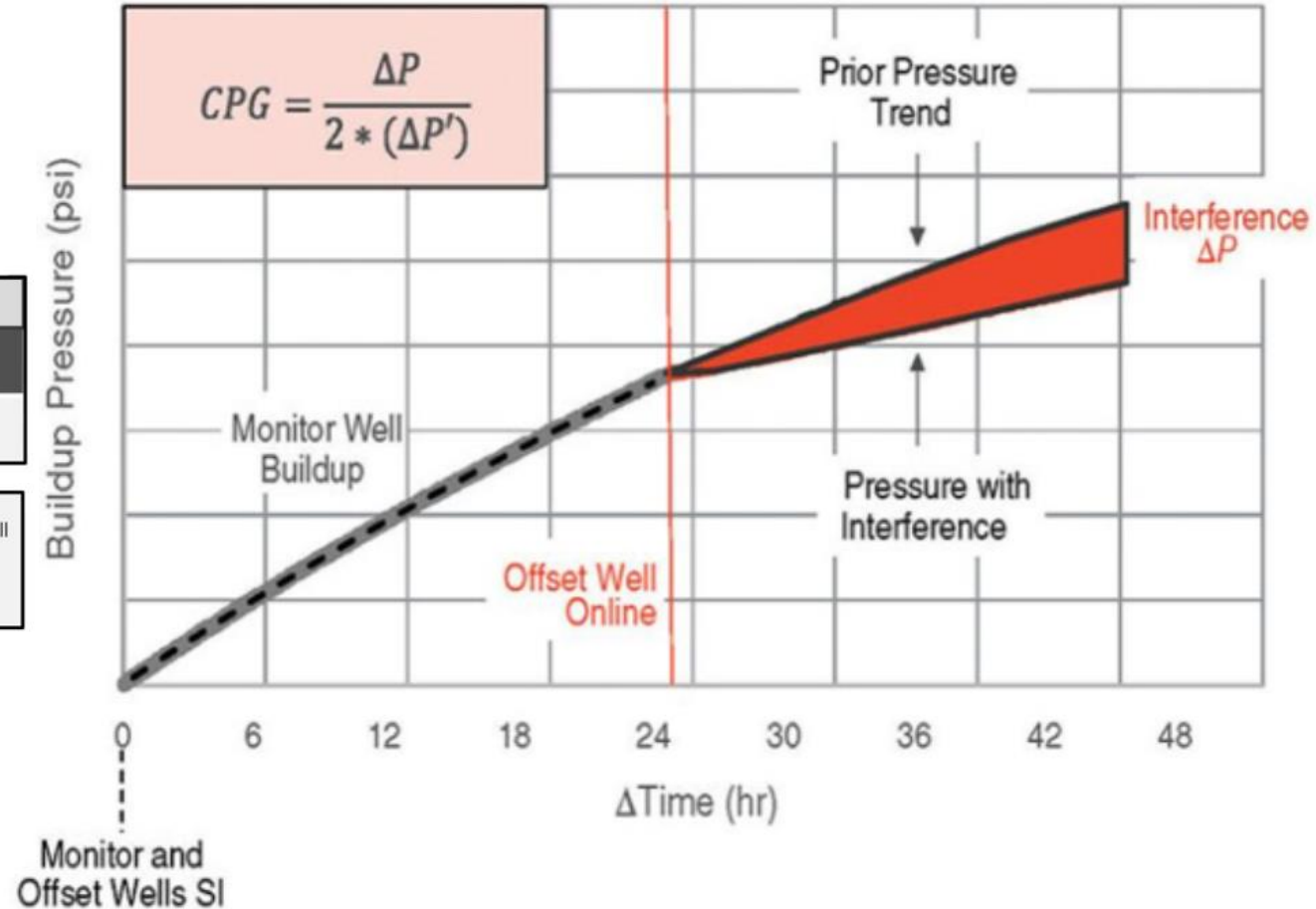
- Run downhole gauge in one or several wells
- Monitor falloff and obtain stable conditions
- Systematically put offset wells on production
- **Monitor deviation from stable conditions**

| Production or Rate Transient Test |             |                       |                   |
|-----------------------------------|-------------|-----------------------|-------------------|
| Initial Infill Conditions         | Source Well | Monitor Well          | Data Analysis     |
| Flowing Wells                     | Shut In     | <b>Remain Flowing</b> | Rates + Pressures |



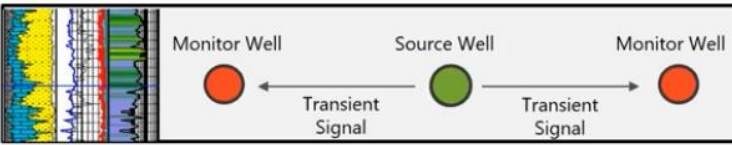
# Buildup CPG Example - PTA

$$CPG = \frac{\Delta P}{2 * (\Delta P')}$$



## Pressure Transient Test

| Initial Infill Conditions | Source Well     | Monitor Well    | Data Analysis |
|---------------------------|-----------------|-----------------|---------------|
| Shut-In                   | Sequence Online | Remains Shut In | Pressure Only |

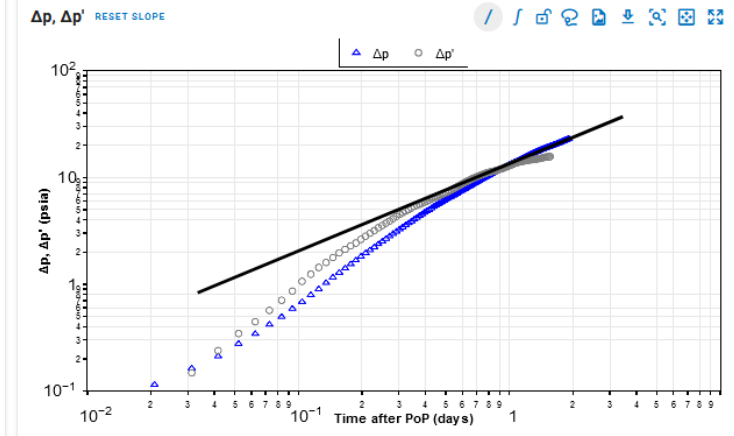
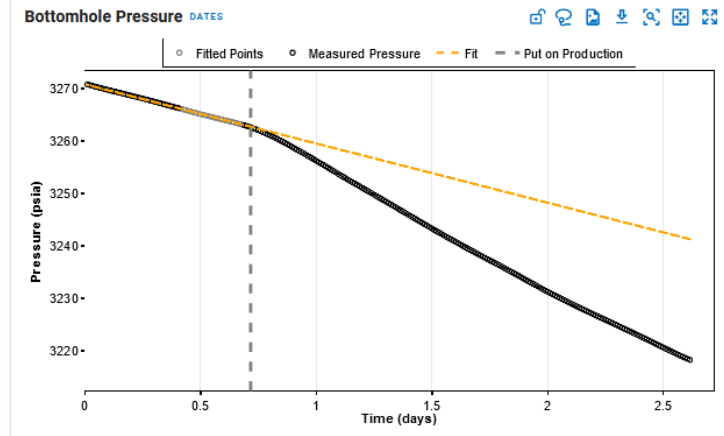
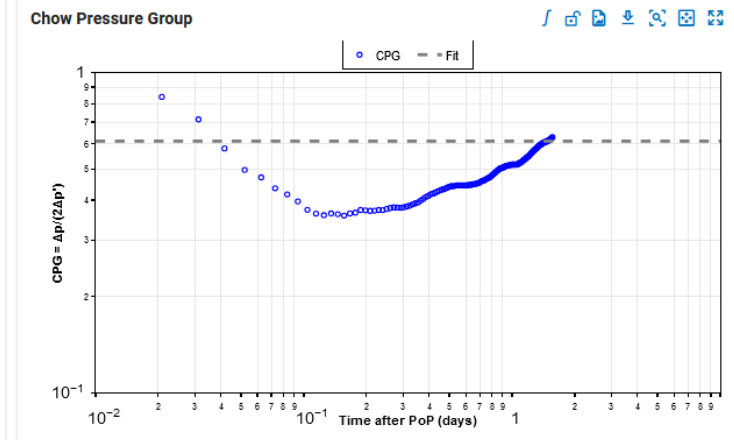
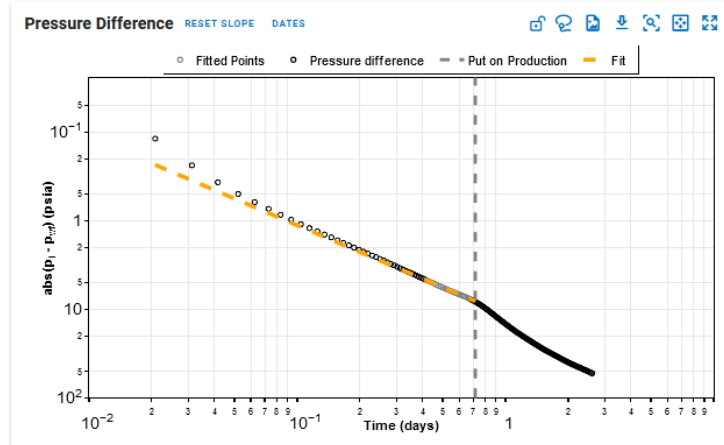




# CPG Workflow Steps

## Steps

- Condition Data
- Select the time offset well is put on production (POP)
- Fit initial pressure trend
- Calculate  $\Delta p$  and  $\Delta p'$
- Calculate CPG and select MPI





# CPG Workflow Options

## Variables


- Data conditioning method
- Data Frequency
- Pressure trend fit
- Derivative Function and window size
- Use of pressure integral vs normal derivatives

### Interpretations

|  |  |
|--|--|
| Chow Pressure Group (CPG) Fit  | R <sup>2</sup> Lasso Fit   |
| 0.61   | -  |
| Start Day  | POP time (mm/dd/yyyy hh:mm)  |
| 0.72 day   | 01/19/2020 16:56  |
| Constant   | Exponent   |
| 11.28  | 1  |
| Derivative Function  | Window Size, L   |
| Bourdet Derivative  | 0.2  |
| <input type="checkbox"/> Build-up  | <input checked="" type="checkbox"/> LOWESS Filter  |
|  | LOWESS Filter Span   |
|  | 0  |

### Key Takeaways

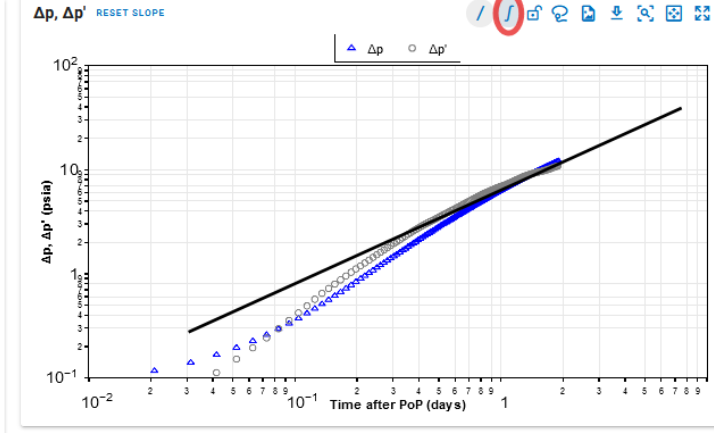
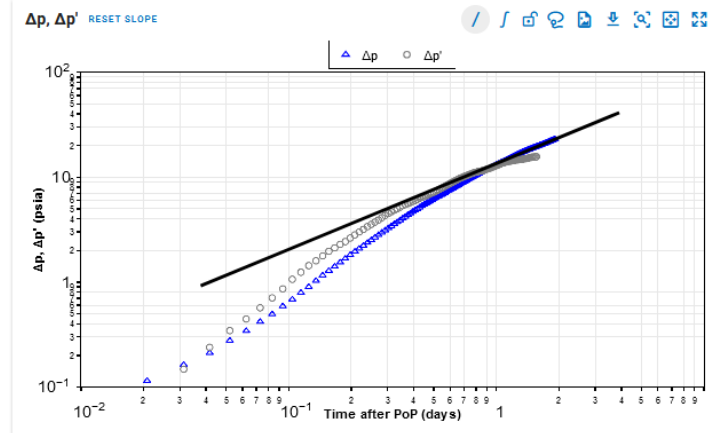
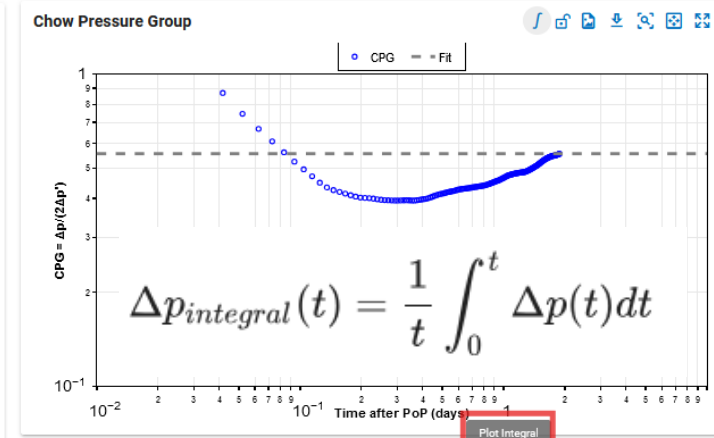
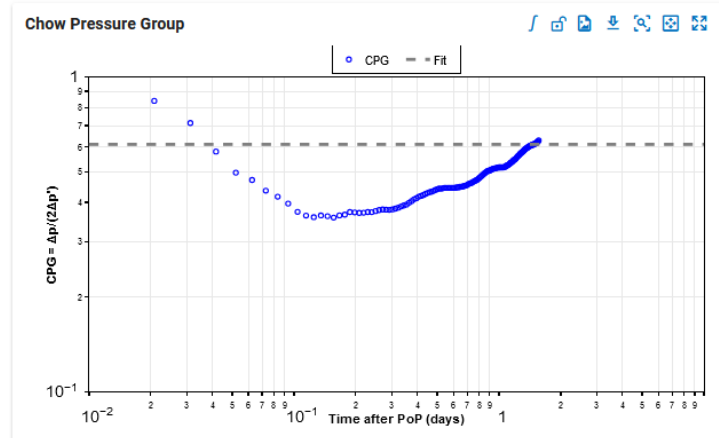
Write key takeaways here



# CPG Workflow Options

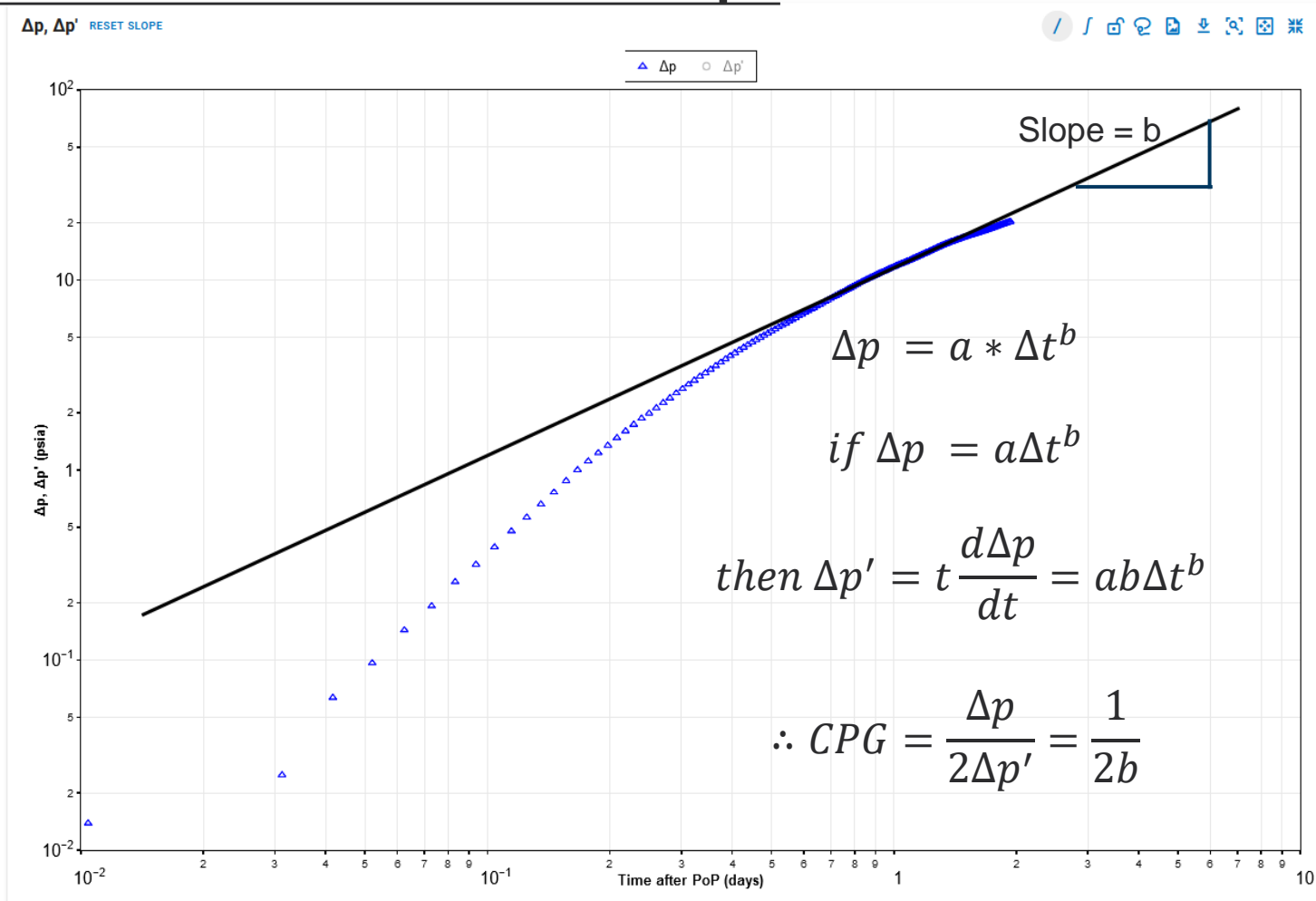
## Pressure Integral

- Pressure data can be used to calculate the pressure integral as shown.
- Preserves the signature of the pressure response with respect to time
- Reduces the noise in the derivatives
- Increases stability in the derivative values, interpretability of the data for calculating MPI



# CPG Workflow Options

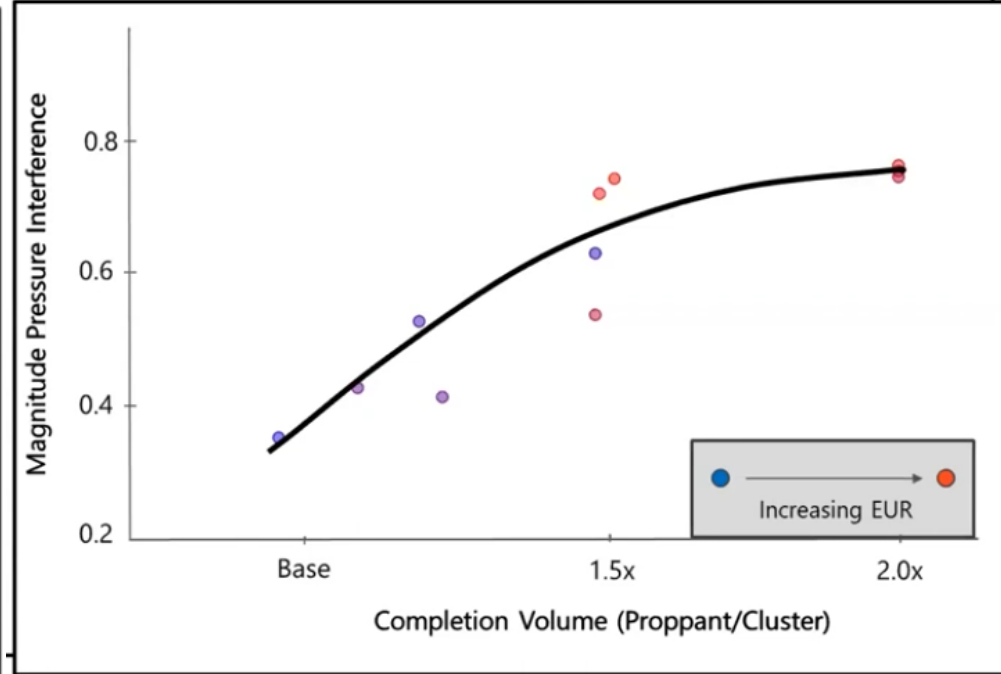
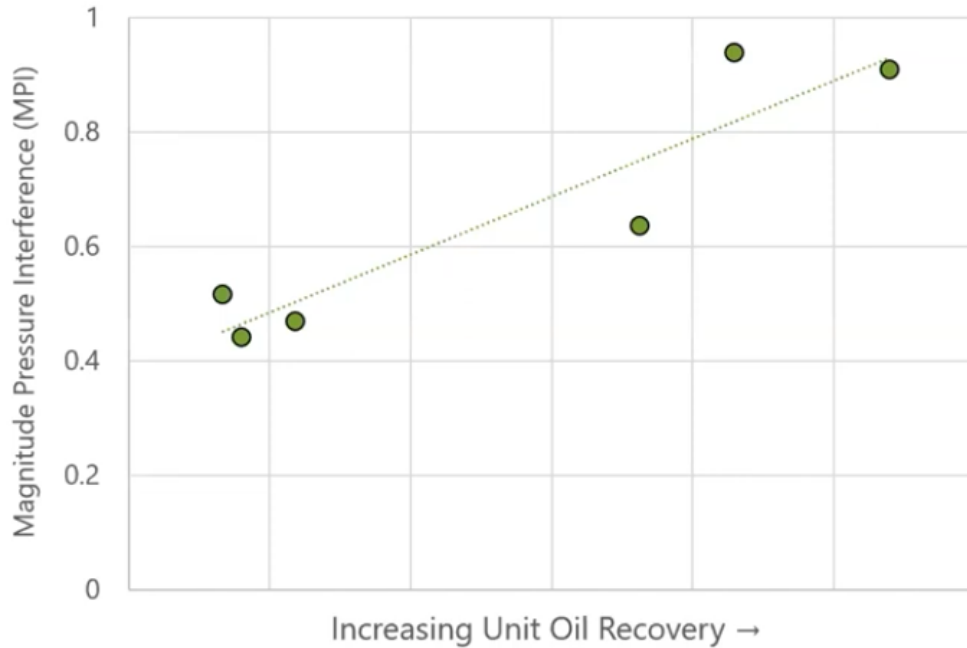
## Stabilized CPG derived from $\Delta P$ slope



Easy way to gather the approximate MPI (stabilized CPG) value

# Value of CPG analysis

\*Ingle et al, Devon: URTEC-2020-3040-MS



- Value to Team

- Calibrate frac models
- Refine expectations of contacted OOIP
- Enhance characterization of appraisal sweet zone spots
- Allows for considerations on completion fluid and volume
- Develop it independently later?

- Key takeaways

- Higher MPI led to higher unit recovery
- Interference tests at various proppant vol. to assess impacts to MPI
- Higher proppant/cluster led to higher MPI but + point of diminishing returns on proppant vol.
- Built economic models of completion vol.

# Summary

---

- CPG analysis in interference tests can be used to assess the conductive fracture overlap and add value to field development decisions
- Short duration tests and data is cost effective to acquire
- Infill wells that have been shut-in are perfect candidates:
  - Gauges do not need to be run prior to well shut-in.
  - Well to well interference test typically takes less than three days.
  - Duration for entire unit might range from 5 to 15 days depending on wells/section, observation time to stabilization, etc)
- Additional references – SPE 191407, SPE 187180 (Chu et. al) - Kappa/Pioneer publications

# More References? How NOT to CPG

Go Forward Approach

- Analyze off the pressure integral
- Use of the Bourdet vs. the Central Difference Method shouldn't matter if the same method is used on all wells
- Use data that has a frequency between 5 to 10 minutes
- Keep the derivative window between .2 and .6
- Qc MPI against the observed  $\Delta P$  of impacted wells

11

1:12:57 / 3:30:00

Mathias Carlsen

Doug Carter

Elliott

Mathias Carlsen

+80

whitcon 2023 – Part 2: How NOT to CPG by Donovan Armistead, Devon

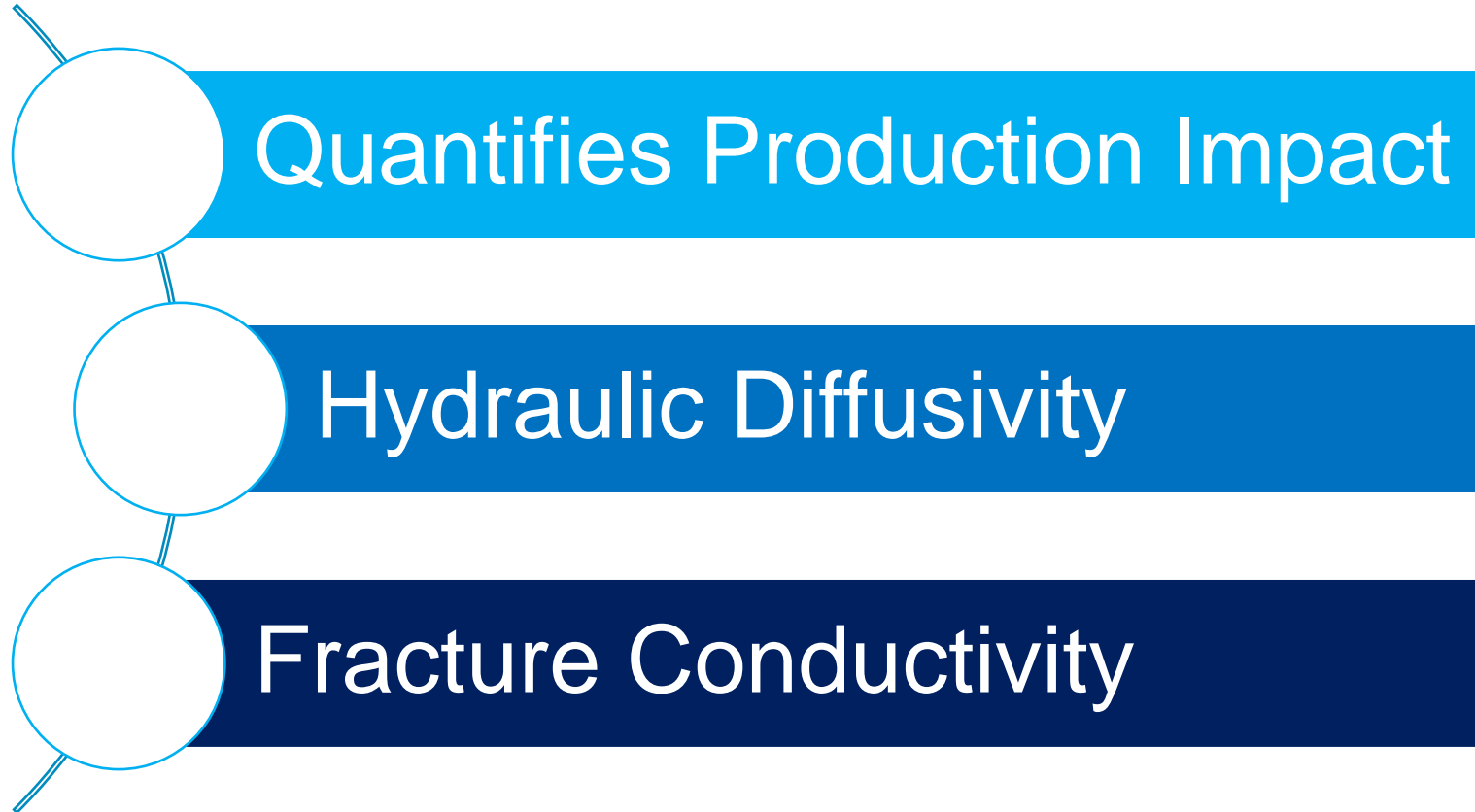
# Exercises



# Part 2 - DQI

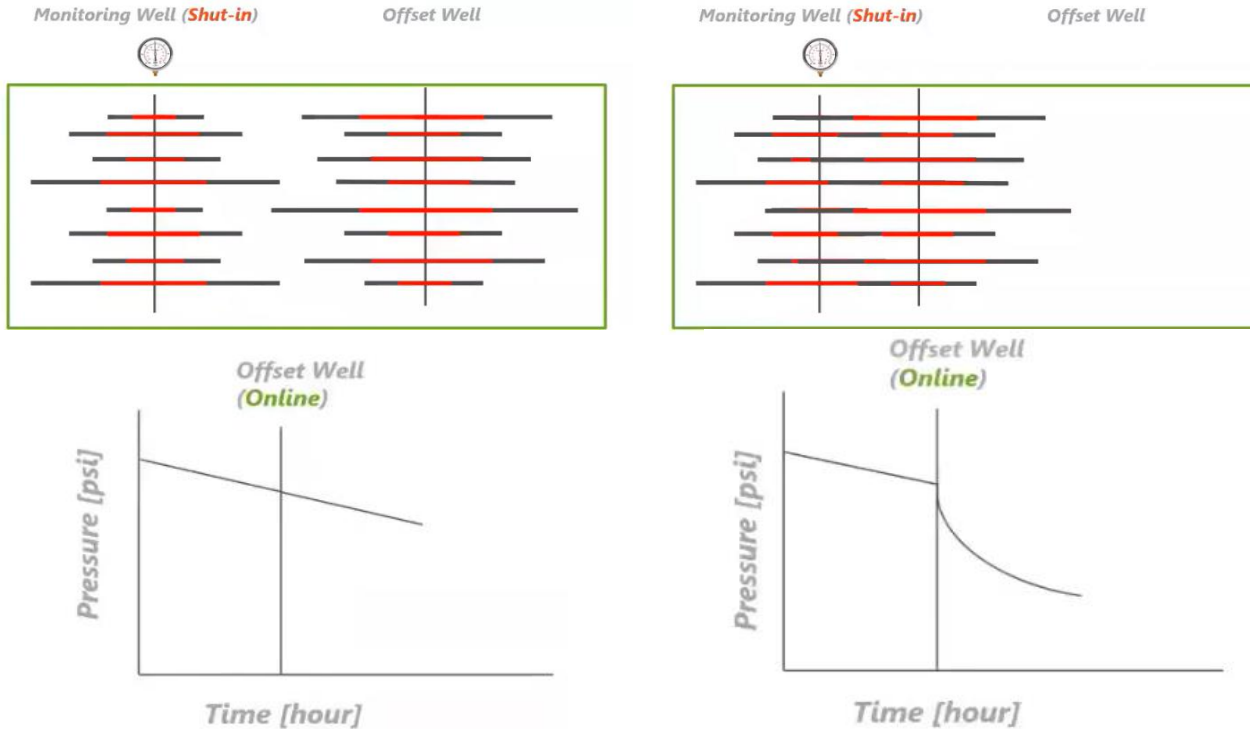
**Why**

# DFIT Key Outcomes



# Devon Quantification of Interference - DQI

- DQI is the procedure to interpret well-to-well interference and calculate the degree of production impact between two wells.
- Offers insights into fracture properties, completion quality, and calculates maximum possible drained fracture length as a function of fluid properties.
- Results in calculation of DPI and dimensionless drainage length – which can be directly used for strategizing well spacing



# DQI versus CPG

## Drawbacks of CPG:

- Not a quantitative estimate of the impact to producing rates
- Same value of CPG may not mean the same amount of production interference
- Accounts for the shape of the pressure interference only, does not account for timing of the interference response or the variability of fluid and rock properties.
- Difficulty in obtaining stabilized CPG values from field data
- Affected by factors such as pressure decline at the production well, matrix permeability, fracture skin and potential anomalous diffusion.
- CPG values from different formations, under different test conditions may not be comparable
- CPG value increases with increase in fracture conductivity but also increases with time – as flow regimes change, the CPG may keep increasing beyond 1.

## Advantages of the DQI:

- Robust to differences in drawdown schedule and/or nonlinearities in the fracture flow.
- Relates the observations to fracture conductivity, a physical parameter that would otherwise be difficult to measure.
- Provides a framework for estimating how production will be impacted by interference.
- Considers the effects of fluid and rock properties (viscosity, compressibility, and matrix perm)

**What**

# Devon Quantification of Interference - DQI

- DQI is the procedure to interpret well-to-well interference
- DQI quantifies the hydraulic diffusivity ( $\alpha$ ) and fracture conductivity between the wells to calculate the dimensionless drainage length ( $L_D$ )
- The  $L_D$  is used to estimate a parameter called the DPI – degree of production interference, defined as –

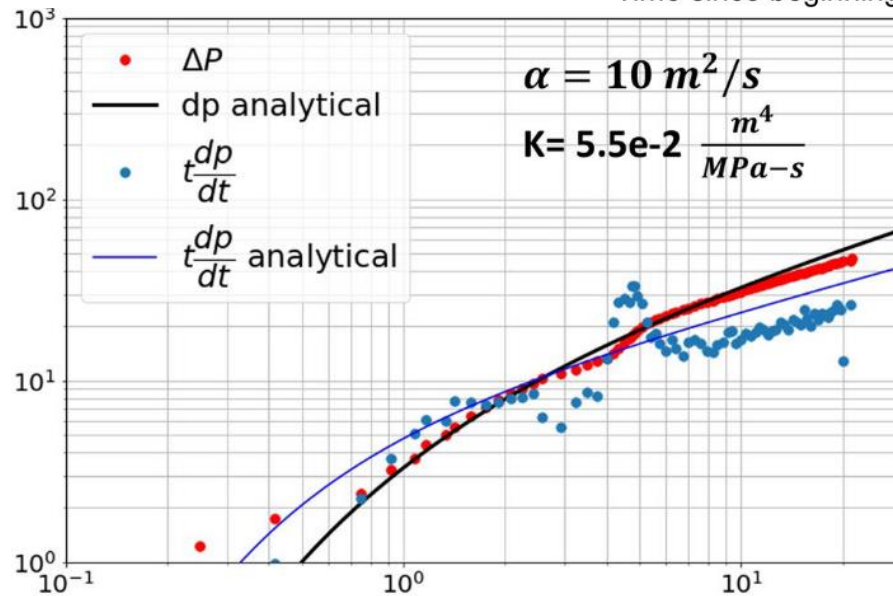
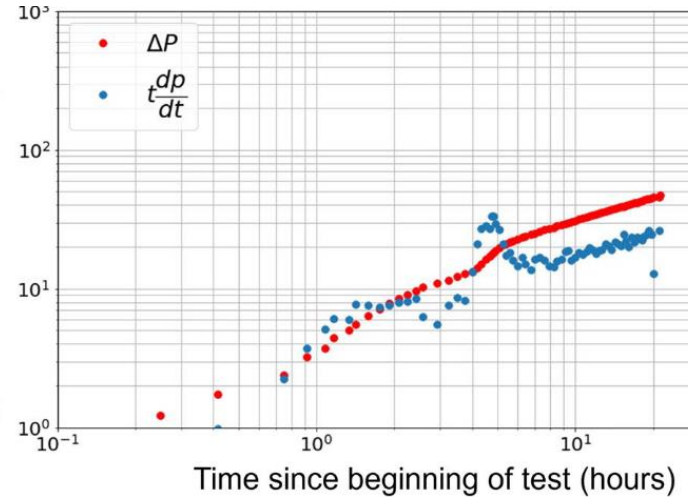
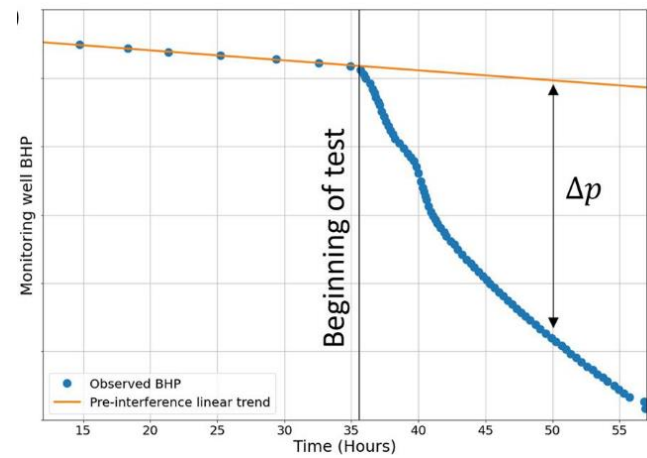
$$DPI = \frac{q_{20 \text{ days}} - q_{bef}}{q_{bef}}$$

- This DPI can be directly linked to the magnitude of change in production expected in an active well when the offset well is shut-in:
  - DPI = 1 or 100% – producing rate should double.
  - DPI = 0.1 or 10% - producing rate should increase by 10%

How



# DQI Steps



Fit the line to the prior pressure trend and move the vertical line to offset well POP

Plot pressure change since the beginning of the test on a log-log plot and calculate the well test derivative

Autofit log-log plot to analytical models for DQI to estimate model parameters

Use estimated model parameters to calculate DPI

Use DPI to infer production impact between wells

# DQI – Underlying Analytical Model

$$P(y, t) - P(y, 0) = \frac{2q_0 \sqrt{\frac{\alpha t}{\pi}}}{K} \exp\left(-\frac{y^2}{4\alpha t}\right) - \frac{q_0 y}{K} \operatorname{erfc}\left(\frac{y}{2\sqrt{\alpha t}}\right)$$

Where, model parameters are:

$$\alpha = \frac{k_f W}{\mu \left(\frac{dW}{dp} + c_f W\right)} = \frac{C}{\mu \left(\frac{dW}{dp} + c_f W\right)} \quad K = \frac{C * H}{\mu}$$

- Use the estimated model parameters to estimate fracture conductivity (C) and calculate 'L' - the maximum possible drainage distance along the fracture if hypothetically it was unbounded and had infinite propped length

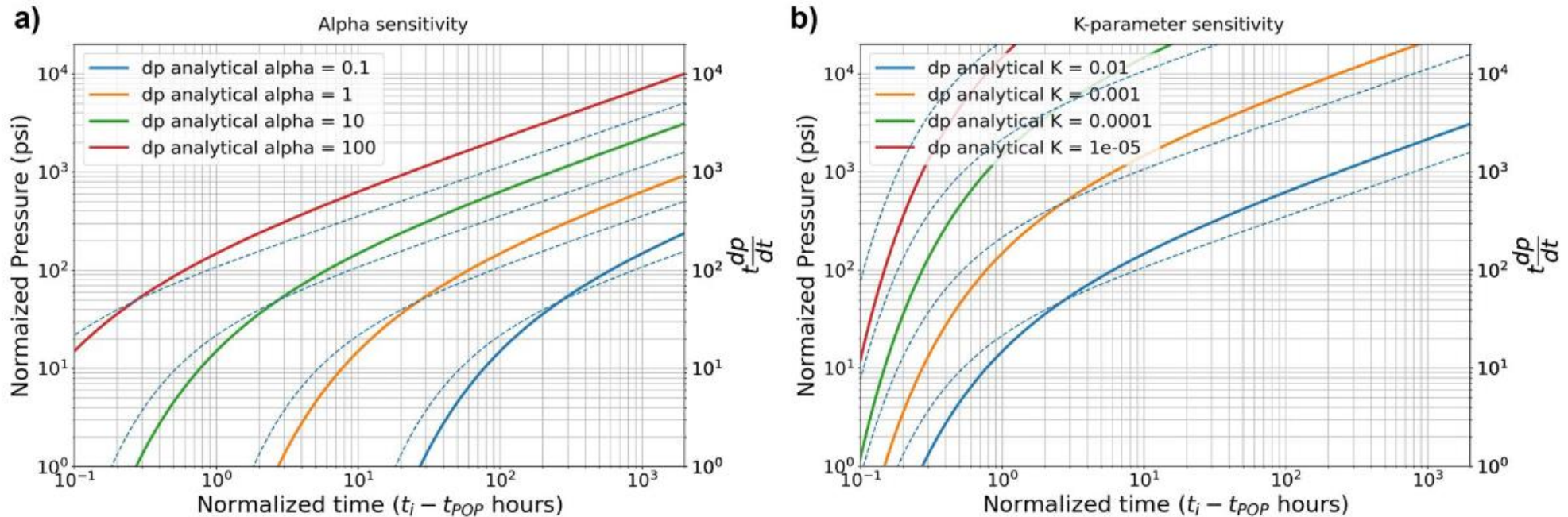
- Pressure response after the initial interference is fit with a solution to the 1-D diffusivity equation at an offset observation point 'y'

- Fit analytical equation to the interference response and resolve model parameters

$$L = \sqrt{\frac{(C_{fracture}) \left(\frac{k_r}{\mu}\right)_{frac,t}}{2 \sqrt{\frac{\phi c_t k}{\pi} \left(\frac{k_r}{\mu}\right)_{mat,t}} t^{-0.5}}}$$

# DQI – Sensitivity to model parameters

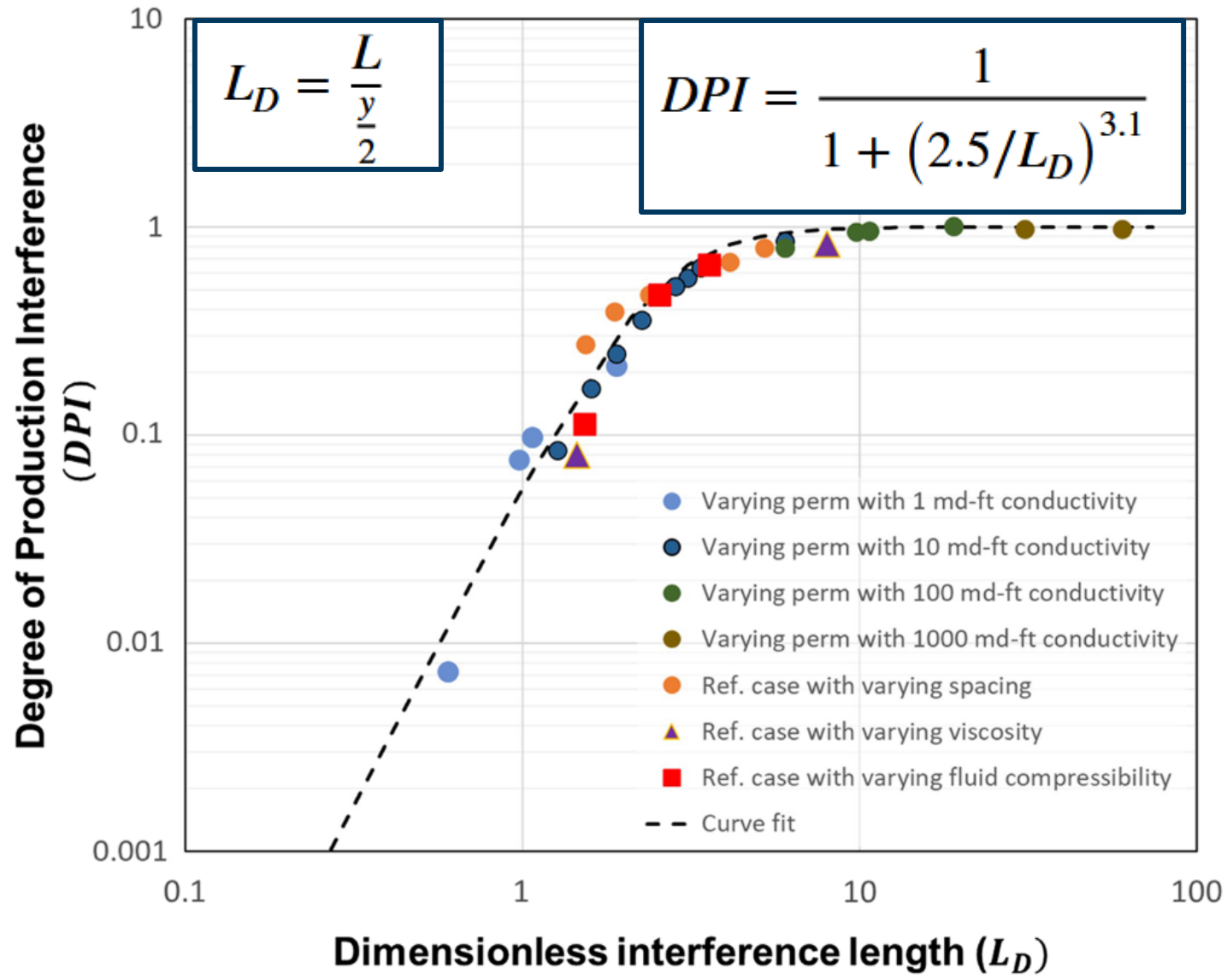
- $\alpha$  – controls diffusivity – timing of the onset of pressure interference
- $K$  – controls fracture conductivity – shape of the curve after the interference



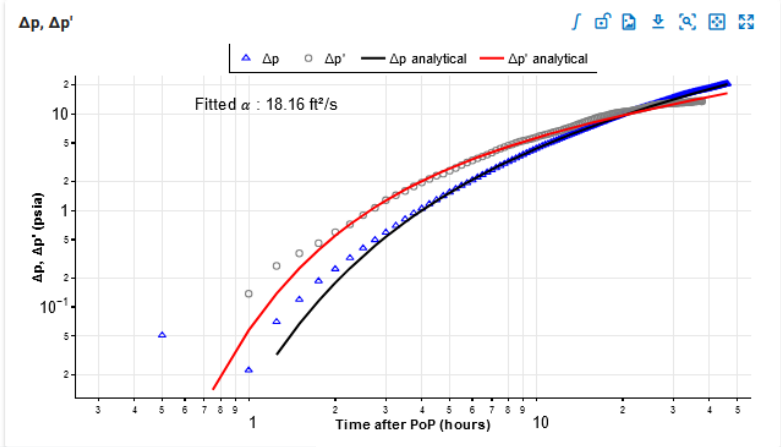
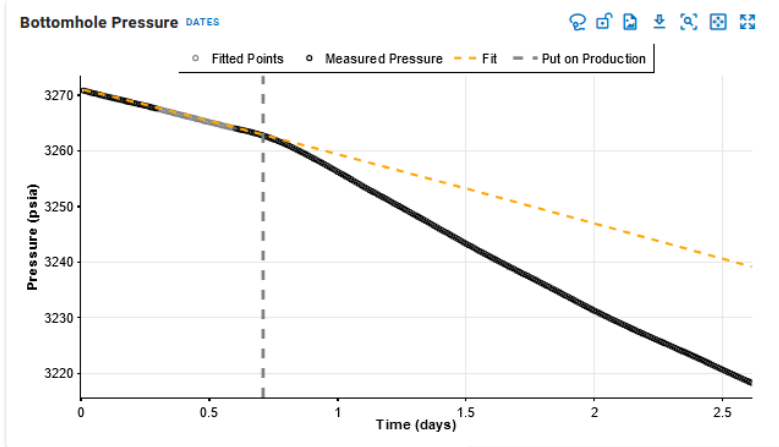
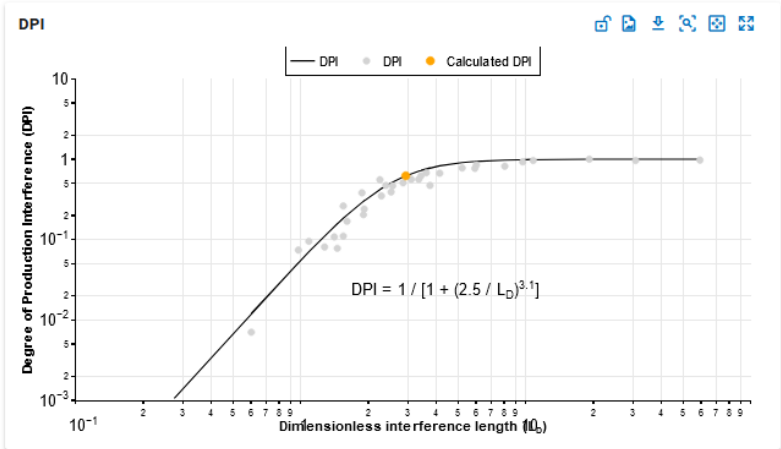
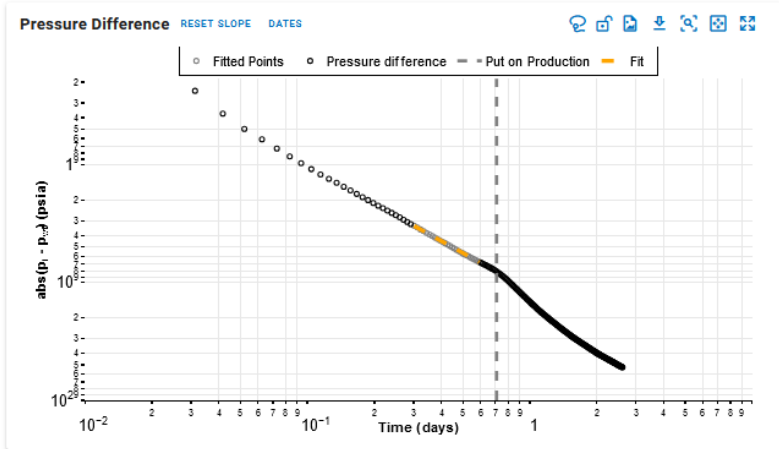
**Fig. 2** The variation in  $dp$  (solid lines) and  $t \frac{dp}{dt}$  (dashed lines) at the offset Monitoring Well calculated with the analytical solution with different values of **a**  $\alpha$  (keeping  $K$  constant = 0.01), and **b**  $K$ -parameter (keeping  $\alpha$  constant = 10). The units of  $\alpha$  are  $\frac{m^2}{s}$  and the units of the  $K$ -parameter are  $\frac{m^4}{MPa*s}$

stant = 0.01), and **b**  $K$ -parameter (keeping  $\alpha$  constant = 10). The units of  $\alpha$  are  $\frac{m^2}{s}$  and the units of the  $K$ -parameter are  $\frac{m^4}{MPa*s}$

# DQI – Sensitivity to varying fluid, completion



# DQI on whitson+



## Steps

- Condition Data
- Select the time offset well is put on production (POP)
- Fit initial pressure trend and calculate  $\Delta p$  and  $\Delta p'$
- AUTOFIT for model parameters
- Infer DPI, fracture conductivity and hydraulic diffusivity

**AUTOFIT** ⓘ

**Interpretations**

|  |      |   |                           |         |       |
|--|------|---|---------------------------|---------|-------|
| Degree of pressure Interference, DPI (%) | 62.1 | % | Fracture conductivity, kW | 50.92   | md-ft |
| Dimensionless Interference Length, $L_D$ | 2.93 |   | Producing Frac Length, L  | 1465.78 | ft    |

# Summary

- DQI goes beyond CPG to maximize the value of downhole pressure gauges.
- Considers the fracture and rock properties, and fluid properties of the interfering fluid present in the fractures to calculate hydraulic diffusivity and fracture conductivity.
- Provides a framework for estimating how production will be impacted by interference.
- DPI is directly proportional to the dimensionless drainage length, expect higher DPI with higher  $L_D$ .
- DPI is a function of fracture conductivity and hence may change over time. As the fracture conductivity decreases, DPI should decrease.

Geomech. Geophys. Geo-energ. Geo-resour. (2023) 9:95  
<https://doi.org/10.1007/s40948-023-00632-1>

---

RESEARCH

## **A new method for interpreting well-to-well interference tests and quantifying the magnitude of production impact: theory and applications in a multi-basin case study**

Mouin Almasoodi · Thad Andrews ·  
Curtis Johnston · Ankush Singh · Mark McClure

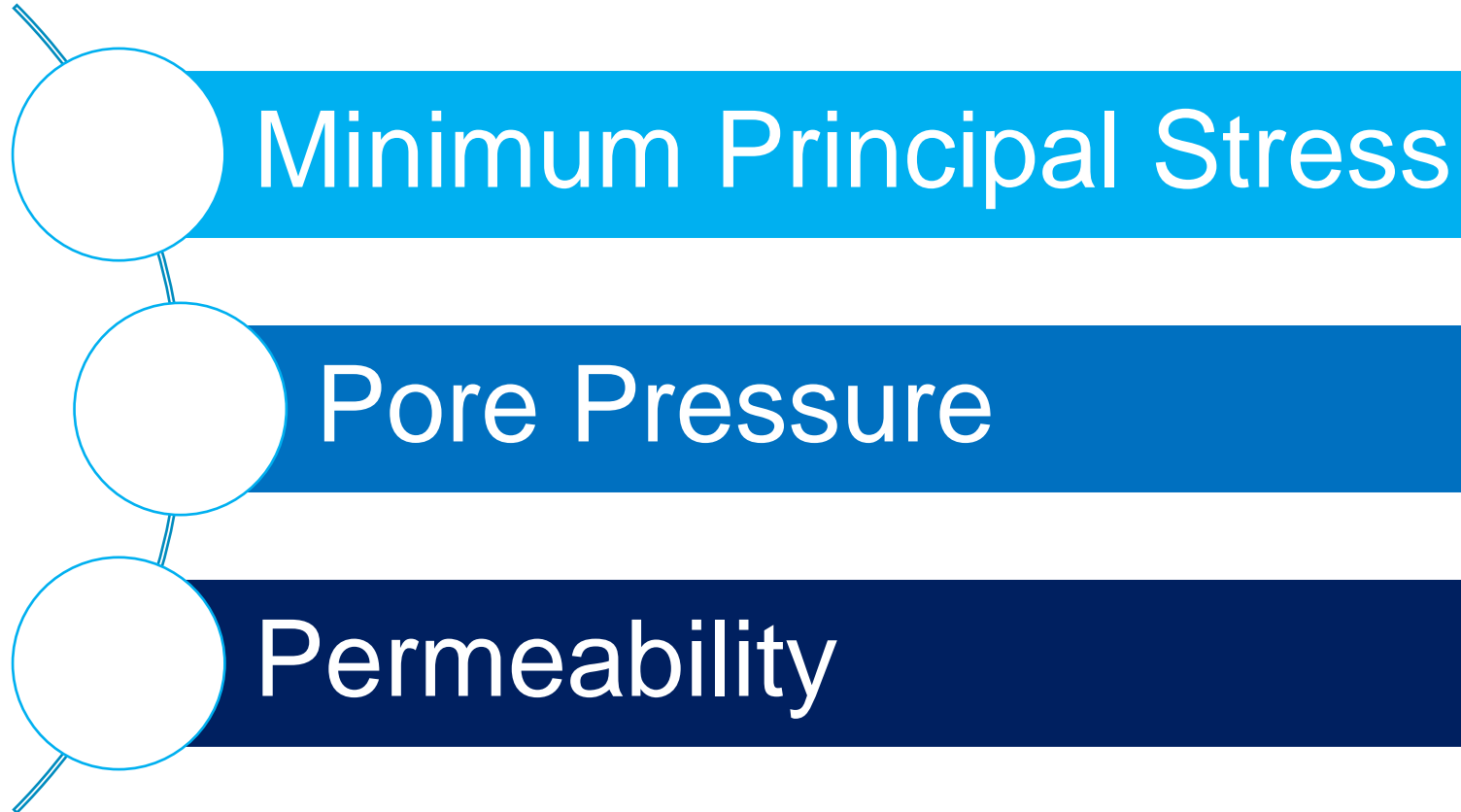
# Exercises

# Part 3 - DFIT



**Why**

# DFIT Key Outcomes



# Why do we need these?

## • **Minimum principal Stress, $S_{h,min}$**

- Exploration and Development – Fault seal analysis
- Drilling – Avoiding lost circulation and maintaining wellbore stability.
- Completion and Production – Estimating net pressure, modelling hydraulic fracture geometry, long term sand production, compaction, subsidence, etc.

## • **Pore Pressure**

- Characterize depletion across the field and vertically in layers.
- Determine the extent of drainage, optimize well spacing.

Without at least a good confidence estimate of the above from DFITs, we cannot proceed further to calculate permeability!

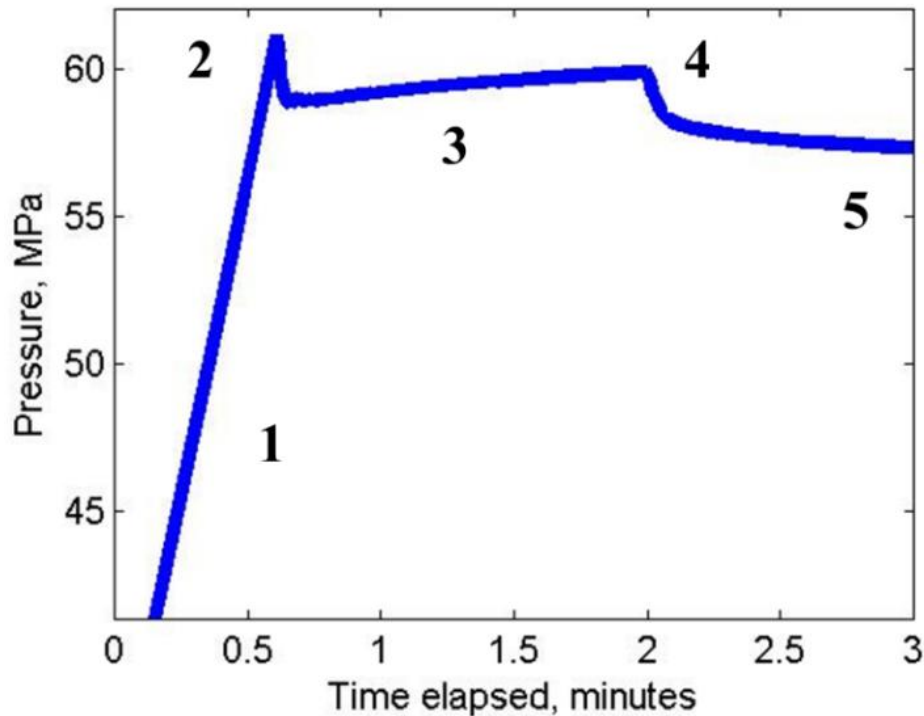
## • **Permeability, $k$**

- Core-derived, RTA-derived permeabilities are prone to assumptions, non-uniqueness.
- DFITs uniquely derive an in-situ estimate of permeability.
- Optimal well spacing differs for different  $k$  to maximize NPV.

**What**

# Diagnostic Fracture Injection/Falloff Tests

Typical Test Sequence in DFITs

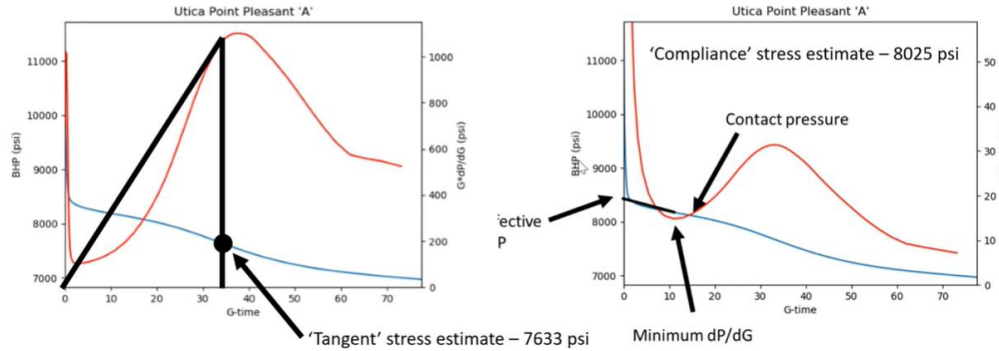


- When –
  - Prior to stimulating a formation volume
- DFITs are -
  - **Low-volume pure water injection tests**
  - **At a sufficient rate and pressure**
  - **Followed by shut-in**
  - **To monitor the pressure falloff during shut-in**
- Costs –
  - ~15k – 75k USD

Depends on duration of the test and BHP vs surface gauge

# Diagnostic Fracture Injection/Falloff Tests

## • Why the SPE 2019-123 Procedure?

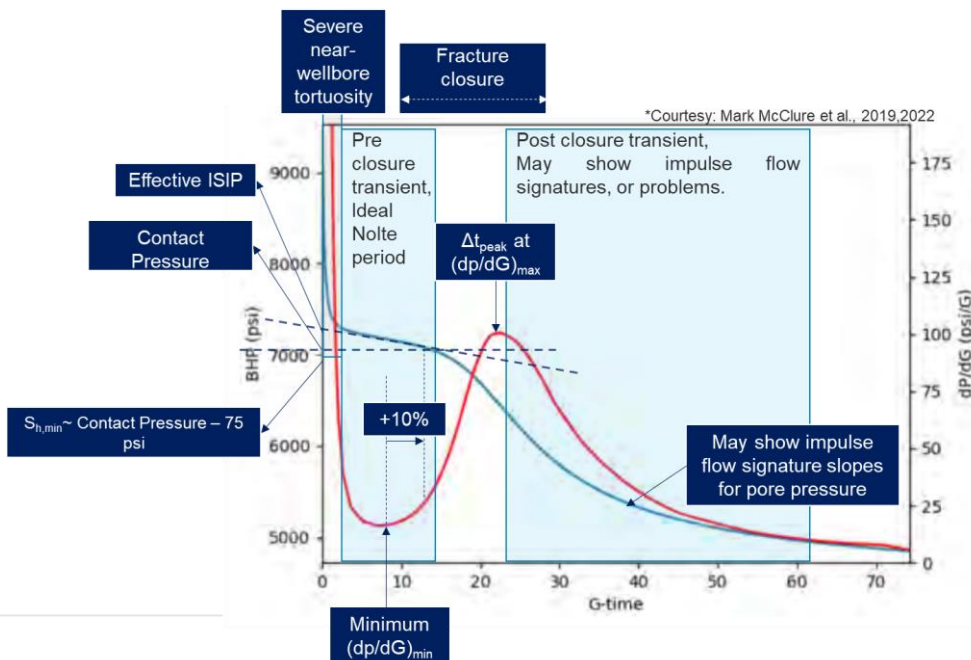


- Procedure diverges significantly from some of the recommendations given by 'holistic' DFIT procedure or the 'tangent method' (given by Barree et al. 2009)

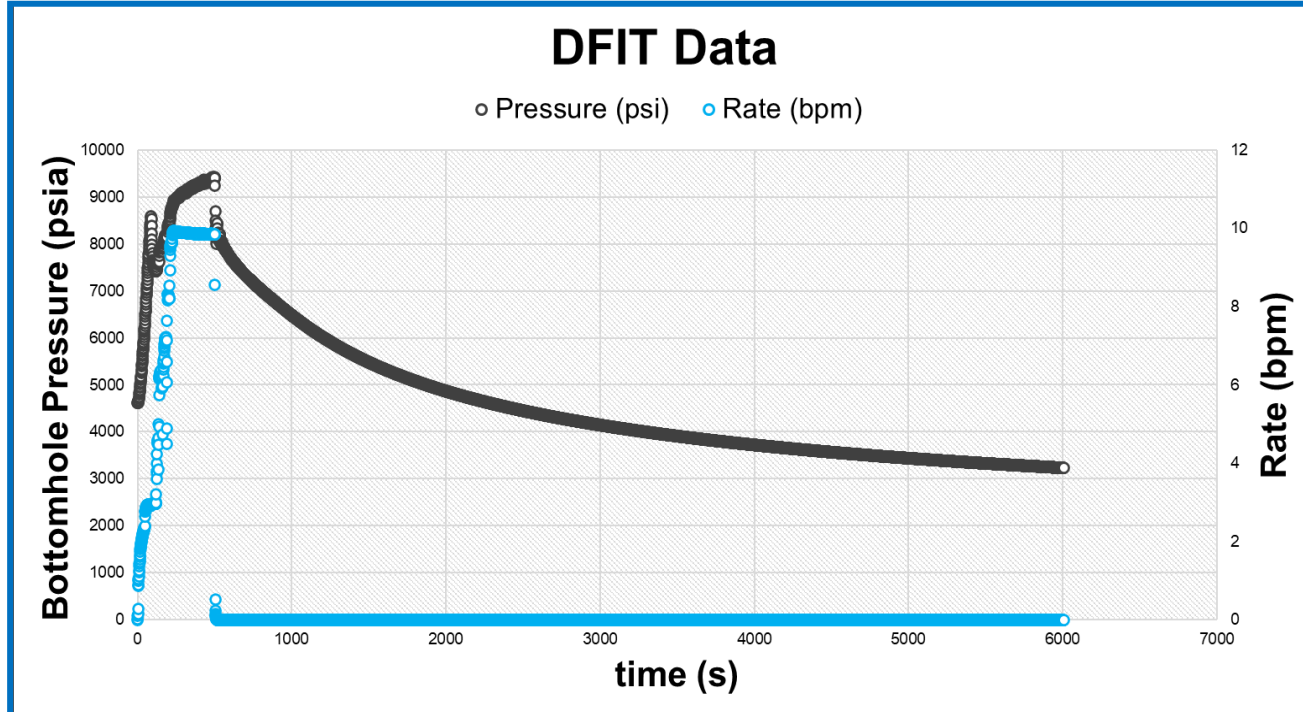
- Stress measurements using the older methods are too low, permeability estimates could be as high 10x to 1000x, leading to underestimation of effective fracture length.

- This fracture compliance method is based on a return to older, classical methods of stress estimation.

- DFIT Analysis in whitson+ focus on this new fracture compliance method for now..



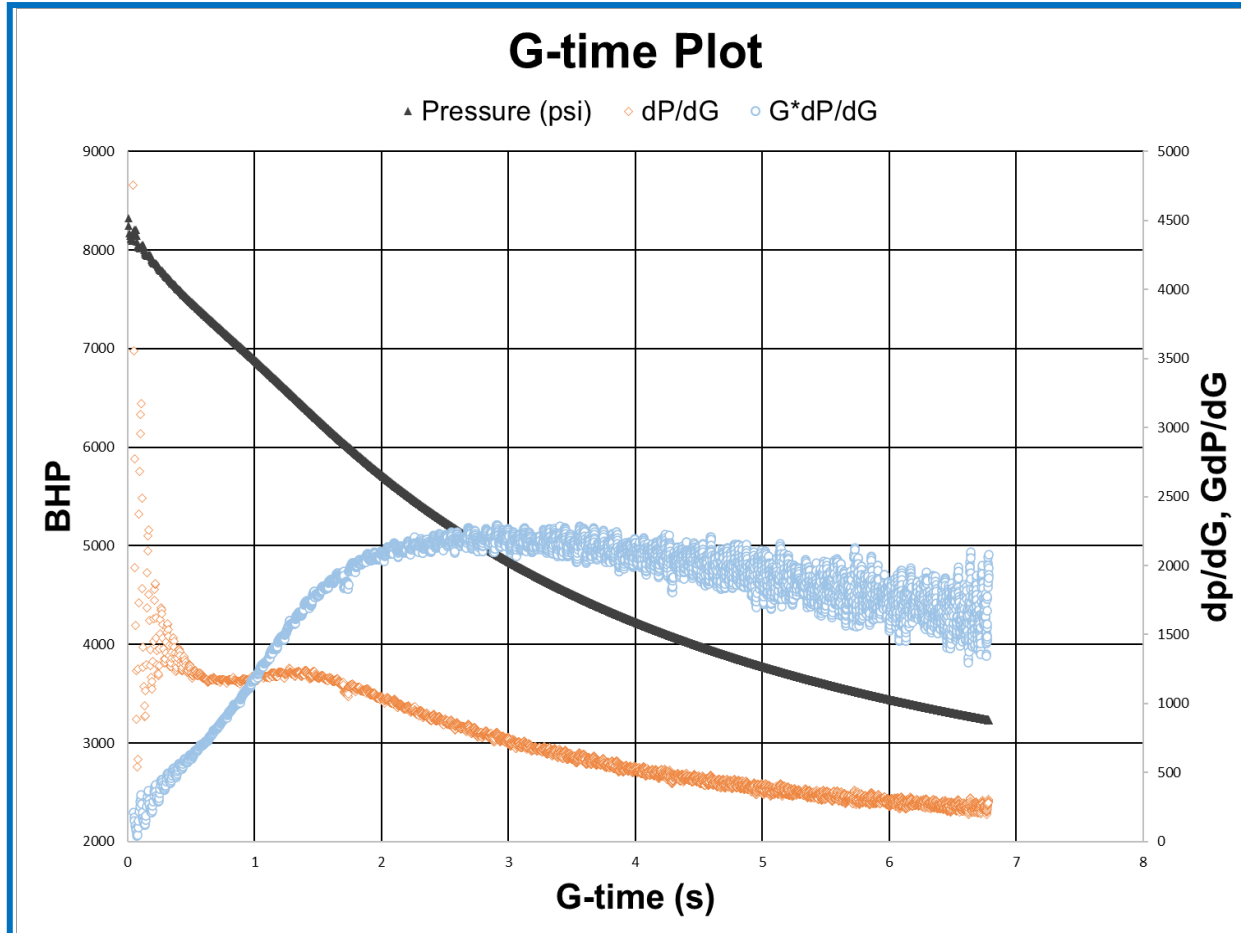
# Plots Typically Used



- Pressure and rate vs time from the start of injection

- Pressure and its derivative vs the G-function or H-function
- Pressure difference and its well-test derivative,  $dp/d\ln(t)$ , with respect to time since shut-in
- “Specialized” plots of pressure for impulse radial or impulse linear flow.

# Plots Typically Used



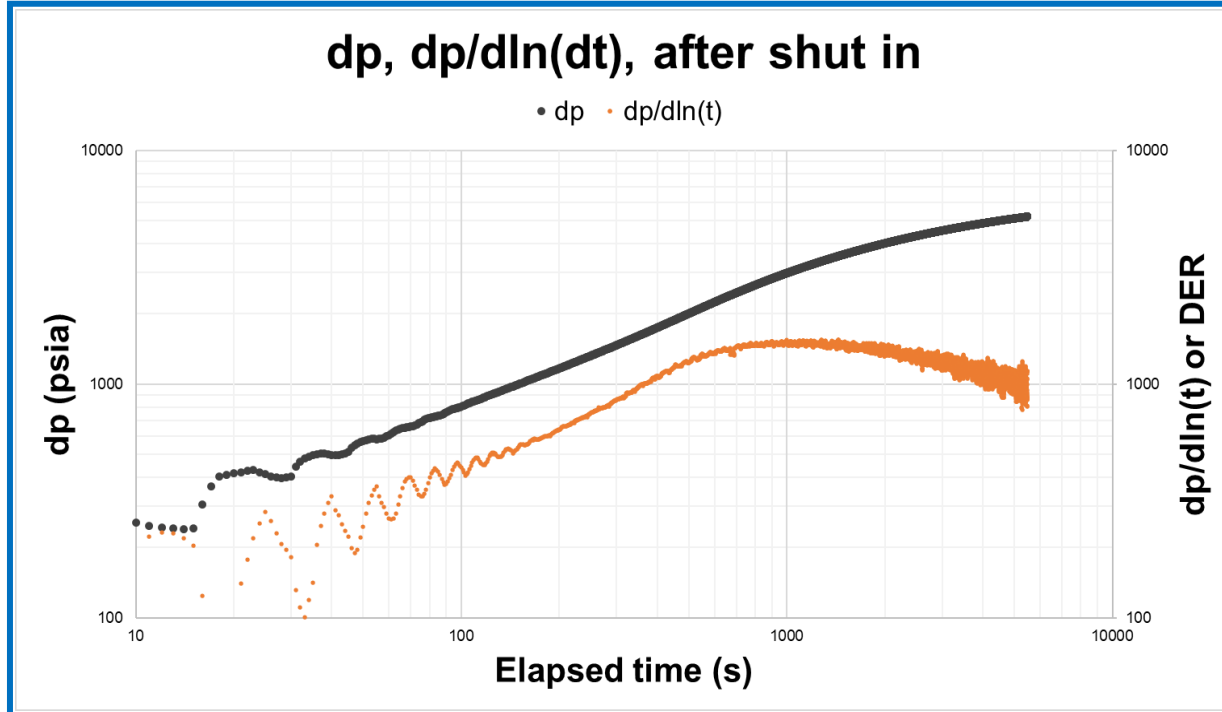
- Pressure and rate vs time from the start of injection

- Pressure and its derivative vs the G-function or H-function

- Pressure difference and its well-test derivative,  $dp/d\ln(t)$ , with respect to time since shut-in
- “Specialized” plots of pressure for impulse radial or impulse linear flow.



# Plots Typically Used



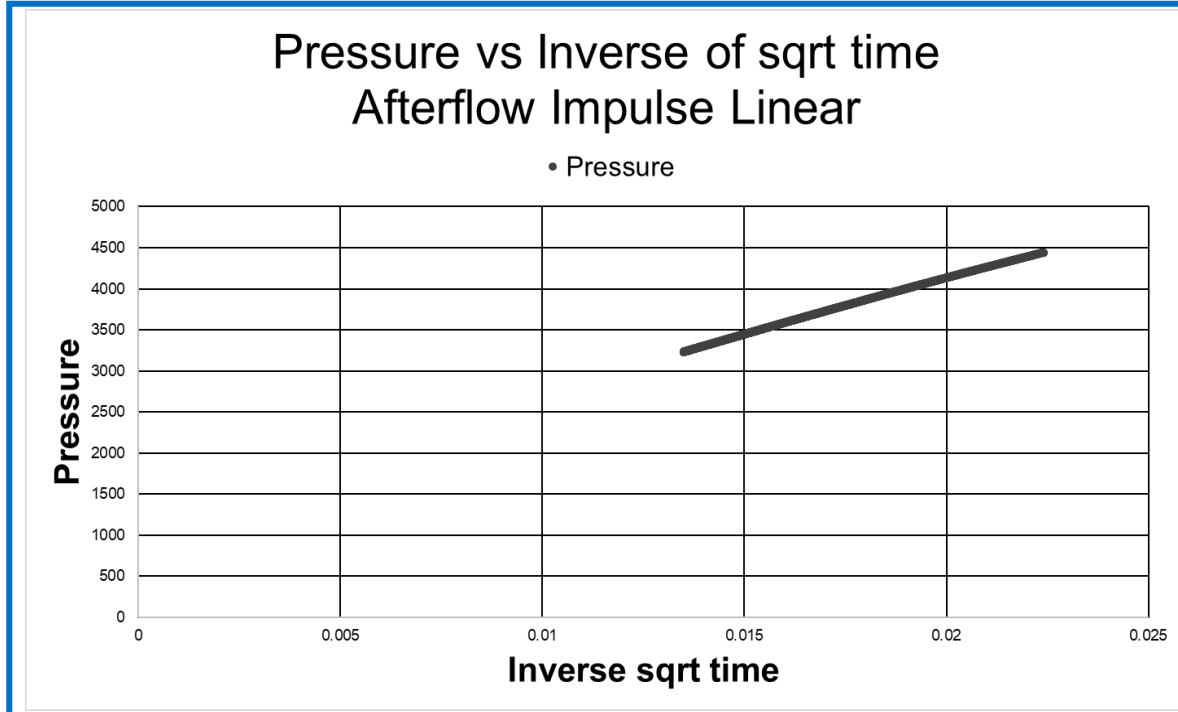
- Pressure and rate vs time from the start of injection

- Pressure and its derivative vs the G-function or H-function

- Pressure difference and its well-test derivative,  $dp/d\ln(t)$ , with respect to time since shut-in

- “Specialized” plots of pressure for impulse radial or impulse linear flow.

# Plots Typically Used

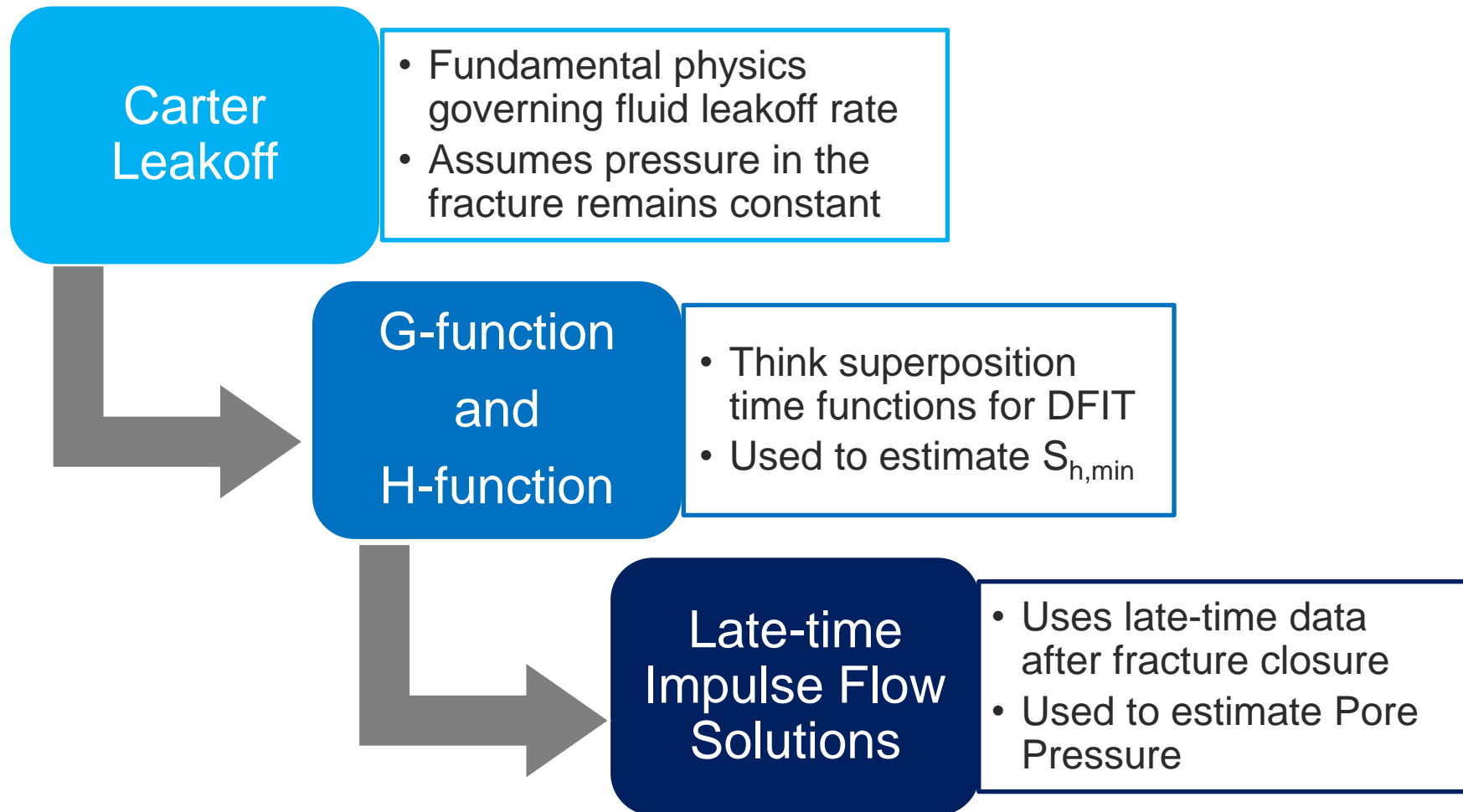


- Pressure and rate vs time from the start of injection
- Pressure and it's derivative vs the G-function or H-function
- Pressure difference and it's well-test derivative,  $dp/d\ln(t)$ , with respect to time since shut-in

- “Specialized” plots of pressure for impulse radial or impulse linear flow.

How

# Theoretical Background



# Superposition Time functions for DFIT

## G-function

$$V_{LS}(\Delta t) = 2AC_L\sqrt{t_e}(g(\Delta t) - g(\Delta t = 0))$$

$$V_{LS}(\Delta t) = \frac{\pi}{2}AC_L\sqrt{t_e}G(\Delta t)$$

- Controlled by Carter leakoff, assumes constant fracture pressure.

$$G(\Delta t) = \frac{4}{\pi}(g(\Delta t) - g(\Delta t = 0))$$

$$G(\Delta t) = \frac{4}{3} \left[ \left(1 + \frac{\Delta t}{t_e}\right)^{1.5} - \left(\frac{\Delta t}{t_e}\right)^{1.5} - 1 \right]$$

- Characteristics of  $dP/dG$  are interpreted for near wellbore tortuosity, effects of closure, leakoff.

$$\frac{dP}{dG} = \frac{1}{C_t} \frac{dV}{dG}$$

- Minimum  $dP/dG$  may still be elevated due to near wellbore tortuosity.

## H-function

$$V_{LS}(\Delta t_k) = 4AH(\Delta t_k) \sqrt{\frac{k\phi c_t}{\pi\mu}}$$

- Accounts for deviation from Carter leakoff, declining fracture pressure

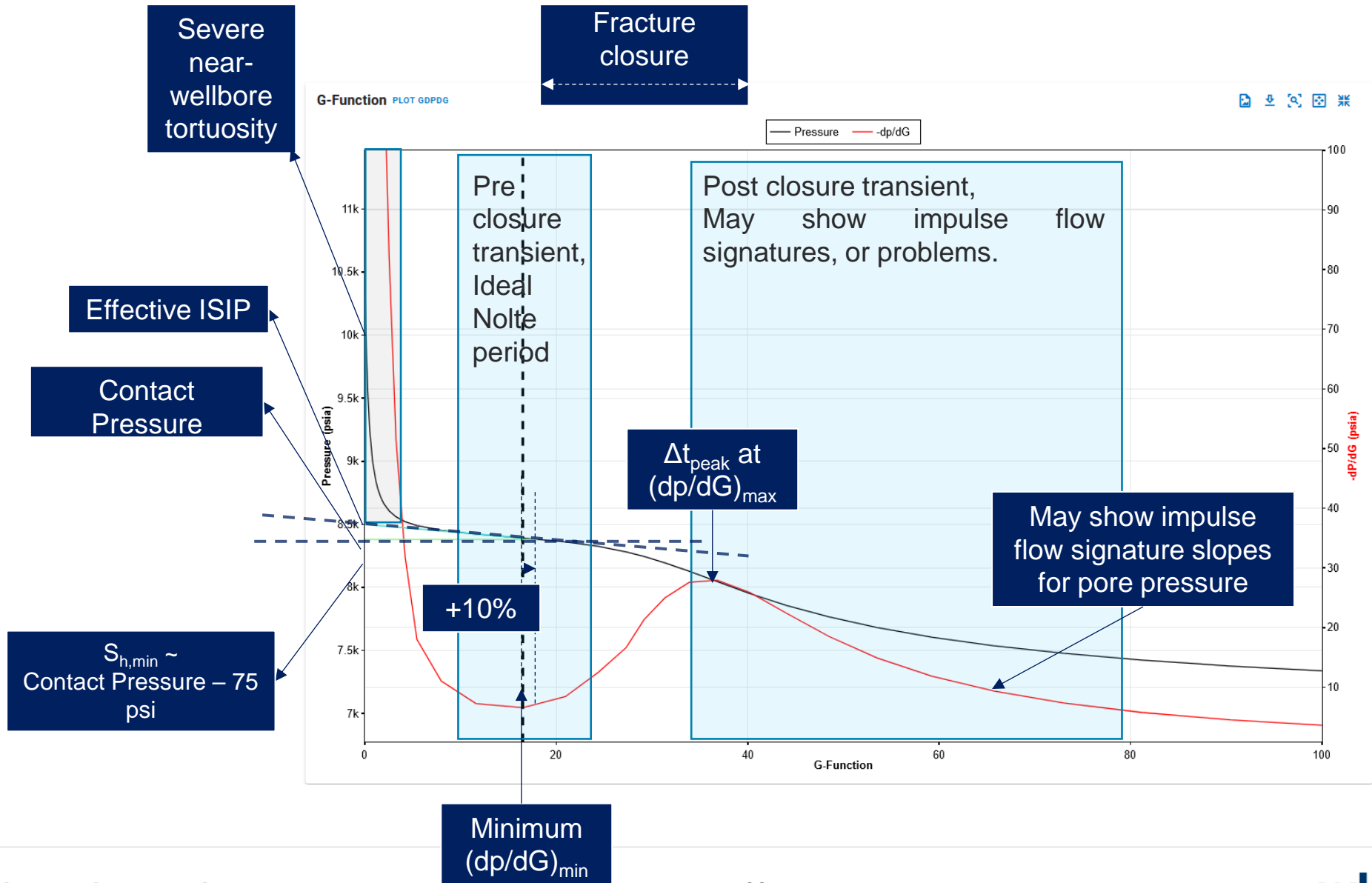
$$H(\Delta t) = \int_{\frac{t_e}{2}}^{\Delta t + \frac{t_e}{2}} \frac{(P(\tau) - P_{res})}{d\tau} \sqrt{\Delta t + \frac{t_e}{2} - \tau} d\tau$$

$$H(\Delta t_k) \approx (P(\tau) - P_{res}) \left( \sqrt{\Delta t_k + \frac{t_e}{2}} - \sqrt{\frac{t_e}{2}} \right)$$

$$+ \sum_{i=1}^k (P_i - P_{i-1}) \sqrt{\Delta t_k - \Delta t_i}$$

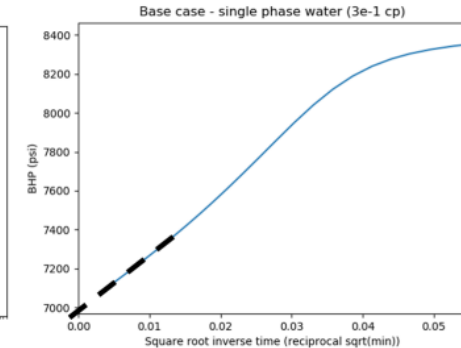
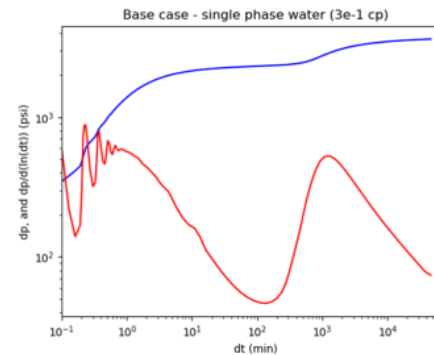
- Uses a time convolution integral of the one-dimensional constant pressure solution for a better estimate of permeability.
- Allows for construction of relative stiffness plots for contact pressure.

# Typical Interpretation of G function plots

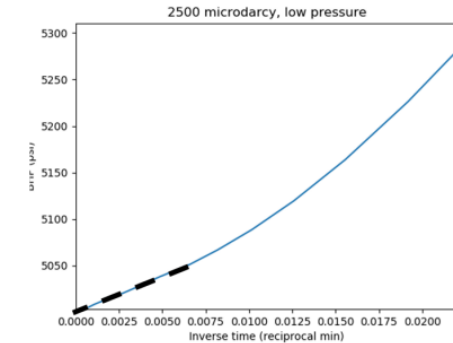
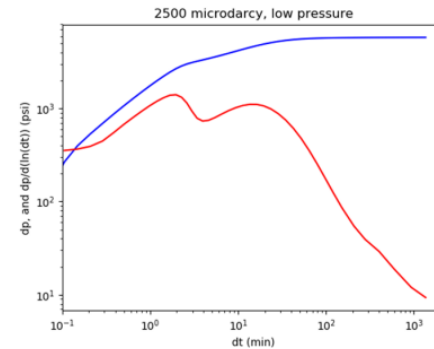


# Late-time Impulse Flow Solutions

Impulse Linear Flow  $\rightarrow$  -0.5 slope  
in  $dp/d\ln(t)$  after closure



Impulse Radial Flow  $\rightarrow$  -1 slope  
in  $dp/d\ln(t)$  after closure, rare



- Plot the data in the identified section against the appropriate time function and extrapolate to find the intercept on the y-axis for estimating the Pore Pressure.
- Post-closure transients can also be used to estimate permeability.

# Permeability

Pick data and equations to work with

1. Preclosure Methods  
G function or H function
2. Postclosure Methods  
Impulse radial or linear

Each method has its own set of equations.

Assume Fracture Geometry

Radial Fracture – common  
PKN Fracture – needs frac height

The equations for stiffness change depending on the assumed geometry

Mass balance for Boundary Conditions

Mass balance equations can be written -

- At the end of injection,
- At minimum  $dP/dG$  or
- At peak  $dP/dG$

Total Volume injected is known/measured in the DFIT test.

$R_f$  or  $L_f$   
 $C_L$   
↓  
 $k_{eff}$

KEY:

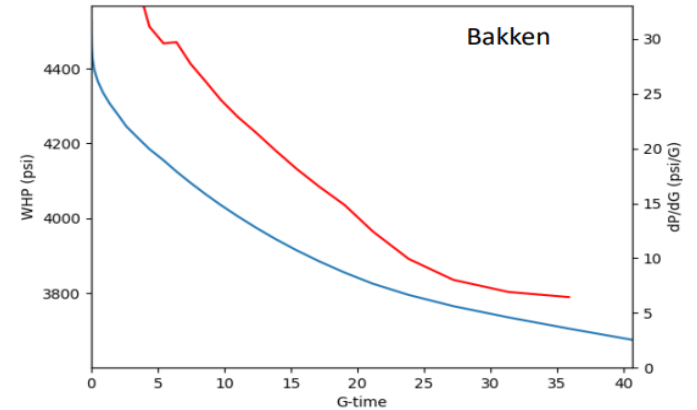
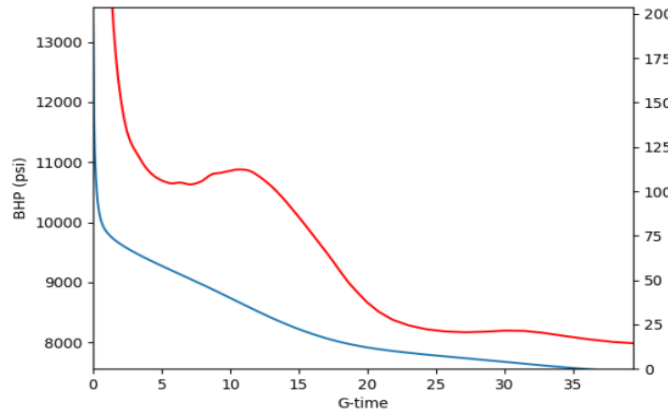
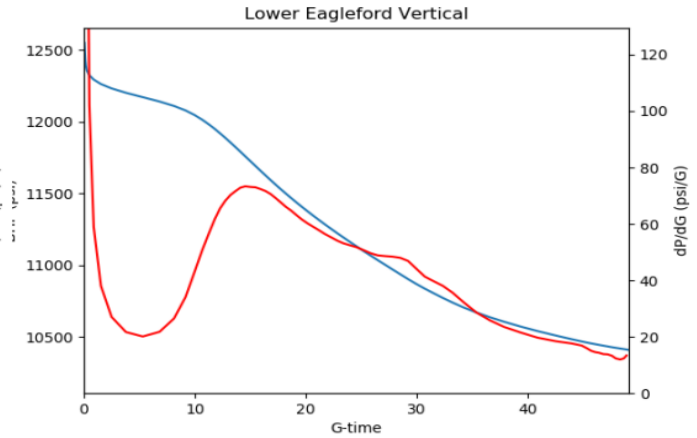
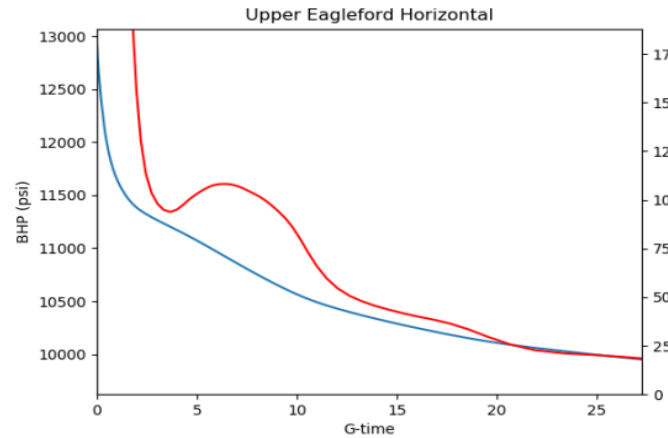
Finding the combination of fracture extent (dimensions) and leak off rate (from  $C_L$ ) that satisfy equations for the same injected volume as measured in the DFIT test.

These equations consider wellbore storage and leakoff!



# SPE 2019-123 More Examples

Vertical wells have minimal wellbore tortuosity compared to horizontal wells



Adequate Response

No compliance response

Storage and leakoff have a conflicting effect. Net result depends on permeability.

# DFIT Cheat Sheet

| Closure interpretation      | Postclosure interpretation             | Stress estimate              | Pore pressure estimate             | Permeability estimate                        |
|-----------------------------|--|------------------------------|------------------------------------|--|
| C-A: Clear contact point    | PC-A: Postclosure linear               | Minimum in dP/dG             | Extrapolate $t^{(-1/2)}$           | Postclosure linear                           |
| C-A: Clear contact point    | PC-B: False radial                     | Minimum in dP/dG             | Extrapolate $t^{(-1)}$             | h-function method divided by 1.5             |
| C-A: Clear contact point    | PC-C: False radial to genuine linear   | Minimum in dP/dG             | Extrapolate $t^{(-1/2)}$           | Postclosure linear                           |
| C-A: Clear contact point    | PC-D: Genuine linear to genuine radial | Minimum in dP/dG             | Extrapolate $t^{(-1)}$             | Postclosure radial and/or postclosure linear |
| C-A: Clear contact point    | PC-E: Peak but no postclosure          | Minimum in dP/dG             | Extrapolate $t^{(-1/2)}$ from peak | h-function method divided by 1.5             |
| C-A: Clear contact point    | PC-F: No peak                          | Minimum in dP/dG             | None                               | None   |
| C-B: Adequate contact point | PC-A: Postclosure linear               | Inflection point in dP/dG    | Extrapolate $t^{(-1/2)}$           | Postclosure linear                           |
| C-B: Adequate contact point | PC-B: False radial                     | Inflection point in dP/dG    | Extrapolate $t^{(-1)}$             | h-function method divided by 1.5             |
| C-B: Adequate contact point | PC-C: False radial to genuine linear   | Inflection point in dP/dG    | Extrapolate $t^{(-1/2)}$           | Postclosure linear                           |
| C-B: Adequate contact point | PC-D: Genuine linear to genuine radial | Inflection point in dP/dG    | Extrapolate $t^{(-1)}$             | Postclosure radial and/or postclosure linear |
| C-B: Adequate contact point | PC-E: Peak but no postclosure          | Inflection point in dP/dG    | Extrapolate $t^{(-1/2)}$ from peak | h-function method divided by 1.5             |
| C-B: Adequate contact point | PC-F: No peak                          | Inflection point in dP/dG    | None                               | None   |
| C-C: No contact point       | PC-A: Postclosure linear               | None                         | Extrapolate $t^{(-1/2)}$           | None   |
| C-C: No contact point       | PC-B: False radial                     | None                         | Extrapolate $t^{(-1)}$             | None   |
| C-C: No contact point       | PC-C: False radial to genuine linear   | None                         | Extrapolate $t^{(-1/2)}$           | None   |
| C-C: No contact point       | PC-D: Genuine linear to genuine radial | None                         | Extrapolate $t^{(-1)}$             | None   |
| C-C: No contact point       | PC-E: Peak but no postclosure          | None                         | Extrapolate $t^{(-1/2)}$ from peak | None   |
| C-C: No contact point       | PC-F: No peak                          | None                         | None                               | None   |
| C-D: Rapid closure          | PC-A: Postclosure linear               | Within a few 100 psi of ISIP | Extrapolate $t^{(-1/2)}$           | None   |
| C-D: Rapid closure          | PC-B: False radial                     | Within a few 100 psi of ISIP | Extrapolate $t^{(-1)}$             | None   |
| C-D: Rapid closure          | PC-C: False radial to genuine linear   | Within a few 100 psi of ISIP | Extrapolate $t^{(-1/2)}$           | None   |
| C-D: Rapid closure          | PC-D: Genuine linear to genuine radial | Within a few 100 psi of ISIP | Extrapolate $t^{(-1)}$             | None   |
| C-D: Rapid closure          | PC-E: Peak but no postclosure          | Within a few 100 psi of ISIP | Extrapolate $t^{(-1/2)}$ from peak | None   |
| C-D: Rapid closure          | PC-F: No peak                          | Within a few 100 psi of ISIP | None                               | None   |

\*[ResFrac Blog post on Practical Guidelines for DFIT interpretation](#)

# Key takeaways

- DFITs are used to provide an estimate of minimum principal stress and pore pressure using the new ‘compliance method’ and  $dP/dG$  instead of  $G*dP/dG$
- DFITs also provide the independent  $k$  estimate to resolve effective fracture area from RTA-derived  $A\sqrt{k}$ .
- DFIT interpretation, typically done in the past, using the ‘tangent method’ proposed by Barree et al. 2009, has shown to overestimate resolved quantities by upto 100x. Result – Suboptimal well spacing design, reduction of NPV.
- Only ‘good’ or ‘adequate’ indication of compliance responses can be used for  $k$  estimation.
- Many reasons could cause monotonic  $dP/dG$  – instant closure, severe wellbore tortuosity, natural fractures, operational issues etc. Interpretation can be relatively uncertain and we cannot estimate  $k$ .
- Permeability pitfalls?
  - Preclosure  $k$  estimate may be about 2 to 3x higher, and postclosure  $k$  estimate is usually lesser and more reliable, used in most reservoir engineering calculations.
  - Analyzing  $k$  from a ‘false’ radial flow regime (typically seen in gas shales, preceding true linear impulse flow) leads to 10-100x overestimate.

# More References?

[whitson webinar] Comparative Analysis of 62 DFITs from Ni...

Watch later Share

BR MF  
Rajappa... Marcelo ...

MM OS  
Mark Mc... SOTO, O...

HH L  
Hugh He... Louis

EY BG  
Yang, Ed... Brian Ga...

NE EM  
Nabiel T... Motame...

BW WH  
Brett Wo... Wai Tiu...

CG GL  
GONZAL... Liu, Gio...

DS +109

**ResFrac**

**Whitson Seminar**  
**Comparative Analysis of 62 DFITs**  
**from Nine Different Shale Plays**  
Mark McClure  
CEO, ResFrac Corporation  
Sept 13, 2023

MORE VIDEOS

4:20 / 55:13

YouTube

# More References?

## Practical guidelines for DFIT interpretation using the ‘compliance method’ procedure from URTeC-2019-123

September 5, 2023

Mark McClure<sup>1</sup>, Dave Ratcliff<sup>1</sup>, Ankush Singh<sup>1</sup>, Chris Ponnors<sup>1</sup>, and Garrett Fowler<sup>1</sup>



URTeC: 123

### A Collaborative Study on DFIT Interpretation: Integrating Modeling, Field Data, and Analytical Techniques

Mark McClure<sup>1</sup>, Vidya Bammidi<sup>2</sup>, Craig Cipolla<sup>3</sup>, Dave Cramer<sup>4</sup>, Lucas Martin<sup>5</sup>, Alexei A Savitski<sup>6</sup>, Dave Sobernheim<sup>2</sup>, and Kate Voller<sup>7</sup>; 1. ResFrac Corporation, 2. Keane Group, 3. Hess Corporation, 4. ConocoPhillips Company, 5. Formerly with Apache Corporation, now with Marathon Oil Corporation, 6. Shell International Exploration and Production Inc., 7. Range Resources Corporation

Copyright 2019, Unconventional Resources Technology Conference (URTeC) DOI 10.15530/urtec-2019-123

SPE-205297-MS

### Best Practices in DFIT Interpretation: Comparative Analysis of 62 DFITs from Nine Different Shale Plays

Mark McClure, Garrett Fowler, and Matteo Picone, ResFrac Corporation

Copyright 2022, Society of Petroleum Engineers DOI 10.2118/205297-MS

## The Fracture-Compliance Method for Picking Closure Pressure From Diagnostic Fracture-Injection Tests

Mark W. McClure and Hojung Jung, University of Texas at Austin; Dave D. Cramer, ConocoPhillips; and Mukul M. Sharma, University of Texas at Austin

# Exercises

# whitson

---

We support energy companies, oil services companies, investors and government organizations with expertise and expansive analysis within PVT, gas condensate reservoirs and gas-based EOR. Our coverage ranges from R&D based industry studies to detailed due diligence, transaction or court case projects.

We help our clients find best possible answers to complex questions and assist them in the successful decision-making on technical challenges. We do this through a continuous, transparent dialog with our clients - before, during and after our engagement.

The company was founded by Dr. Curtis Hays Whitson in 1988 and is a Norwegian corporation located in Trondheim, Norway, with local presence in USA, Middle East, India and Indonesia.

---

## Global

Curtis Hays Whitson, PhD  
curtishays@whitson.com

## Asia-Pacific

Kameshwar Singh, PhD  
singh@whitson.com

## Middle East

Ahmad Alavian, PhD  
alavian@whitson.com

## Americas

Mathias Carlsen, MSc  
carlsen@whitson.com

---

## Whitson AS

Skonnertvegen 7, 7053  
Trondheim, Norway  
www.whitson.com

## Whitson USA LLC

3410 W Dallas St.  
Houston, TX 77019, US