UPDATED

whitson

FMB

in whitson⁺

Mathias Carlsen | Mohamad Dahouk | Curtis Whitson

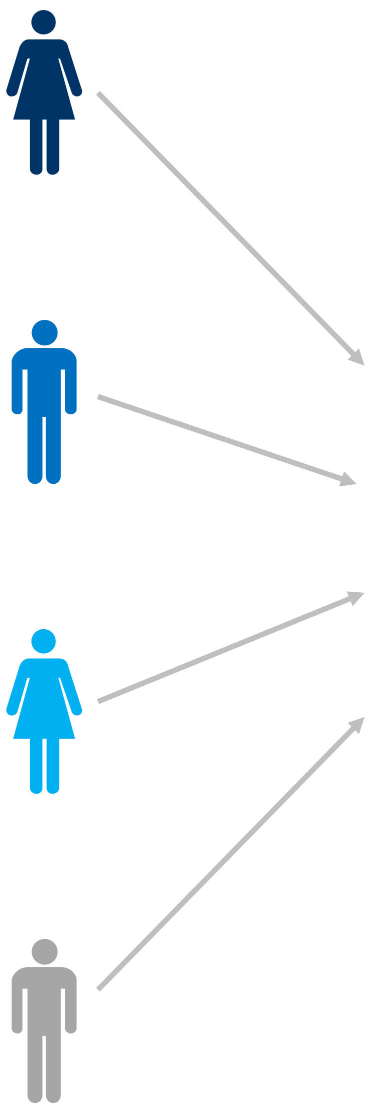
Course held Virtually

21 August 2024

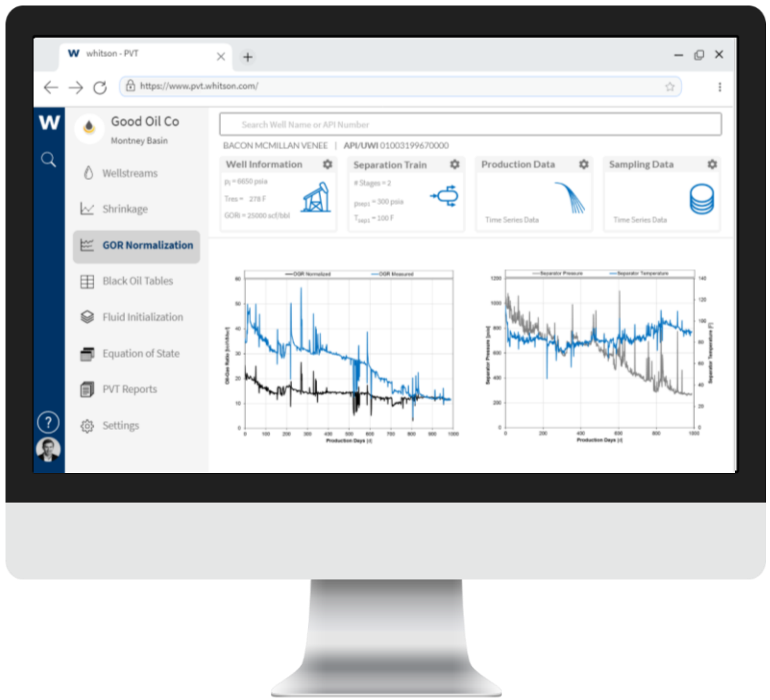
The course is recorded

Software

Access to whitson+



NOT YOUR COMPANY DOMAIN



www.courses.whitson.com

Username: your e-mail

Password: WhitsonFMB2024*

*Send an e-mail to support@whitson.com if you need help to login.

Introduction

Small Courses throughout the Year

Half-day courses (3-4 hrs), hands-on focus with software and theory

✔ ~~14 Feb: PVT & Phase Behavior in whitson+~~
🎥 Recording: https://youtu.be/m7EISdxyZ2U, 📄 Slides: https://shorturl.at/gzBNW

✔ ~~24 April: Bottomhole Pressure in whitson+~~
🎥 Recording: https://youtu.be/0pvojymb-5U, 📄 Slides: https://shorturl.at/wLWZ9

✔ ~~26 June: Analytical & Numerical RTA in whitson+~~
🎥 Recording: https://youtu.be/A2Ov8P6GrEI 📄 Slides: https://shorturl.at/wTrGw

✔ 21 August: Flowing Material Balance (FMB) in whitson+

✔ 02 October: Nodal Analysis in whitson+

✔ 16 October: Well tests (CPG & DFIT) in whitson+

✔ 04 December: DCA & Type Well in whitson+

Send e-mail to carlsen@whitson.com if you haven't received the invite to the courses.

Need Course Certificate?

Contact dahouk@whitson.com

General Information

- 3–4-hour course
- Interactive class
- Ask questions – drive the course emphasis
    - In chat or unmute to speak (mute when not talking ☺)
- Will send out all digital material after class
- Some content in this slide deck is meant for presentation purposes, while some parts are meant for reference.

What we will Cover

- **whitson**+ and **multiphase FMB** basics
  - Login & Access
  - Workflow ("Clicking the buttons")
  - General structure and functionality
- **The course has an FMB Focus primarily**
  - Multiphase FMB
  - Recovery Factor Analysis

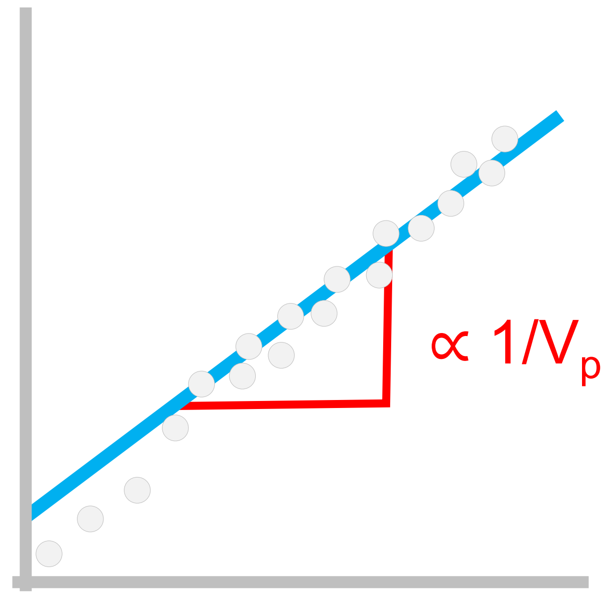
We'll assume the inputs are correct (PVT, BHP, etc.)


I BELIEVE IN
A
REPETITION
imgflip.com

Flowing Material Balance (FMB) 1.01

What is it used for?

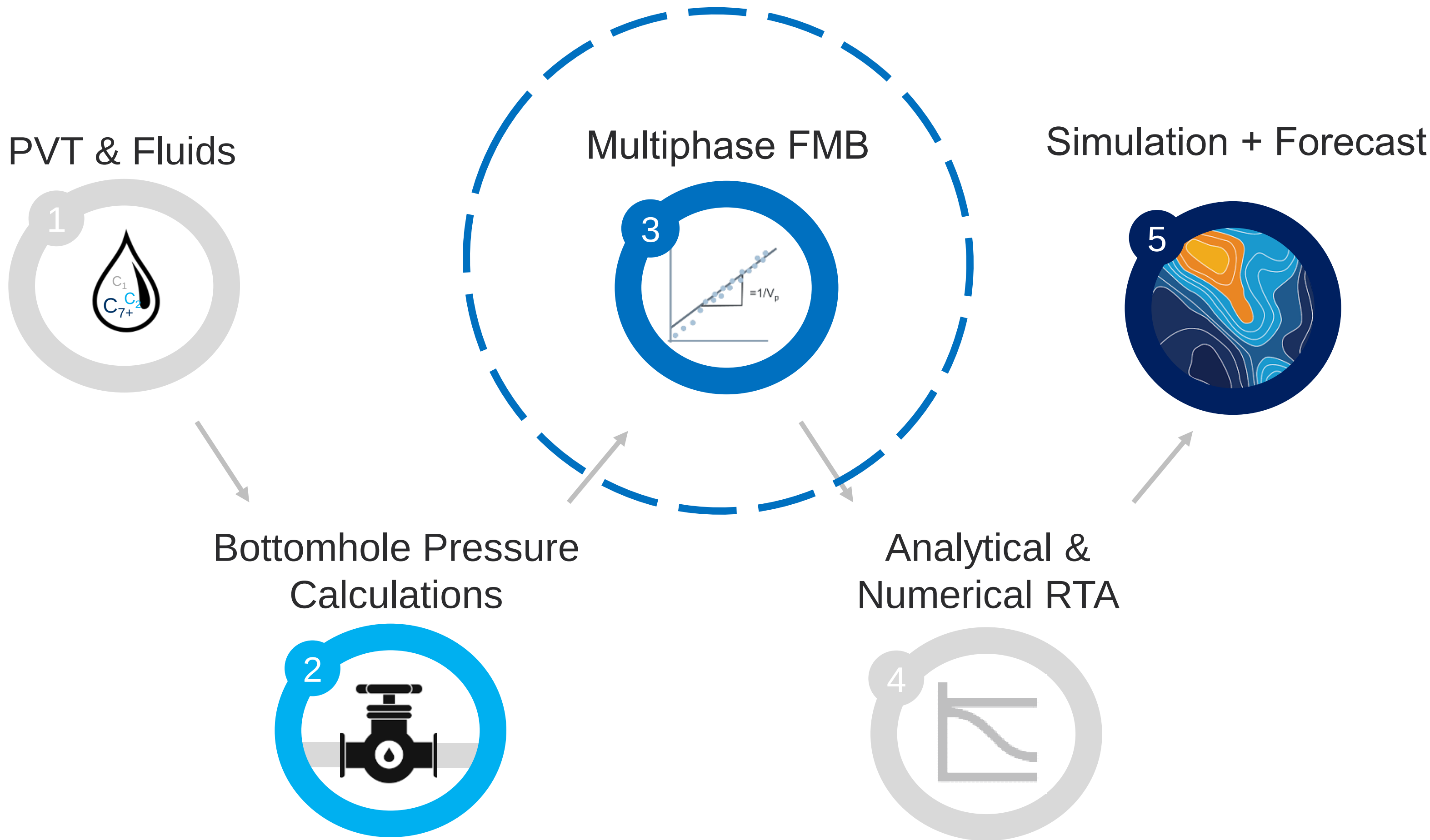
Obtain estimates of drained reservoir volume.



“It is better to be roughly right, than precisely wrong”

- John Maynard Keynes

Unconventional Reservoir Workflow



Flow Regimes 1.01

Infinite acting flow ends as pressure transient reaches *one* reservoir boundary

↑ ↑ ↑ ↑ ↑

Transitional flow (period in between)

↓ ↓ ↓ ↓ ↓

Boundary dominated flow starts when the wellbore pressure response is affected by *all* reservoir boundaries

What can be Derived "Uniquely" from RTA?

LFP

(or A√k)

Observed during
infinite-acting, linear flow

<u>**CONTACTED**</u>

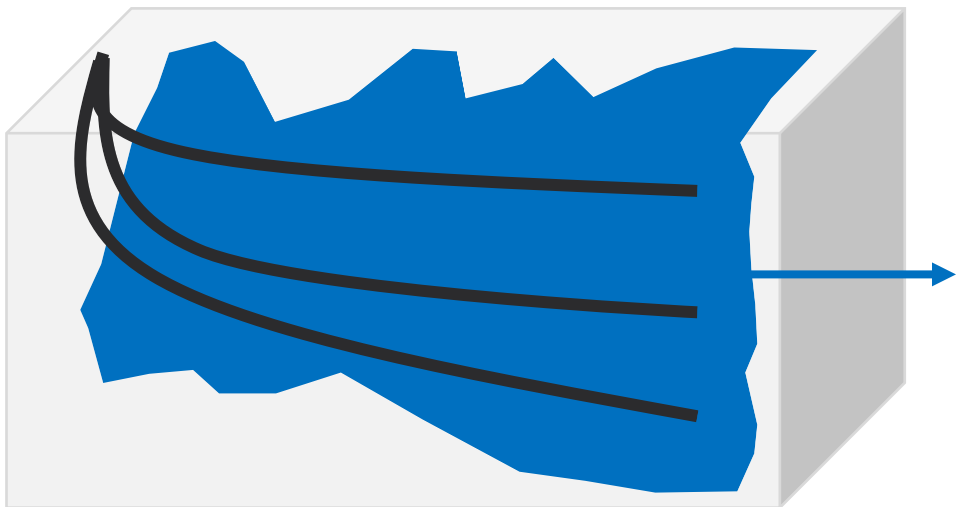
OOIP

(or OGIP)

Observed during
boundary dominated flow

Volume Resolved from RTA

How much pore volume is a well “seeing” / draining????



What should we call this volume?

- Contacted pore volume (or contacted OOIP/OGIP)
- Stimulated rock volume
- Other (e.g., drained rock volume, use all interchangeably)

Contacted Pore Volume (V_p)

All the below used interchangeably

$$V_p = HCPV/(1-S_{wi})$$

$$OOIP = HCPV/B_{oi}$$

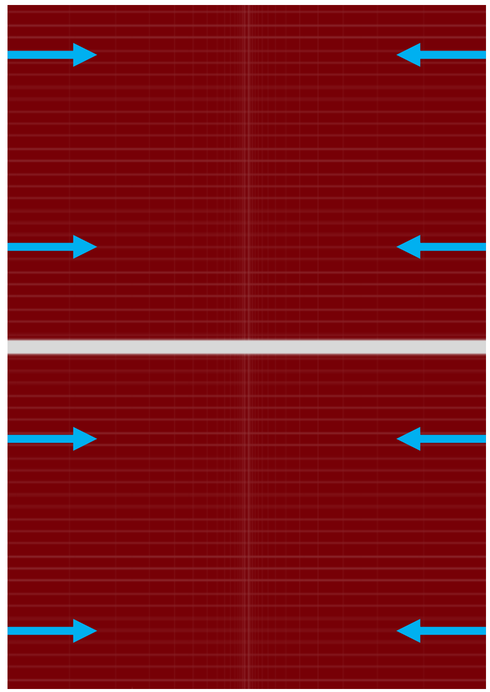
$$OGIP = OOIP x R_{si}$$

$$OWIP = PV x S_{wi}/B_w$$

whitson

How many boundaries?

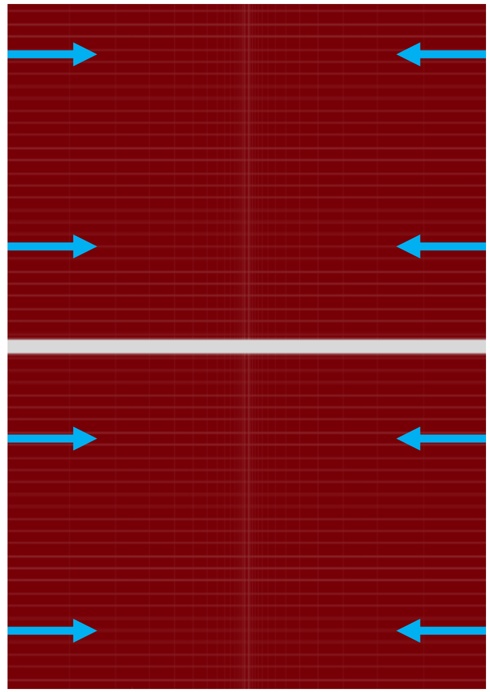
1 boundary



1 dimensional model

How many flow regimes?

2 flow regimes

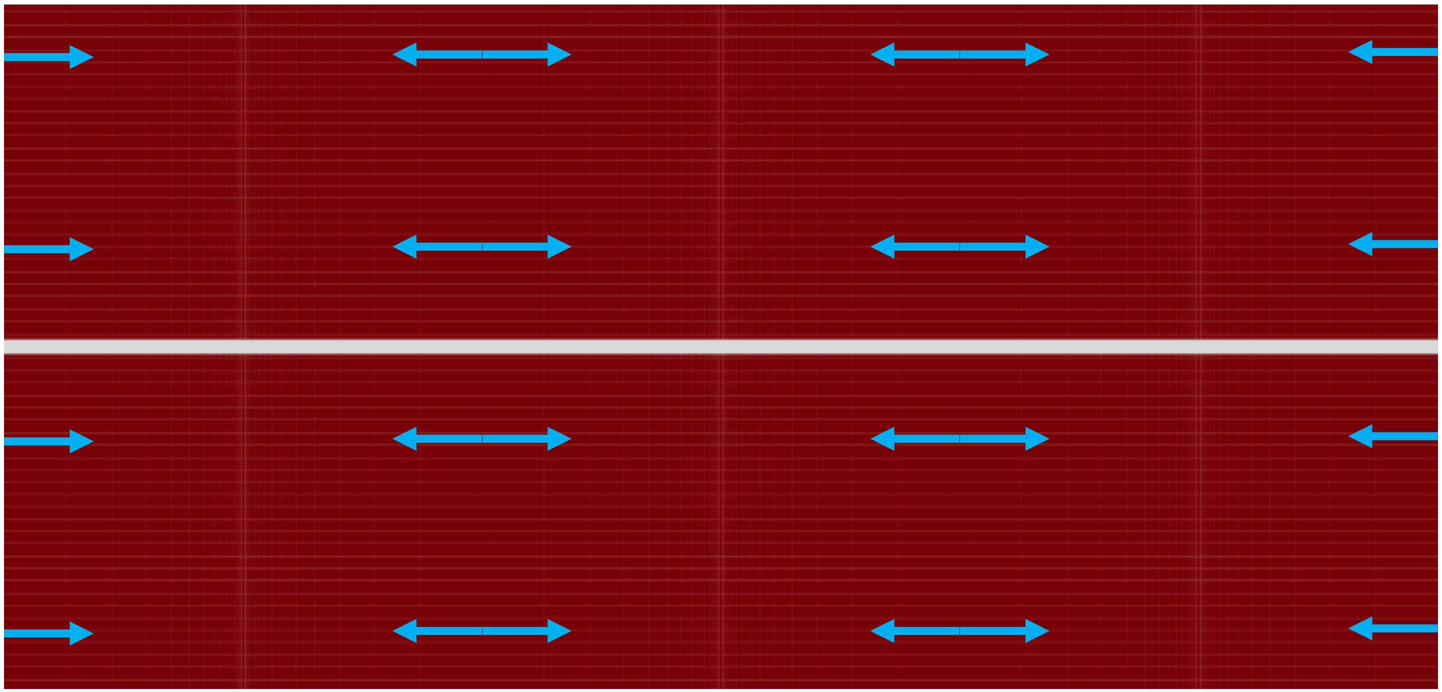


1. Infinite acting (IA)

2. followed by boundary dominated (BDF)

How many boundaries?

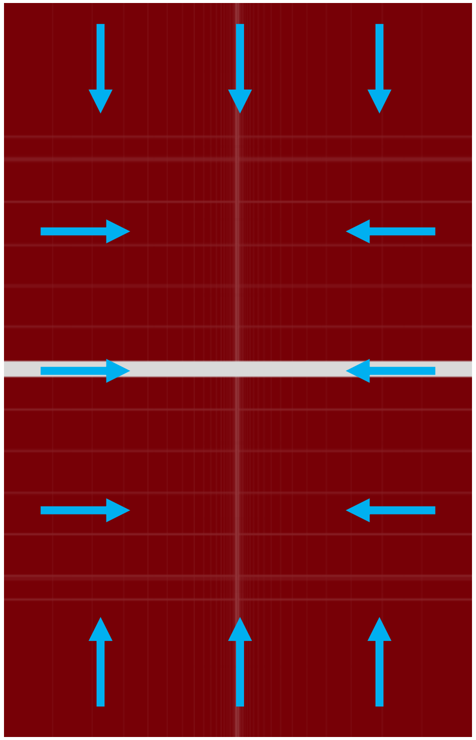
1 boundary



1 dimensional model

How many boundaries?

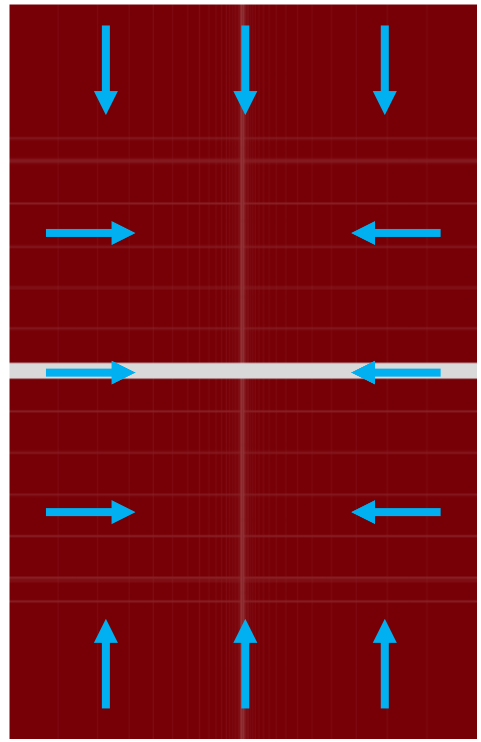
2 boundaries



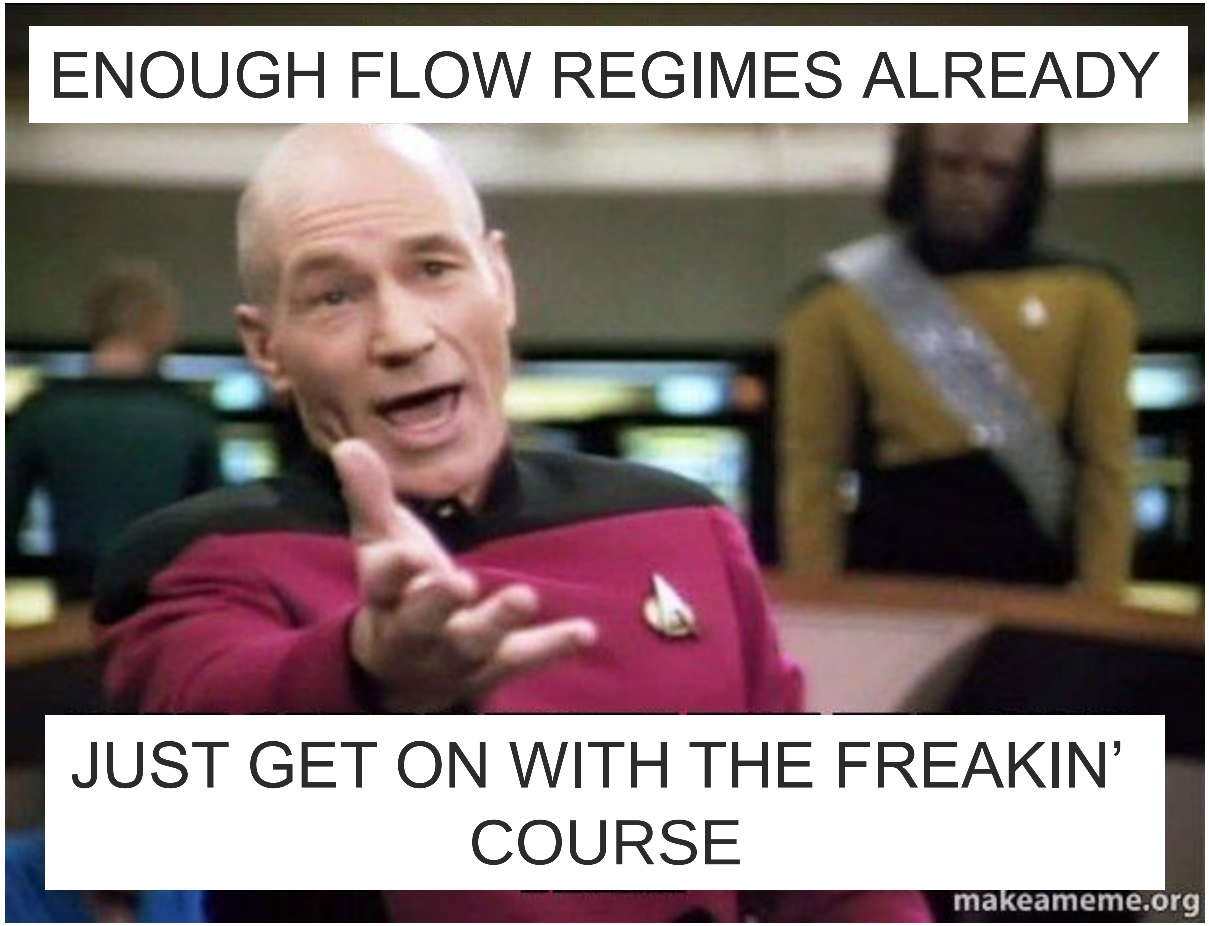
2-dimensional model

How many flow regimes?

3 flow regimes



1. Infinite acting (IA)
2. Transitional Flow
3. Boundary dominated (BDF)


ENOUGH FLOW REGIMES ALREADY
JUST GET ON WITH THE FREAKIN' COURSE
makeameme.org

Multiphase FMB - Crash Course

Problem

Model

Reality

DON’T HAVE

Multiphase Flowing Material Balance

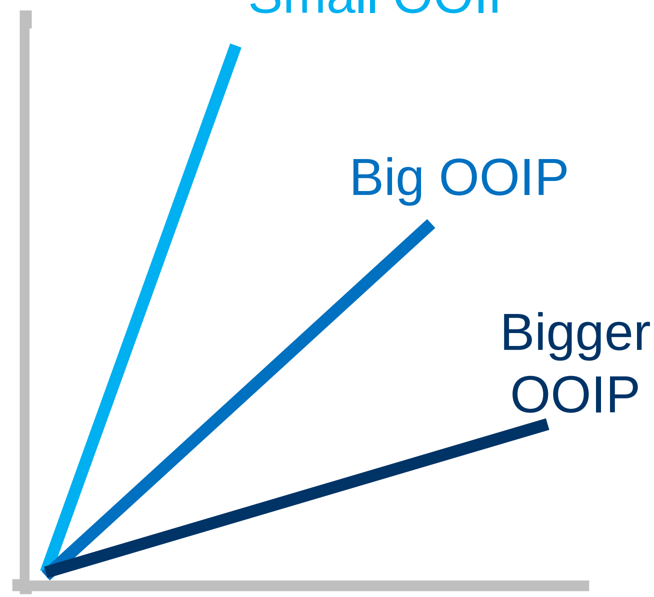
2020: New FMB method

- ✓ No rel. perms required
- ✓ Geometry agnostic
- ✓ Outputs contacted OOIP (or OGIP)

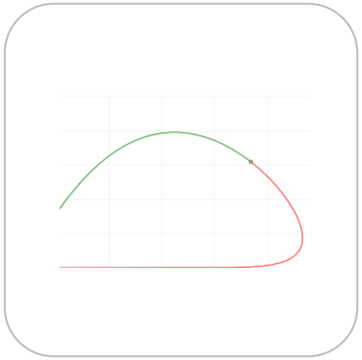

BS.

Multiphase Flowing Material Balance

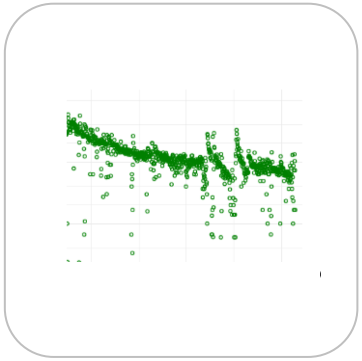
- ✓ No rel. perms required
- ✓ Outputs OOIP
- ✓ Geometry agnostic
- ✓ Assumes boundary dominated flow
- ✓ Bound RTA analysis



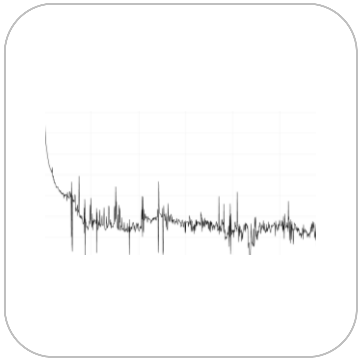
Multiphase FMB … Inputs



PVT



Rates



BHPs

Multiphase FMB Eq.

Governing equation

$$\rho = \frac{m}{V}$$

whitson

Multiphase FMB Eq.

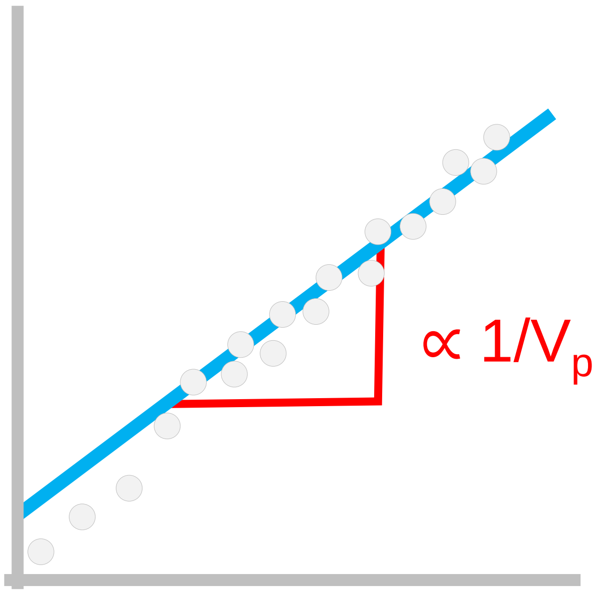
Governing equation

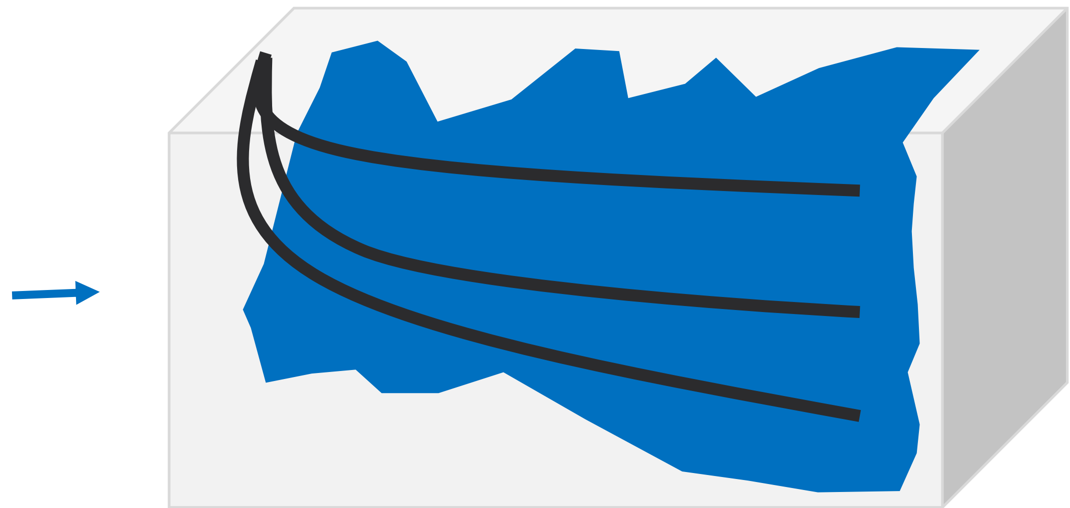
$$y = ax + b$$

Recovery Factor Analysis – Crash Course

Multiphase FMB

How much pore volume is a well "seeing" / draining????





What else would you need?

RF

Recovery Factor

EUR

Estimated Ultimate Recovery

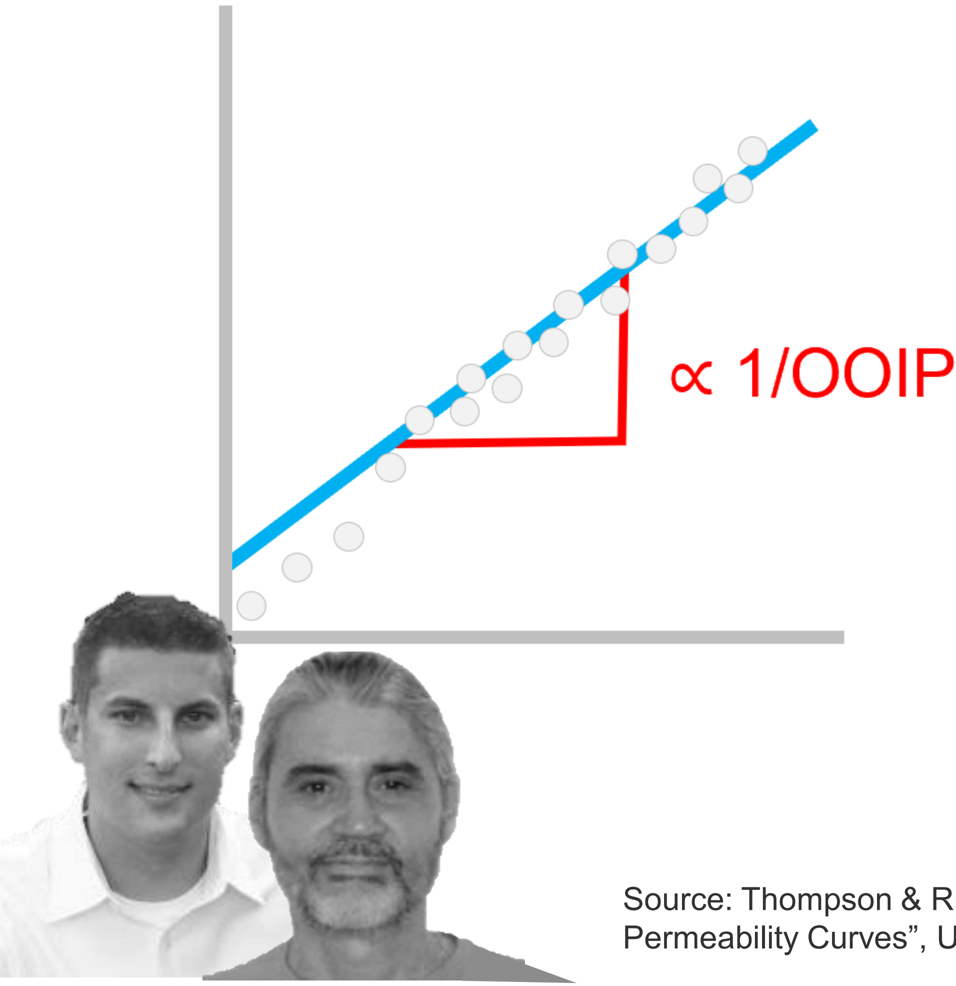
Physically Constrained

Theory

Multiphase Flowing Material Balance

without Relative Permeability

Multiphase Flowing Material Balance

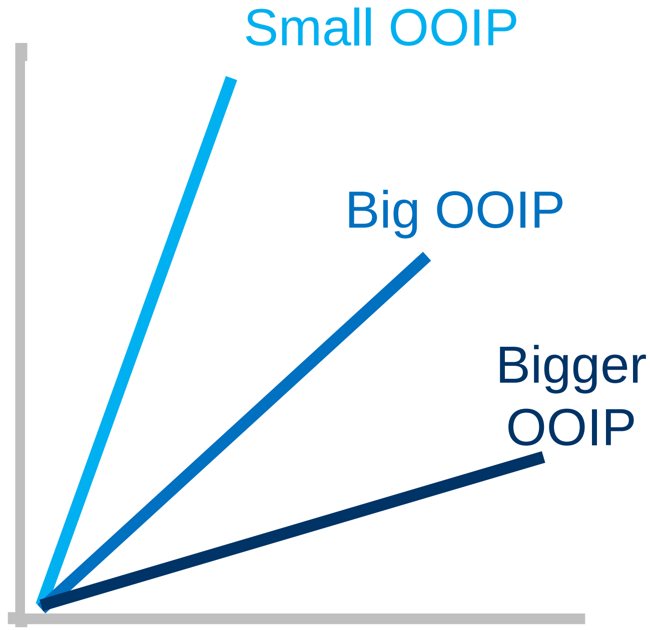


- Developed by Leslie Thompson & Barry Ruddick (2017-2022)
- Plotting technique to analyze multiphase production data
- Outputs V_p, OOIP, OGIP, OWIP
- Requires PVT, production data, bottomhole pressures and initial reservoir conditions

Source: Thompson & Ruddick (2022), "Multiphase Flowing Material Balance Without Relative Permeability Curves", URTeC: 3718045

Multiphase Flowing Material Balance

- ✓ No rel. perms required
- ✓ Outputs OOIP
- ✓ Geometry agnostic
- ✓ Assumes boundary dominated flow
- ✓ Bound RTA analysis



Source: Thompson & Ruddick (2022), "Multiphase Flowing Material Balance Without Relative Permeability Curves", URTeC: 3718045

Multiphase FMB Eq.

Governing equation

Mixture density change   Material balance time   Intercept

$$\frac{\beta_i - \beta_{well}}{\dot{m}\left(t\right)} = \frac{1}{V_p} MBT_M + \frac{1}{b_M}$$

Mass rate   Pore volume

Source: Thompson & Ruddick (2022), "Multiphase Flowing Material Balance Without Relative Permeability Curves", URTeC: 3718045

Multiphase FMB

Define insitu mixture density as

$$\beta = 5.615\rho_{osc}\left(\frac{S_o}{B_o} + \frac{r_v S_g}{B_g}\right) + 1000\rho_{gsc}\left(\frac{R_s S_o}{B_o} + \frac{S_g}{B_g}\right) + 5.615\rho_{wsc}\frac{S_w}{B_w}$$

Density Change

$$\triangle\beta = \beta_i - \beta$$

Mass Rate

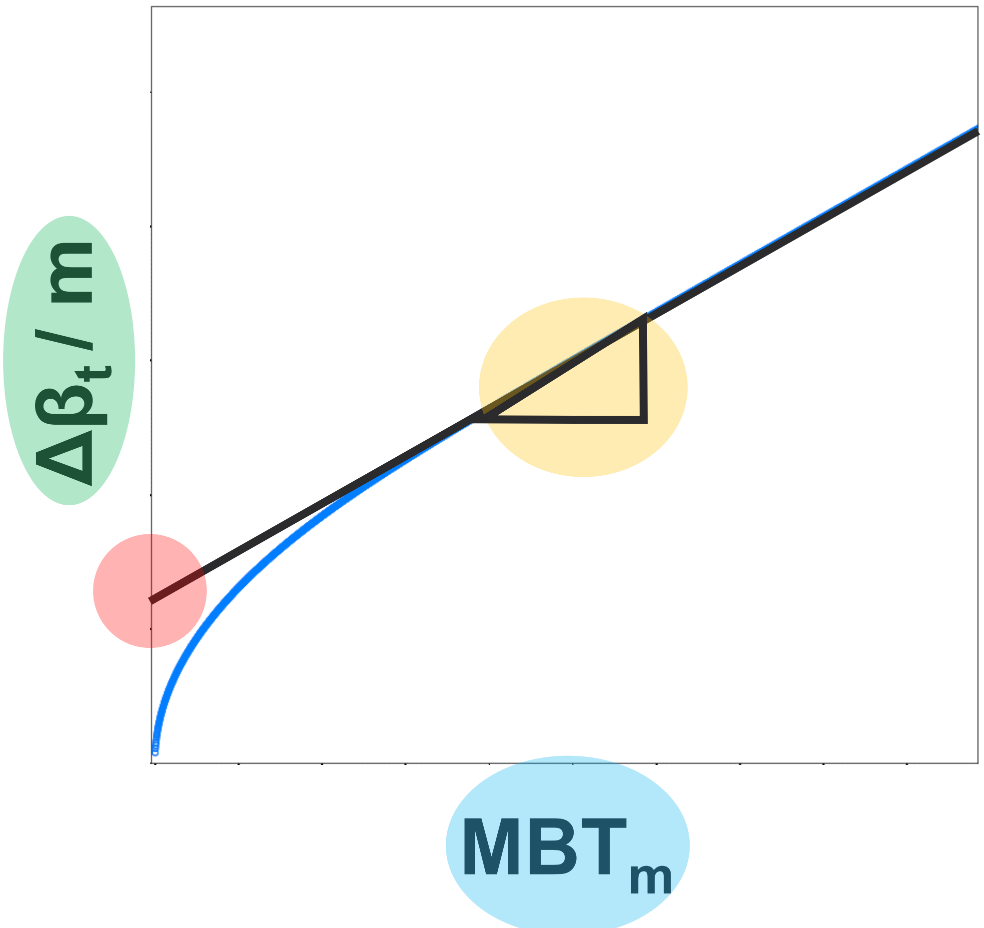
$$\dot{m}\left(t\right) = 5.615\rho_{osc}q_o(t) + 1000\rho_{gsc}q_g\left(t\right) + 5.615\rho_{wsc}q_w(t),$$

Mass material balance time

$$MBT_M = \frac{\int_0^t \dot{m}\left(t\right)dt}{\dot{m}\left(t\right)} = \frac{M_T\left(t\right)}{\dot{m}\left(t\right)}$$

Source: Thompson & Ruddick (2022), “Multiphase Flowing Material Balance Without Relative Permeability Cu

Multiphase FMB



$$\frac{\beta_i - \beta_{well}}{\dot{m}(t)} = \frac{1}{V_p} MBT_M + \frac{1}{b_M}$$

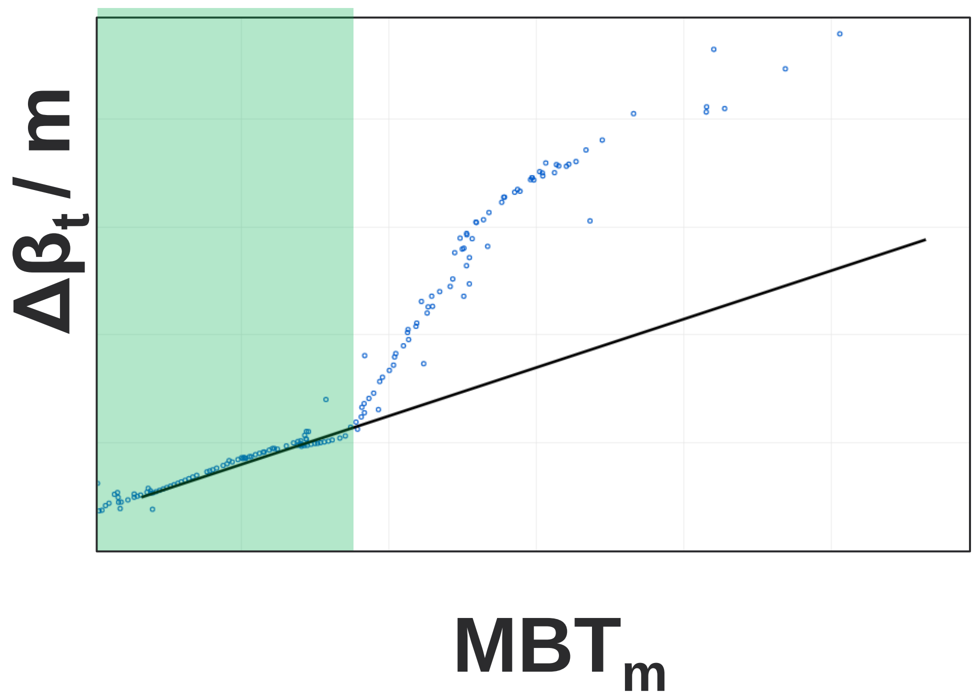
Practice

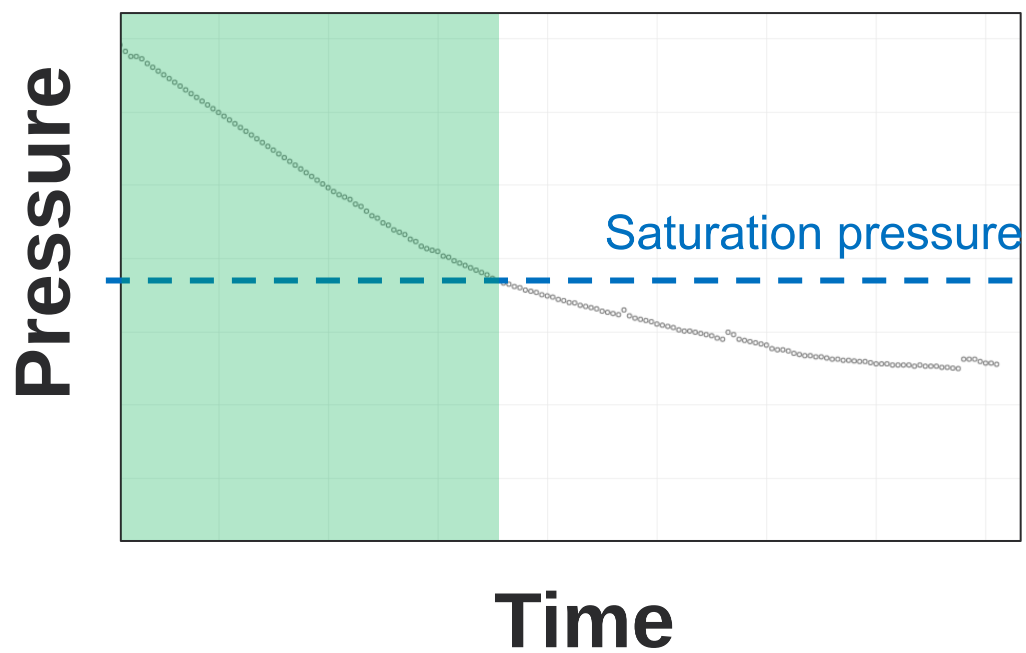
Multiphase Flowing Material Balance

without Relative Permeability

Multiphase FMB – Three Key Periods

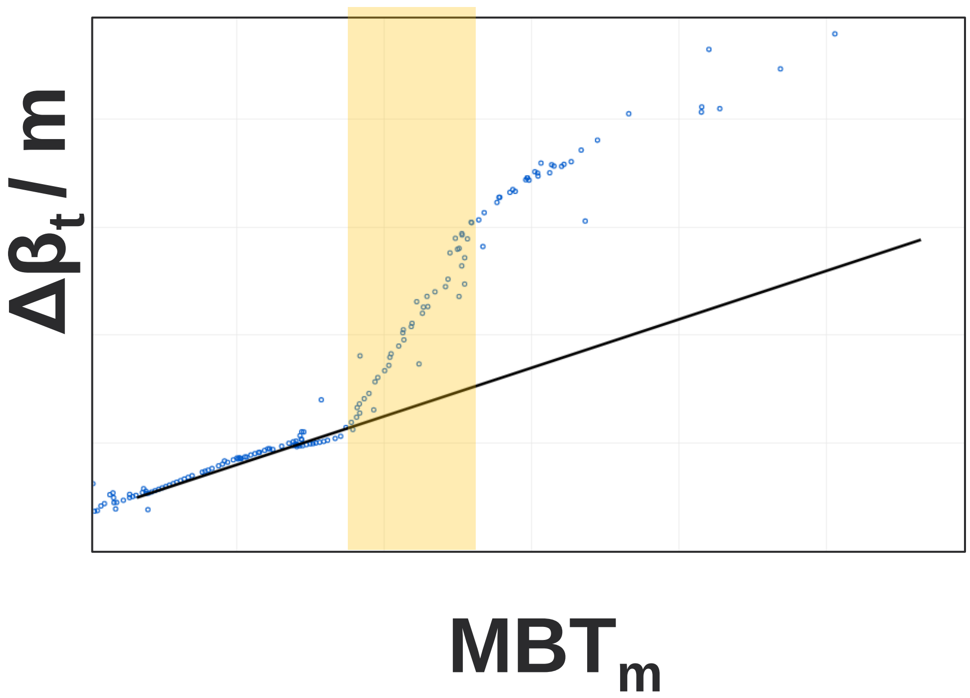
Period 1: Before $p_{wf} < p_{sat}$ ("single-phase flow")

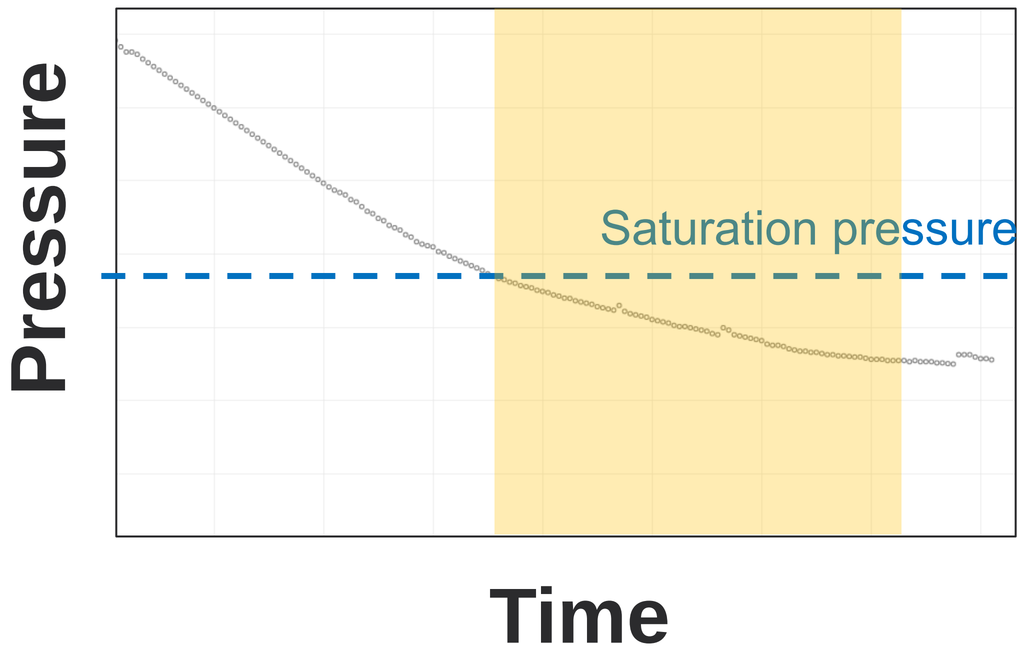




Multiphase FMB – Three Key Periods

Period 2: Transition period due to multiphase flow effects (gas enters the system, and gas is more compressible)

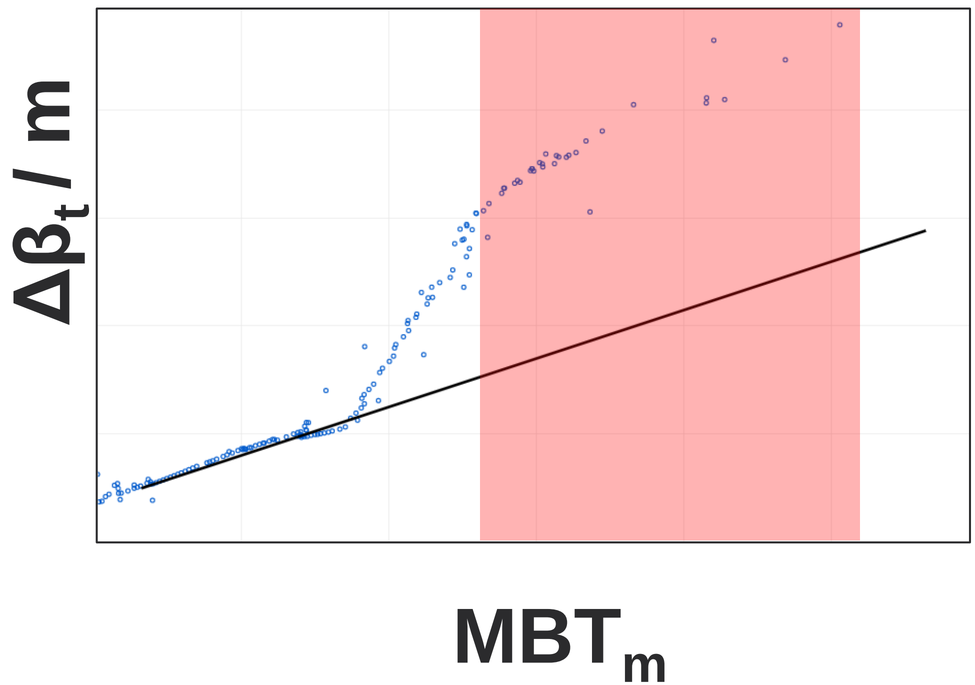


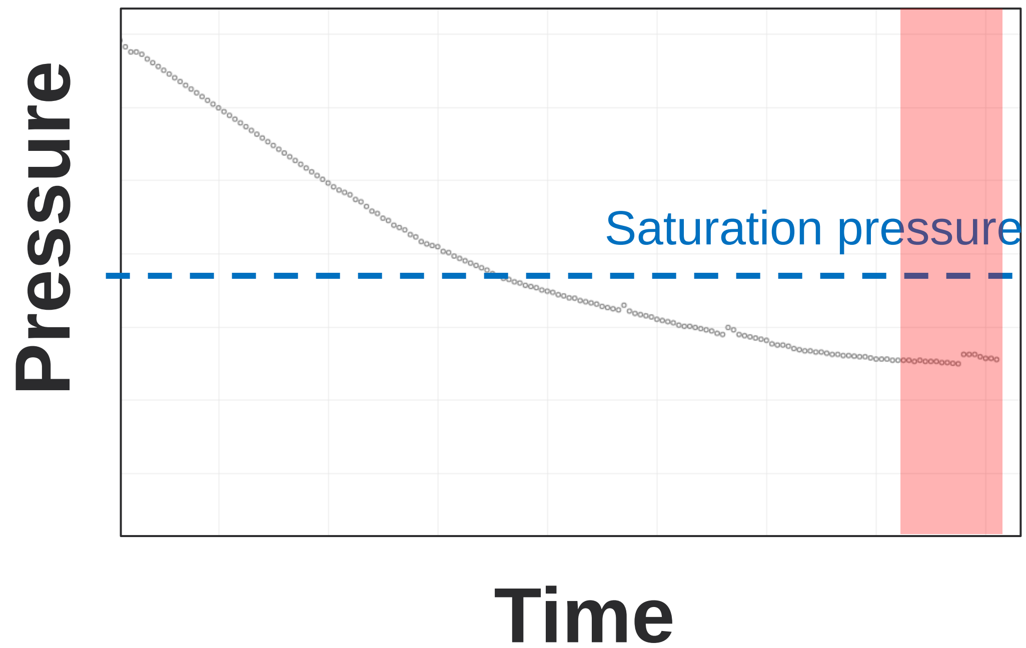


whitson

Multiphase FMB – Three Key Periods

Period 3: Second stabilized slope

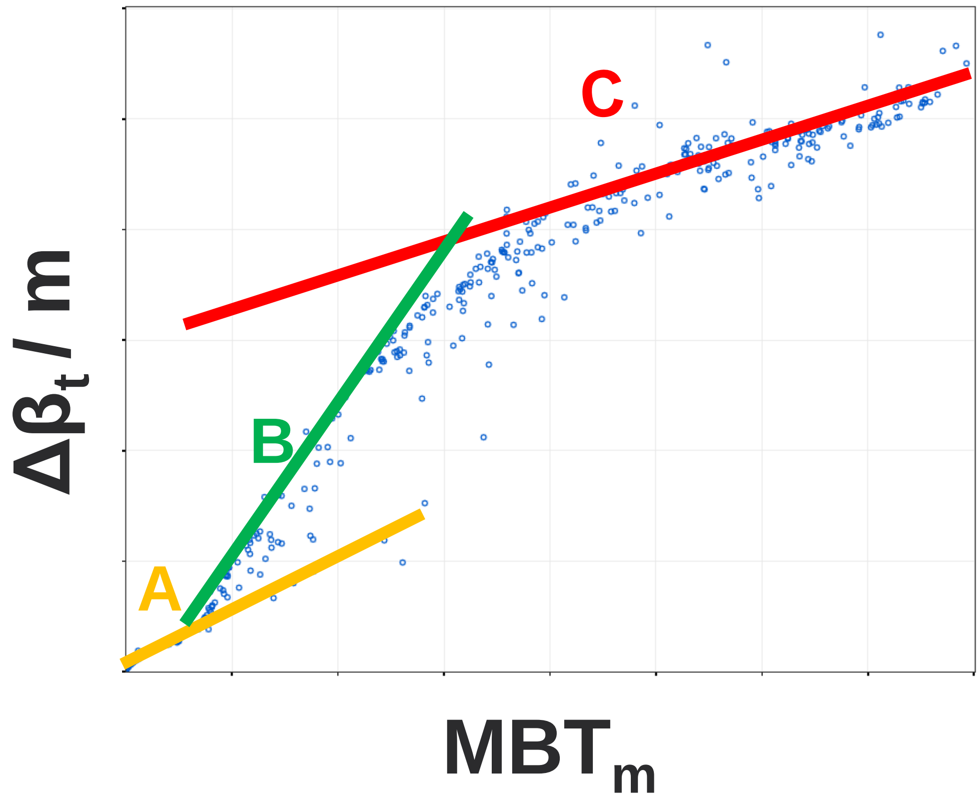


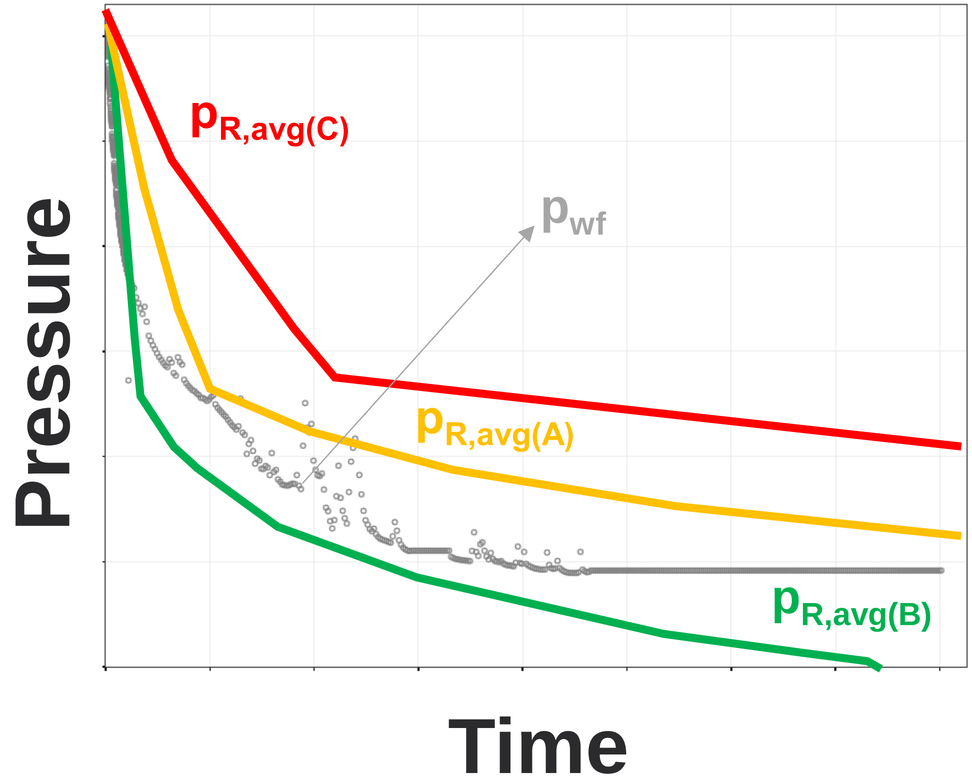


whitson

Multiphase FMB: Several Slopes

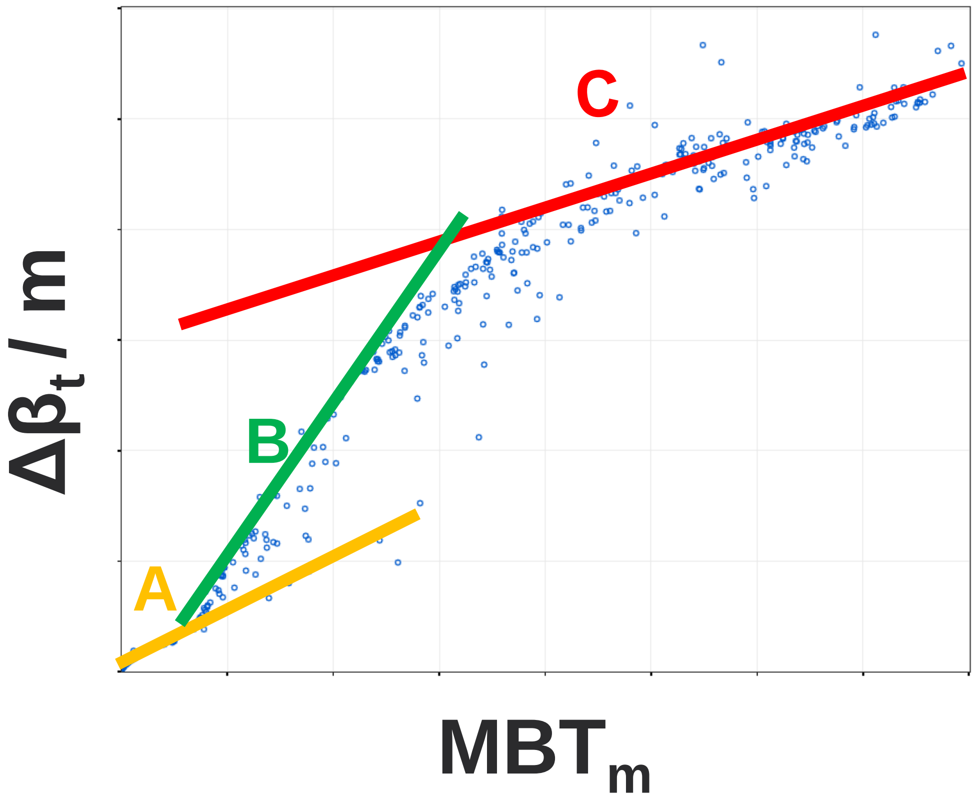
When working with real data – which slope to pick?

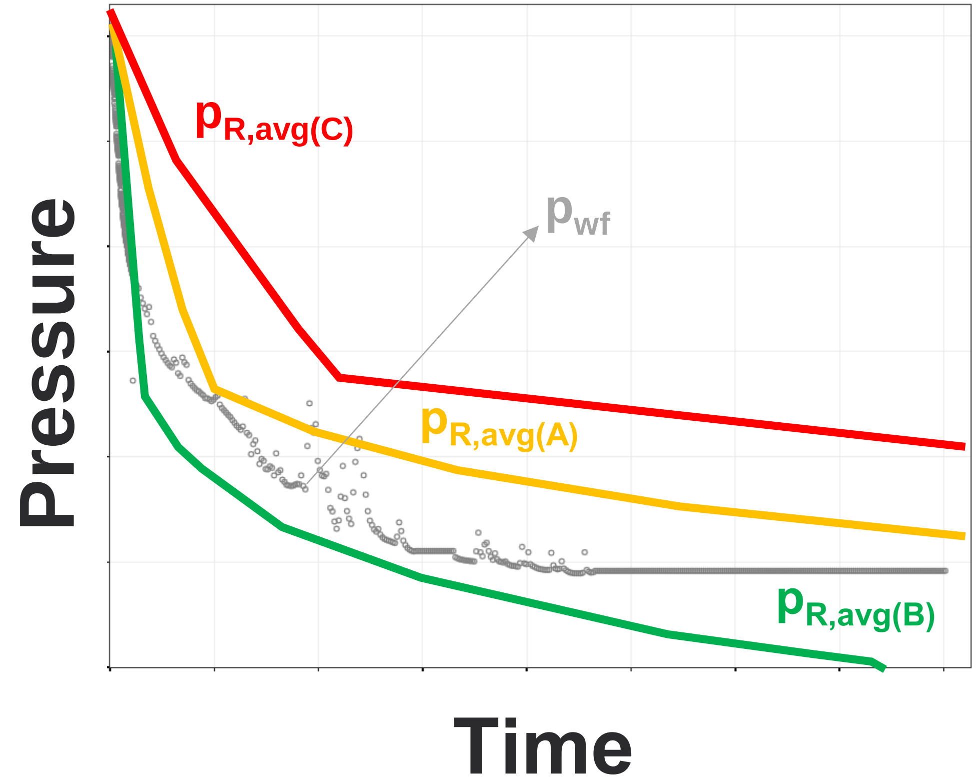




Multiphase FMB: Several Slopes

When working with real data – which slope to pick?



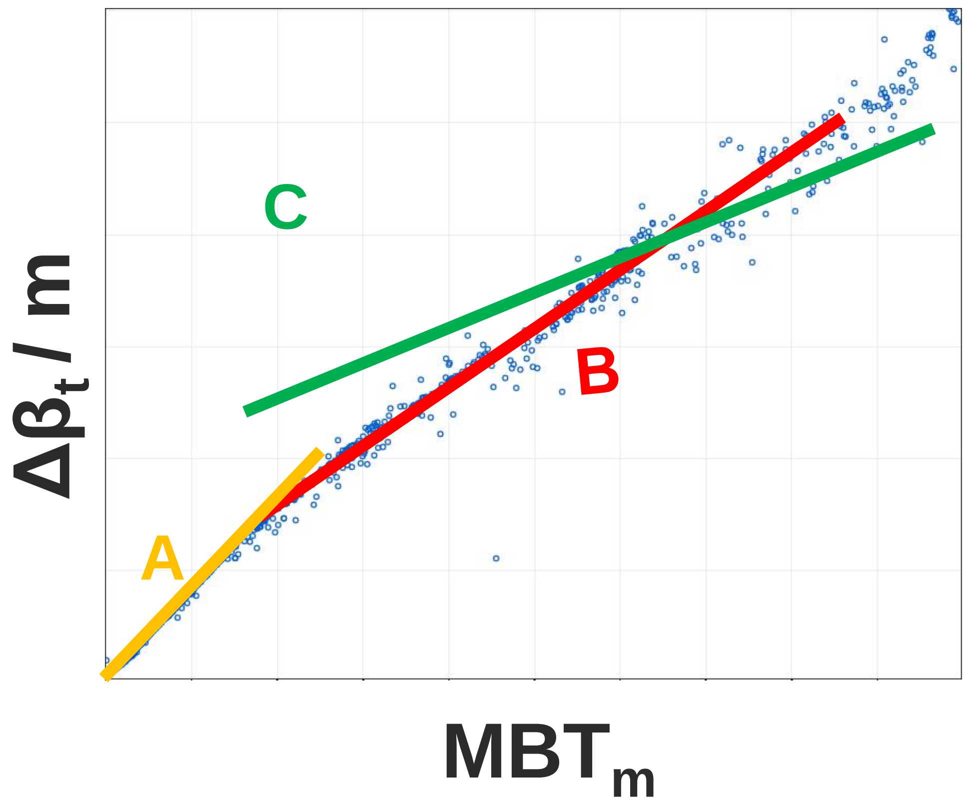


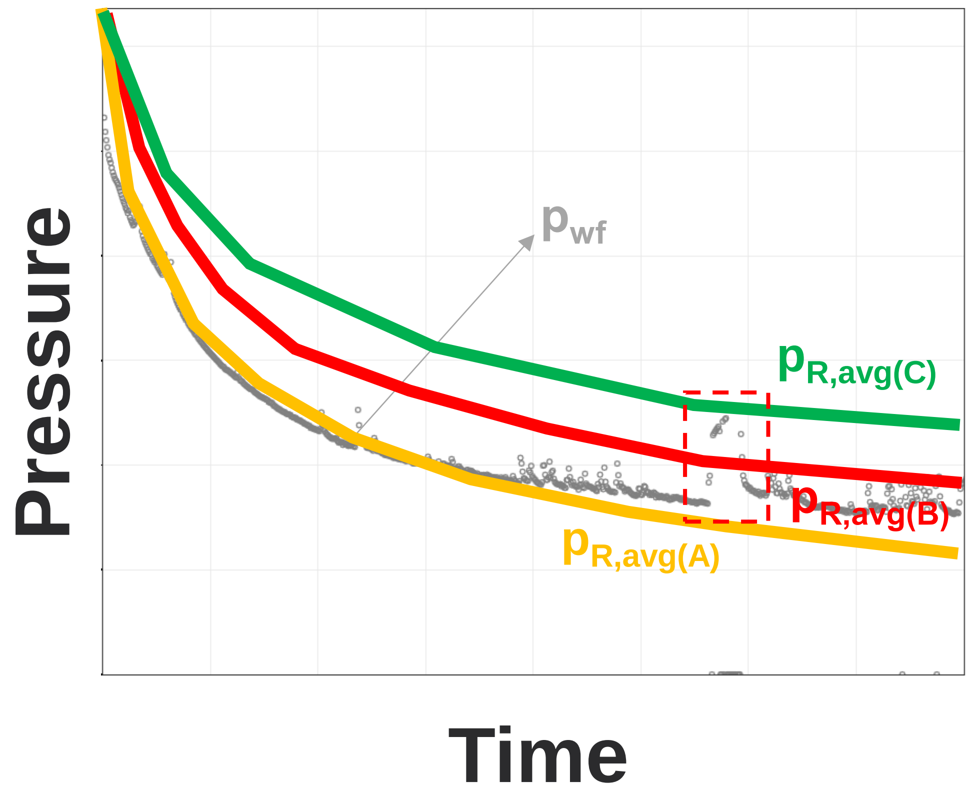
Pick the shallowest observed slope i.e., the "largest pore volume observed".

whitson

Multiphase FMB: Buildups Present

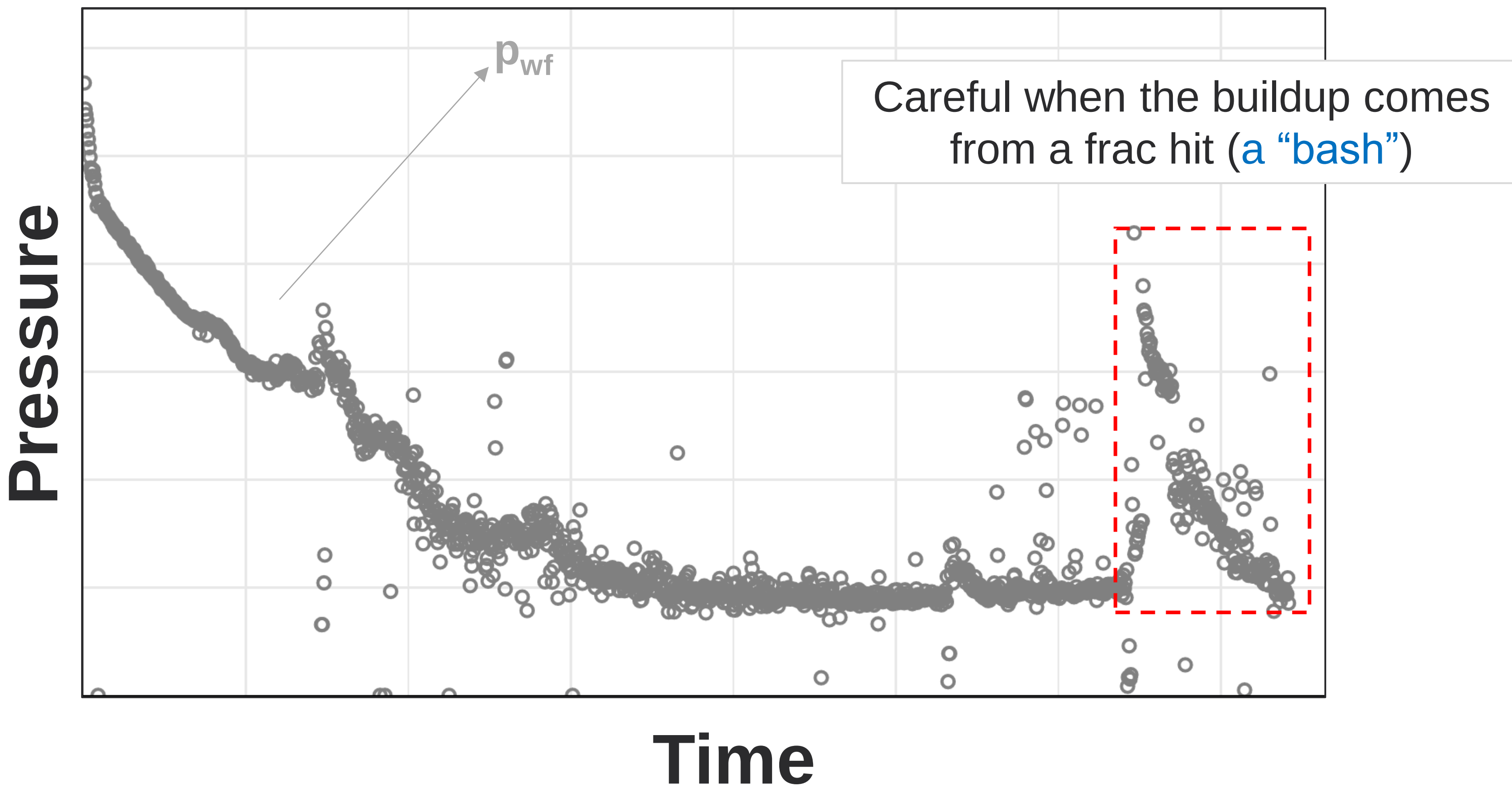
When working with buildup data – which slope to pick?





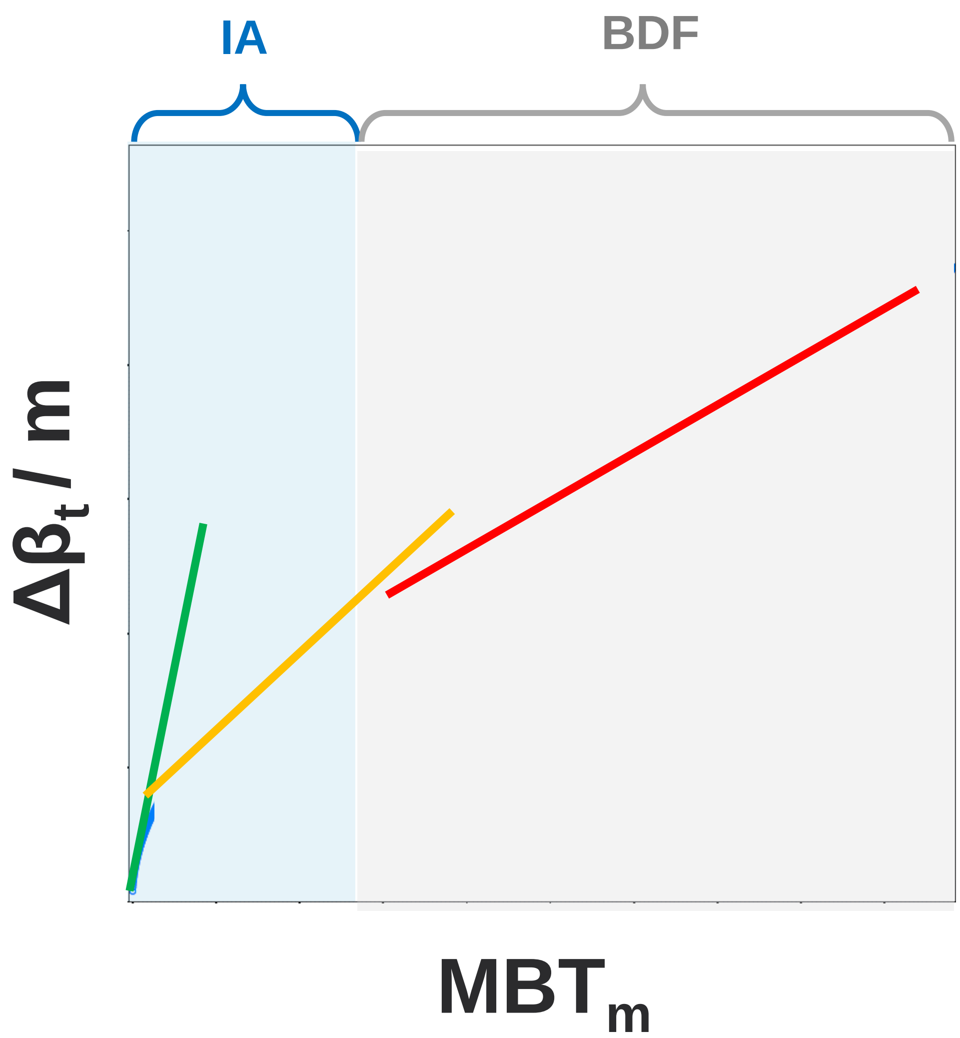
If buildup data is present, adjust the slope until it just honors the buildup data. This slope might be shallower (i.e., “larger pore volume”) than what the depletion data only suggests.

Multiphase FMB: Frac hits present



If a frac hit ("bash") is observed, this part of the data should be ignored.

Multiphase FMB: Still Infinite Acting



$OOIP_A$ = 500 MSTB

$OOIP_B$ = 2000 MSTB

$OOIP_C$ = 3400 MSTB

$OOIP_{actual}$ = 3400 MSTB

whitson

Conclusion

- Pick the shallowest observed slope i.e., the "largest pore volume observed".

- If buildup data is present, adjust the slope until it just honors the buildup data. This slope might be shallower (i.e., "larger pore volume") than what the depletion data only suggests.

- If a frac hit ("bash") is observed, this part of the data should be ignored.

- If well is still infinite acting (IA), multiphase FMB provides a conservative estimate of pore volume (OOIP | OGIP | OWIP). Numerical RTA can be used to evaluate if the well is still infinite acting.

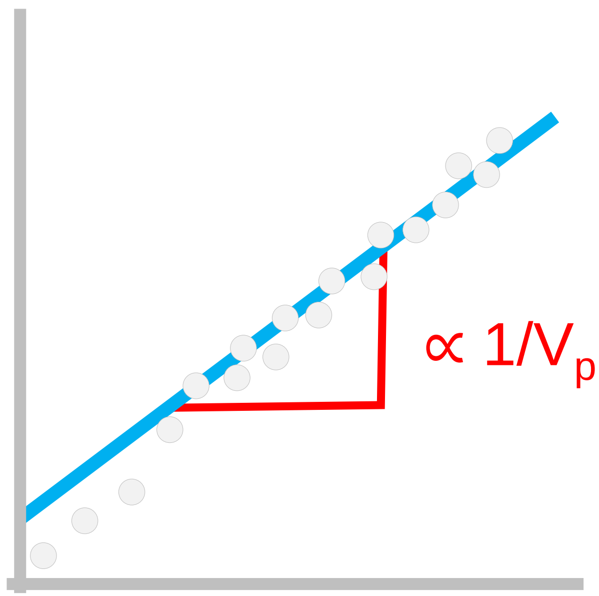
whitson

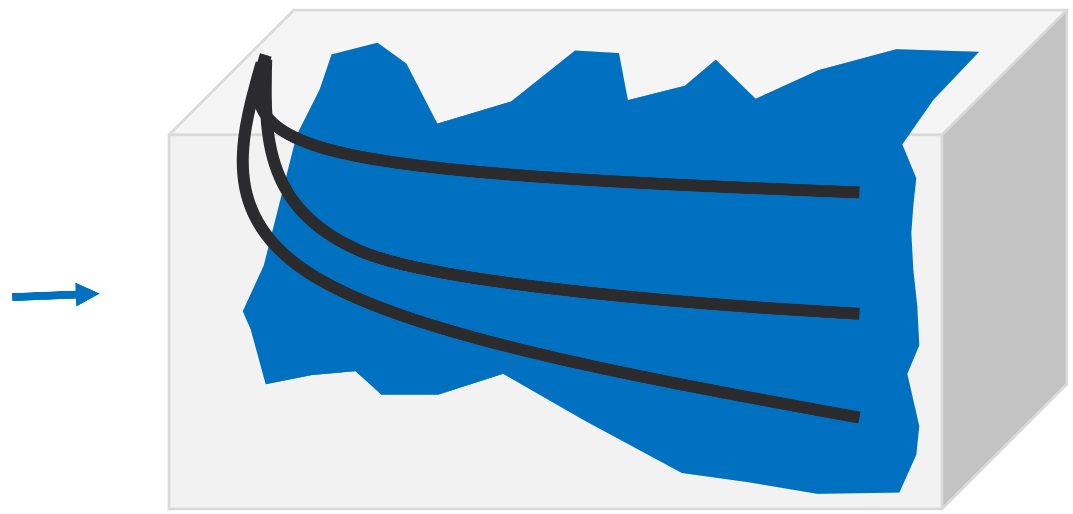
Theory

Recovery Factor Analysis

Multiphase FMB

How much pore volume is a well "seeing" / draining????





What else would you need?

RF

Recovery Factor

EUR

Estimated Ultimate Recovery

Physically Constrained

What else would you need?

$$EUR_o = OOIP \times RF_o$$

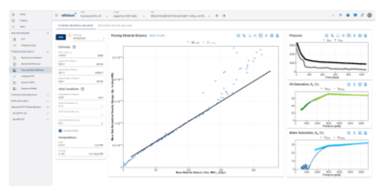
$$EUR_g = OGIP \times RF_g$$

$$EUR_w = OWIP \times RF_w$$

What else would you need?

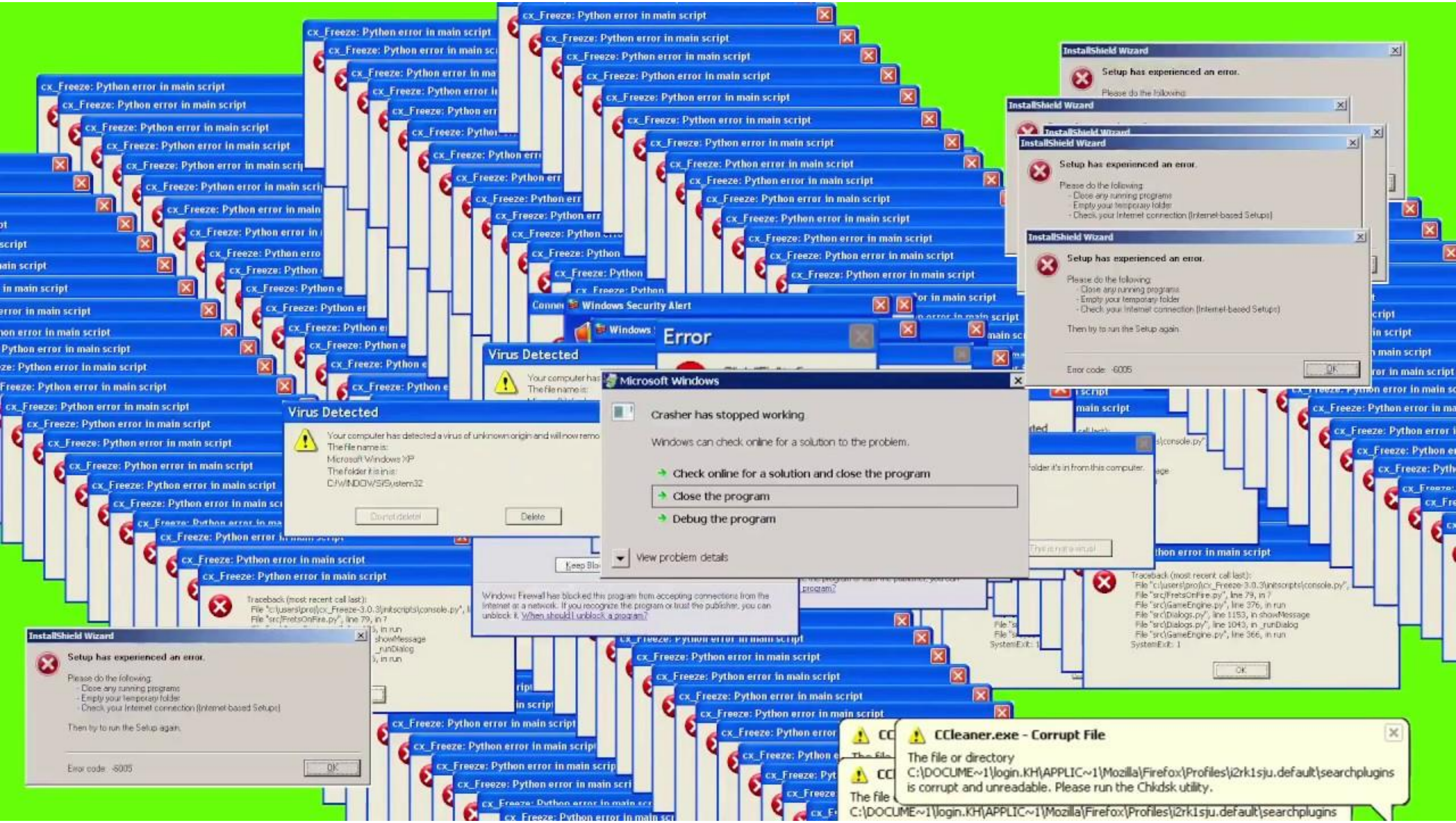
Recovery Factor Analysis

$$EUR_o = OOIP \times RF_o$$



Multiphase FMB

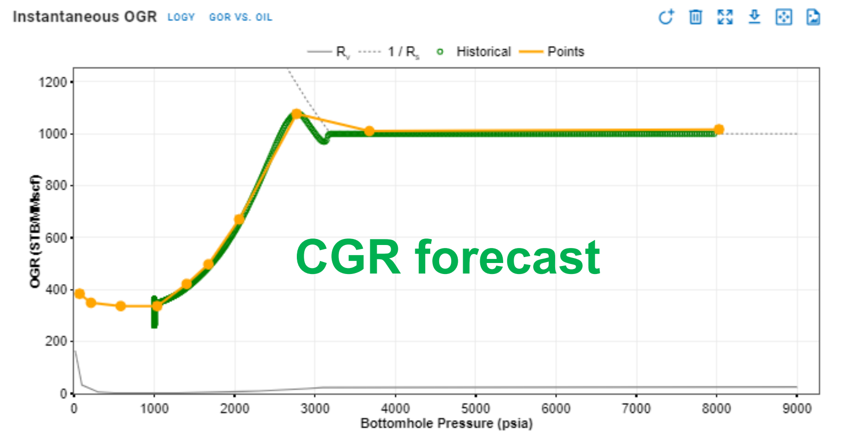
Calculate Recovery Factors from Material Balance?

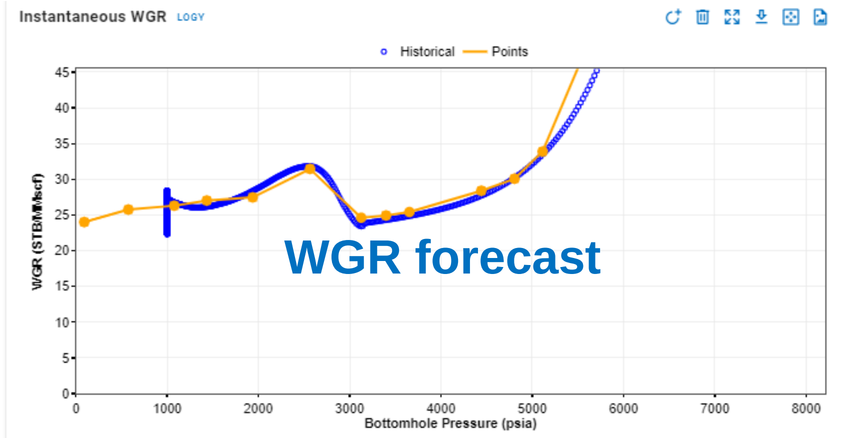


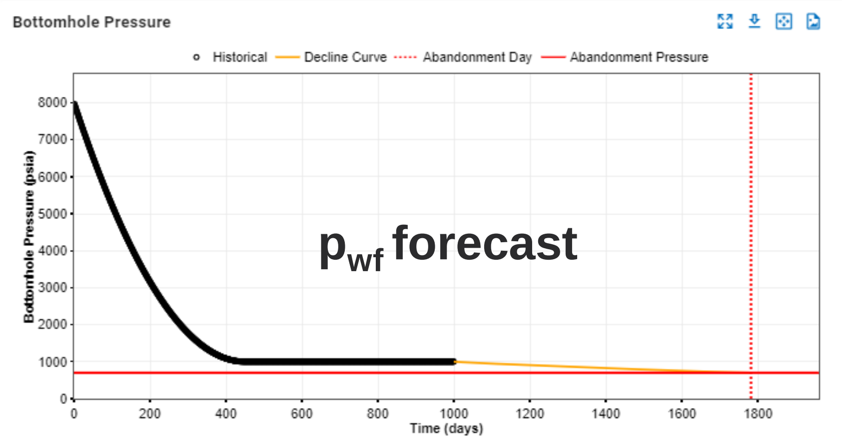
Calculate Recovery Factors from Material Balance?

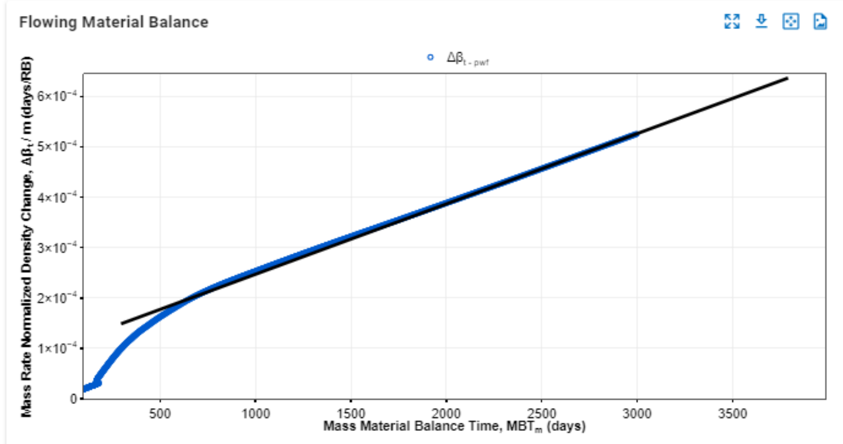
$$RF_{@abandonement} = f(PVT_{@abadonment}, OGR_{cum}, WGR_{cum})$$

RF Analysis

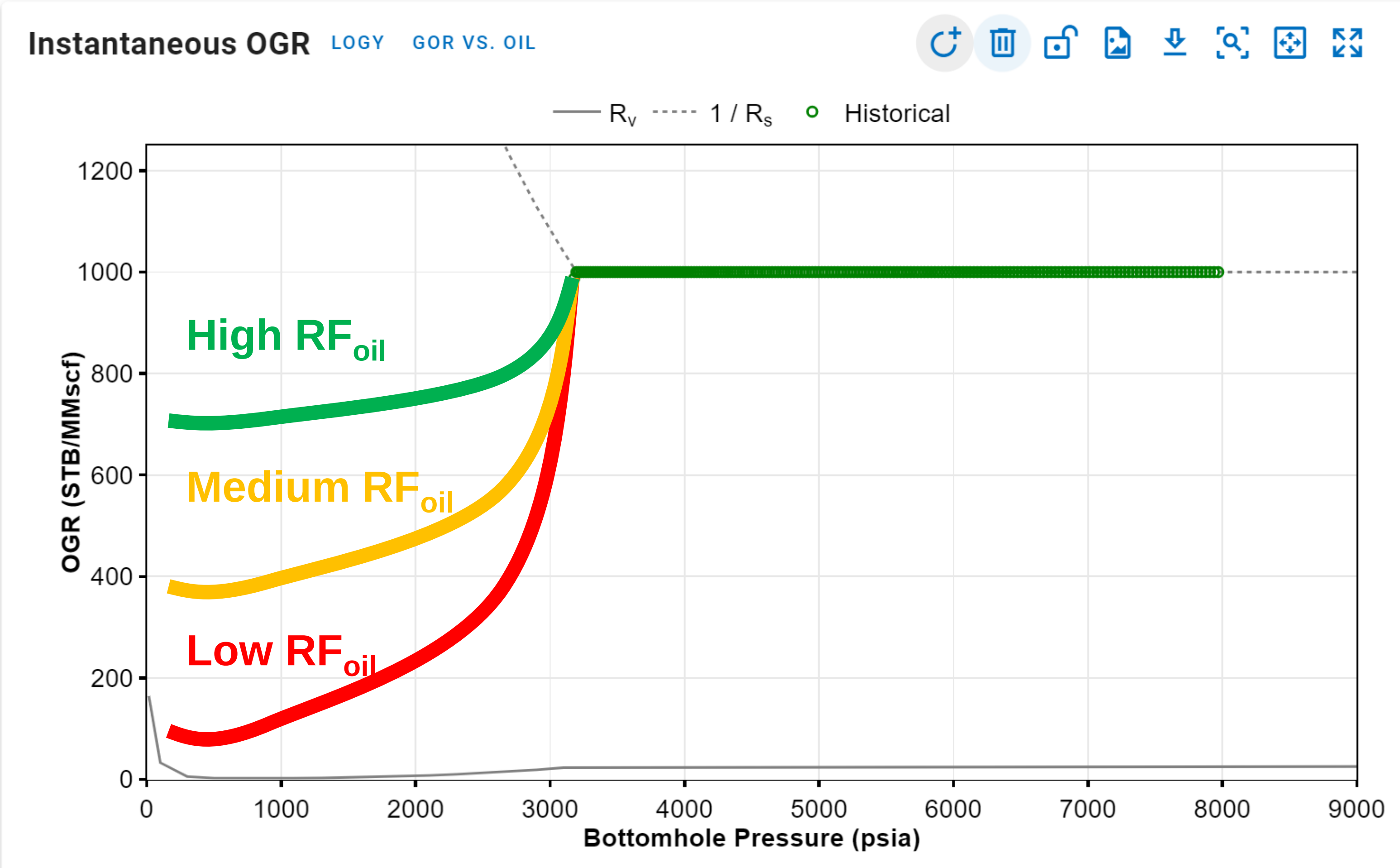

Instantaneous OGR
LOGY
GOR VS. OIL
R_v
$1 / R_s$
Historical
Points
CGR forecast
OGR (STB/MMscf)
Bottomhole Pressure (psia)


Instantaneous WGR
LOGY
Historical
Points
WGR forecast
WGR (STB/MMscf)
Bottomhole Pressure (psia)


Bottomhole Pressure
Historical
Decline Curve
Abandonment Day
Abandonment Pressure
p_{wf} forecast
Bottomhole Pressure (psia)
Time (days)


Flowing Material Balance
$\Delta\beta_{t-pwf}$
Mass Rate Normalized Density Change, $\Delta\beta_t$ / m (days/RB)
Mass Material Balance Time, MBT_m (days)

CGR Forecast



Why no need for Relative Perm?

Short Answer

OGR

WOR

CGR

λ + PVT → **Fluid Ratios**

WOR

WGR

Why no need for Relative Perm?

Short Answer

$$R_p = R_s + \frac{k_{rg} B_o \mu_o}{k_{ro} B_{gd} \mu_g}$$

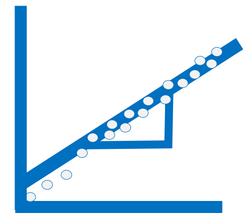
Producing GOR

RF Analysis in whitson+

Numerical Model

Simple Material Balance

Recovery Factor Analysis

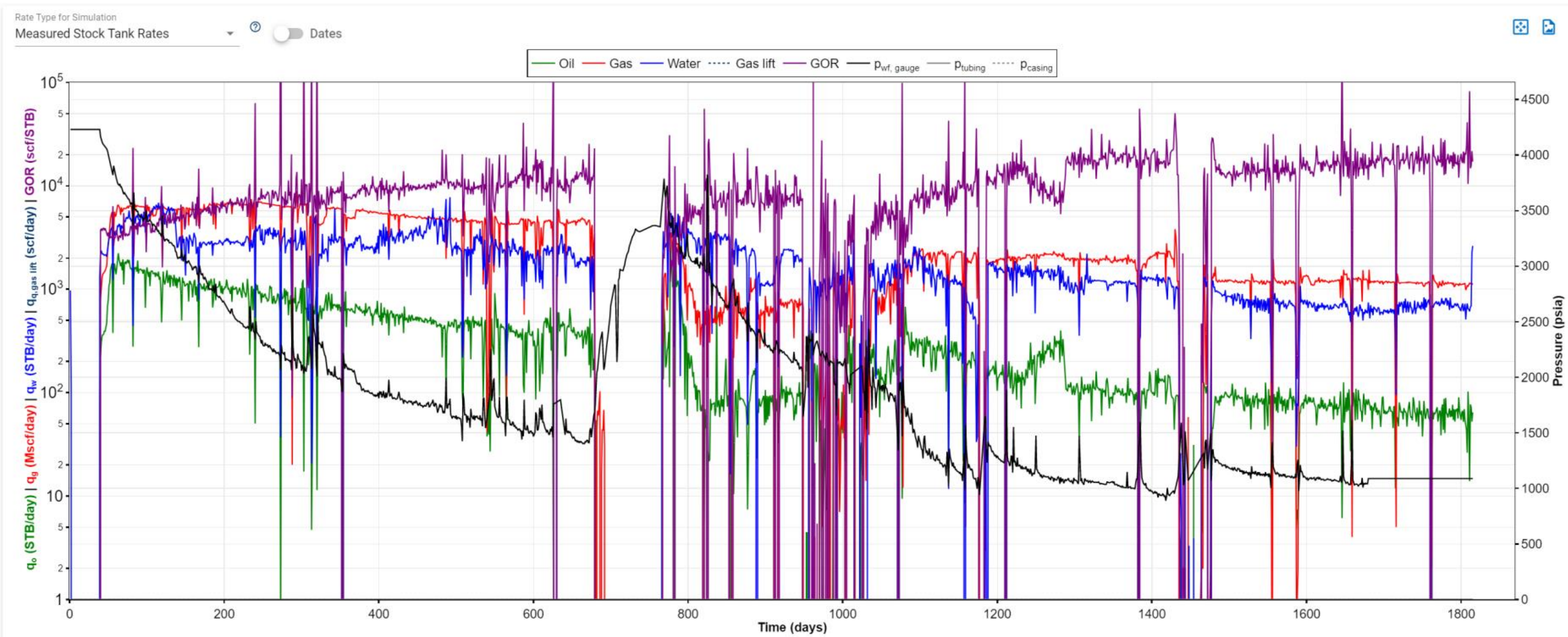


Same **RF_o** | **RF_g** for the
same **abandonment pressure**
and **cumulative GOR (or CGR)**

1

Example 1
Permian Case Study

1 Permian Parent Production



Parent
Infill Wells
Workover
Workover

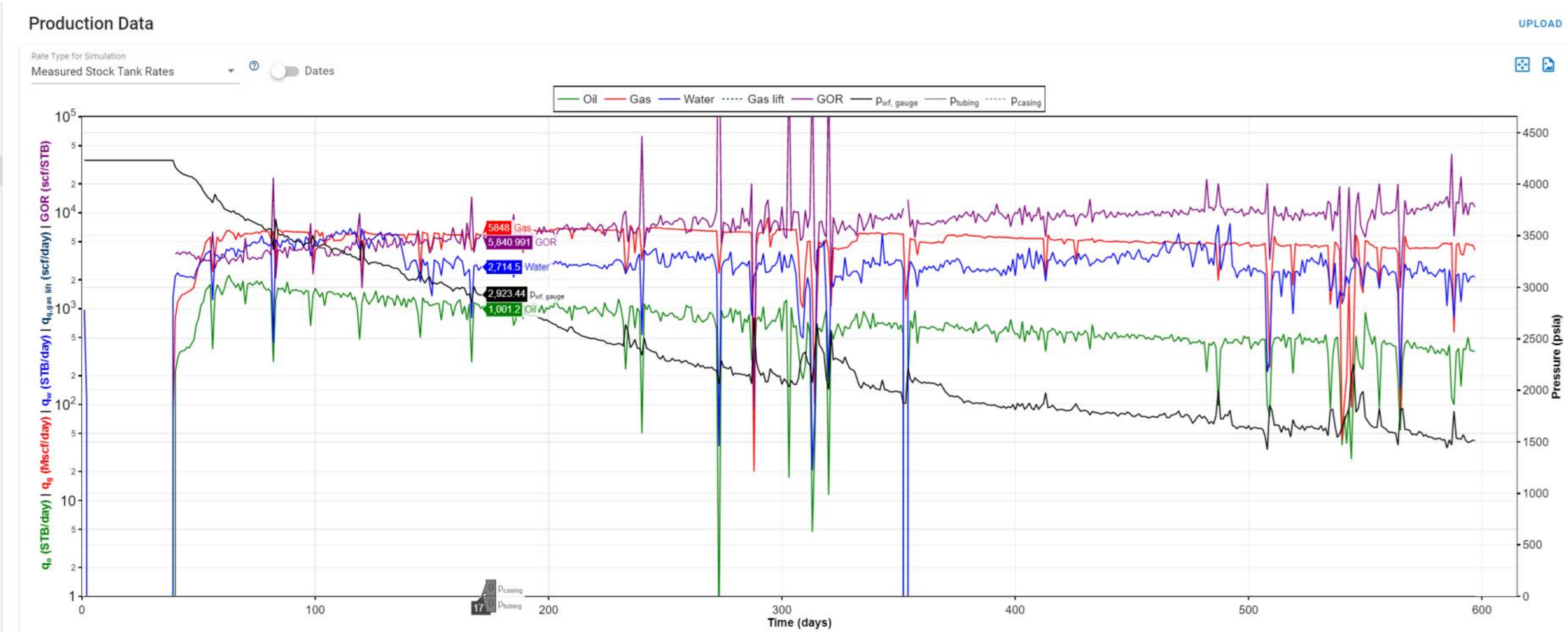
1

Quick Well Facts

- First well analyzed using MFMB analysis
- Initially saturated volatile oil well
- Downhole Pressure Gauge
- Approximately 5 years of production
  - Approximately 2 years as a parent before infill wells were drilled and fractured
  - 2 subsequent workovers
- Quality of water production data questionable at times
- Initial water saturation assumed to be 30%

1

Early Production



Initial Analysis – S_{wi} = 30%

1 Initial MFMB Analysis

RUN ✓

Estimates

Pore Volume, V_p
9588 MRB

Original Oil in Place, N
2432 MSTB

Original Gas in Place, G
8088 MMscf

Original Water in Place, W
2877 MSTB

Initial Conditions

Initial Reservoir Pressure
4370 psia

Initial Oil Saturation, S_{oi}
56.6 %

Initial Gas Saturation, S_{gi}
13.4 %

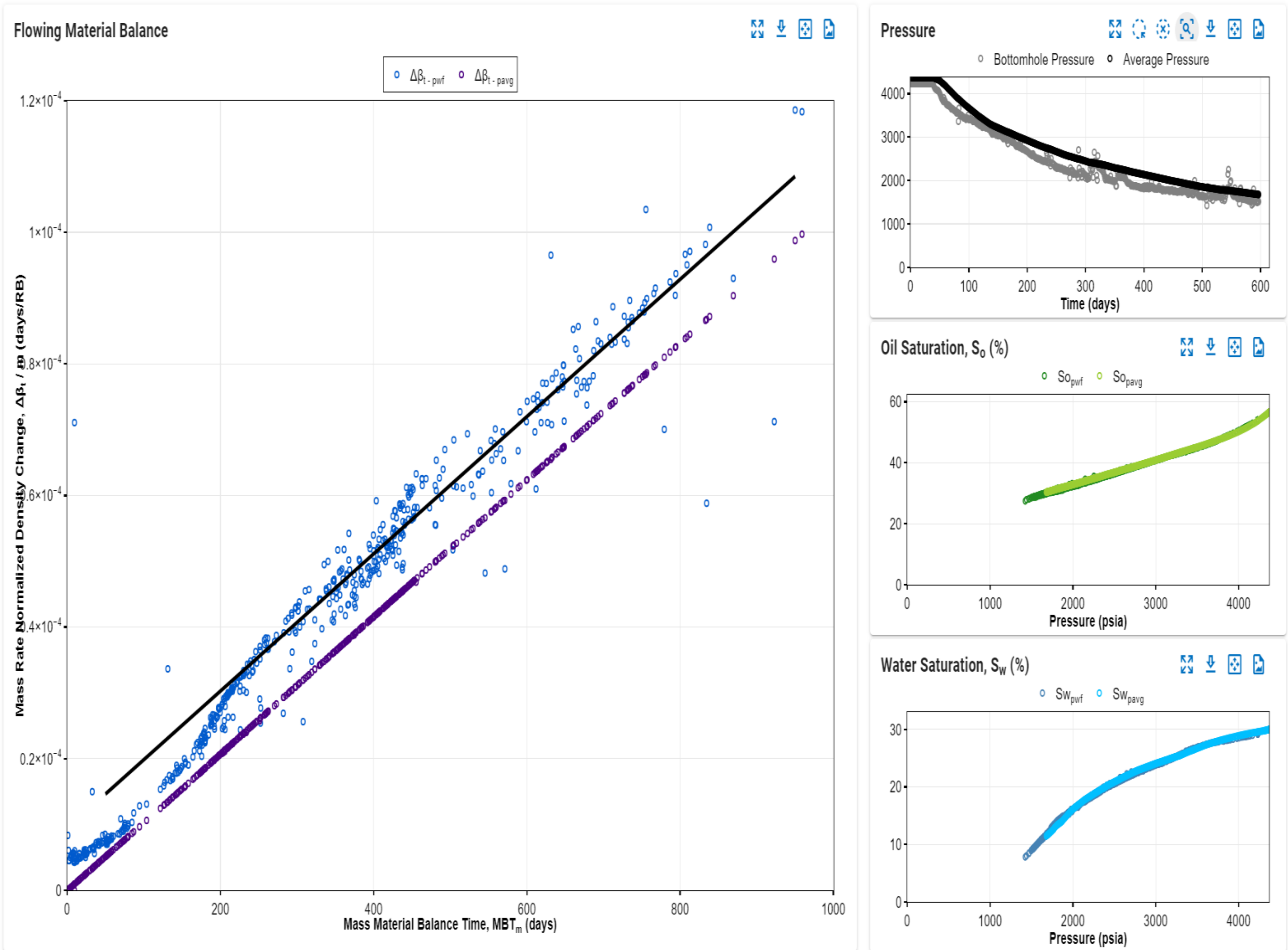
Initial Water Saturation, S_{wi}
30 %

☑ Include Water

Interpretations

Slope
0.104 1e-6/RB

Intercept
0.094 1e-4 days/RB



1 Initial Analysis - MFMB

RUN

Estimates

Pore Volume, V_p
9588 MRB

Original Oil in Place, N
2432 MSTB

Original Gas in Place, G
8088 MMscf

Original Water in Place, W
2877 MSTB

Initial Conditions

Initial Reservoir Pressure
4370 psia

Initial Oil Saturation, S_{oi}
56.6 %

Initial Gas Saturation, S_{gi}
13.4 %

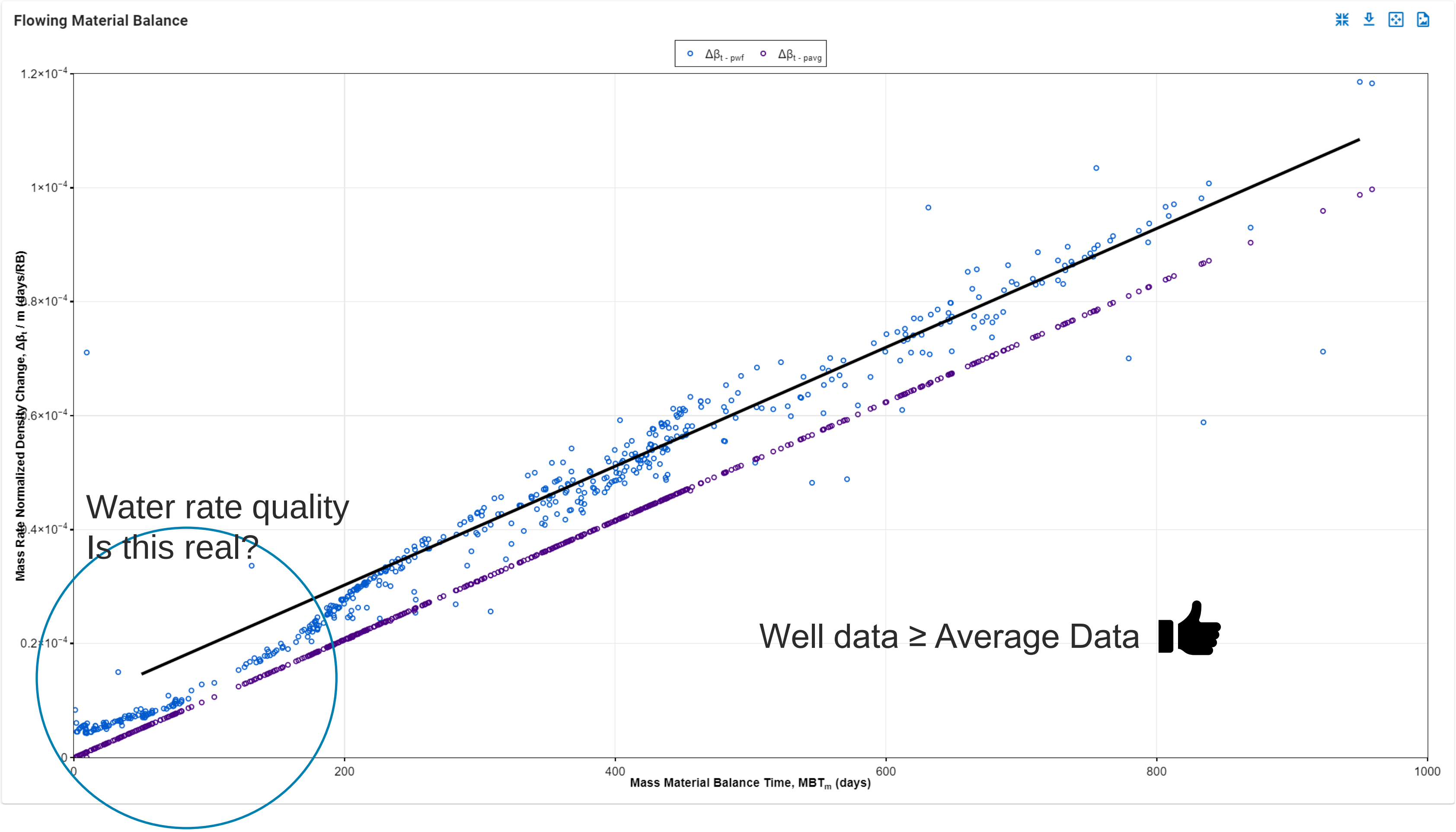
Initial Water Saturation, S_{wi}
30 %

Include Water

Interpretations

Slope
0.104 1e-6/RB

Intercept
0.094 1e-4 days/RB



1 Initial Analysis – Average Pressure

RUN

Estimates

Pore Volume, V_p
9588 MRB

Original Oil in Place, N
2432 MSTB

Original Gas in Place, G
8088 MMscf

Original Water in Place, W
2877 MSTB

Initial Conditions

Initial Reservoir Pressure
4370 psia

Initial Oil Saturation, S_{oi}
56.6 %

Initial Gas Saturation, S_{gi}
13.4 %

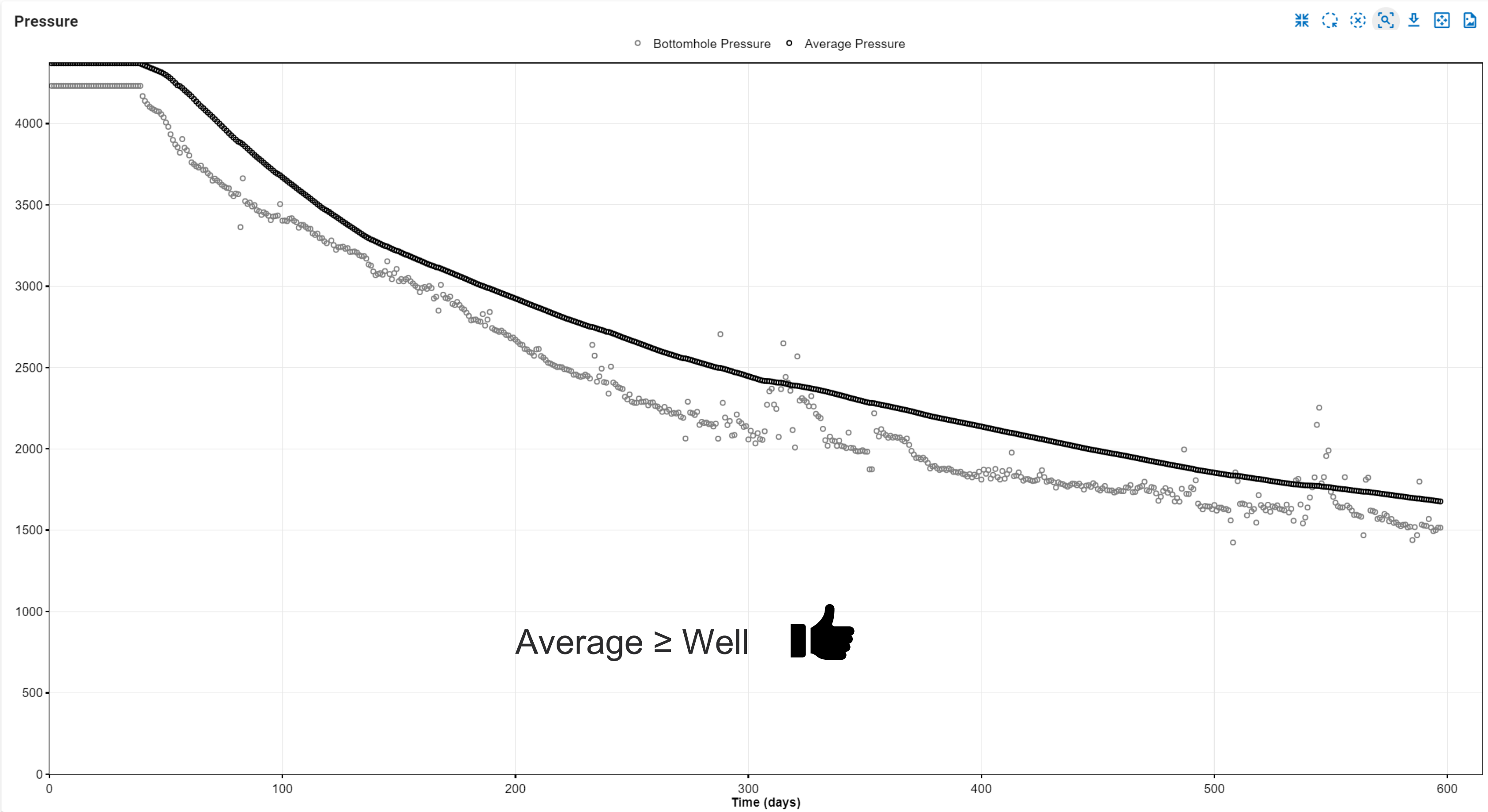
Initial Water Saturation, S_{wi}
30 %

☑ Include Water

Interpretations

Slope
0.104 1e-6/RB

Intercept
0.094 1e-4 days/RB



1 Initial Analysis – Water Saturation

RUN ✓

Estimates

Pore Volume, V_p
9588 MRB

Original Oil in Place, N
2432 MSTB

Original Gas in Place, G
8088 MMscf

Original Water in Place, W
2877 MSTB

Initial Conditions

Initial Reservoir Pressure
4370 psia

Initial Oil Saturation, S_{oi}
56.6 %

Initial Gas Saturation, S_{gi}
13.4 %

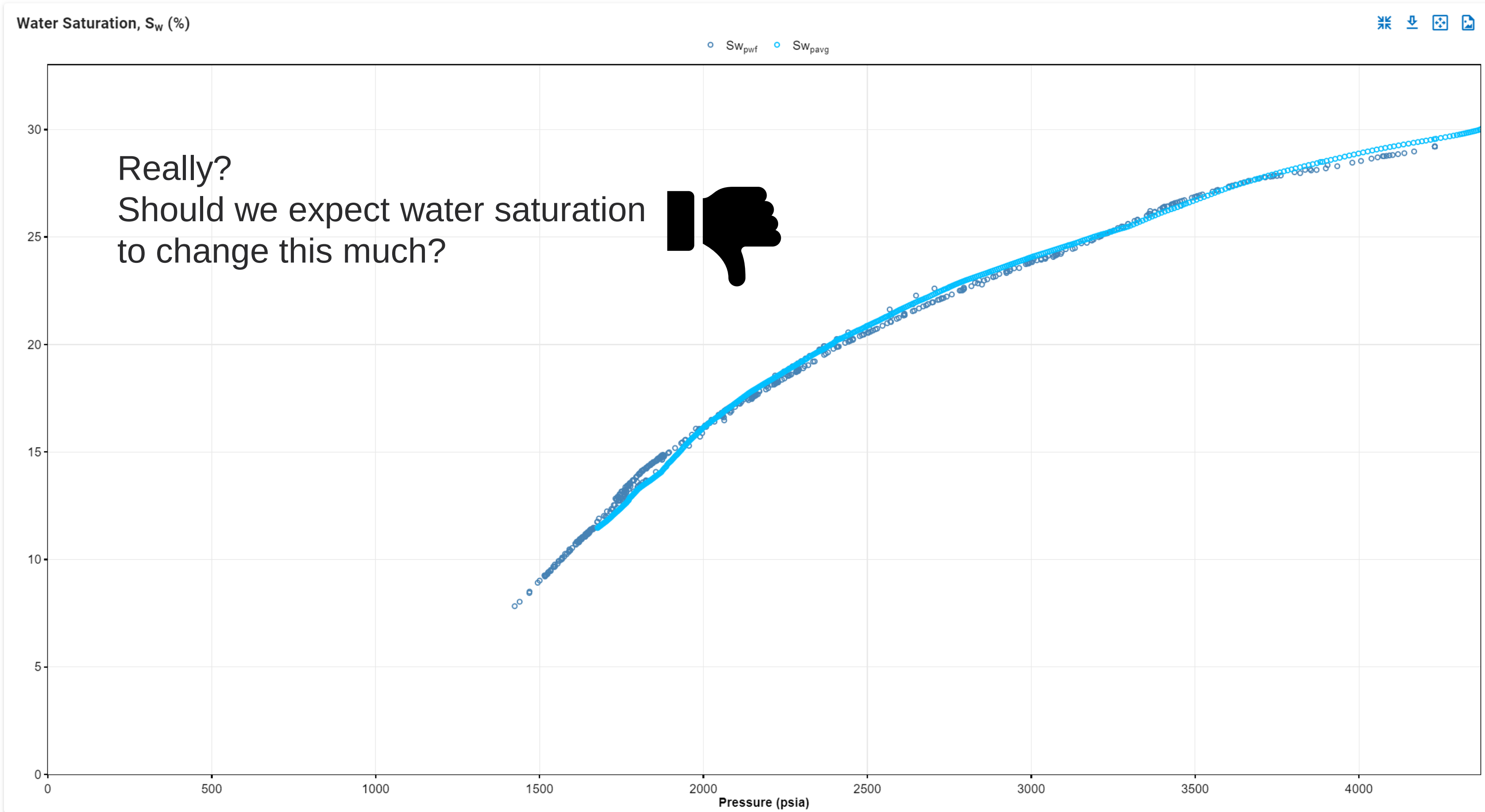
Initial Water Saturation, S_{wi}
30 %

☑ Include Water

Interpretations

Slope
0.104 1e-6/RB

Intercept
0.094 1e-4 days/RB



Really?
Should we expect water saturation to change this much?

1 Initial Analysis - Comments

- Analysis seems consistent *except* for huge change in water saturation.
- Two paths forward:
  - Confer with team to re-evaluate initial water saturation.
  - Perform the analysis without water.

1

Water Saturation (re-)evaluation

- Where did the fracs penetrate?
- Which water producing intervals should be included in the tank?
- **Initial water saturation was reset to 70%.**

whitson

1 Initial Analysis – S_{wi} = 70%

RUN ✓

Estimates

Pore Volume, V_p
21341 MRB

Original Oil in Place, N
2320 MSTB

Original Gas in Place, G
7715 MMscf

Original Water in Place, W
14939 MSTB

Initial Conditions

Initial Reservoir Pressure
4370 psia

Initial Oil Saturation, S_{oi}
24.26 %

Initial Gas Saturation, S_{gi}
5.74 %

Initial Water Saturation, S_{wi}
70 %

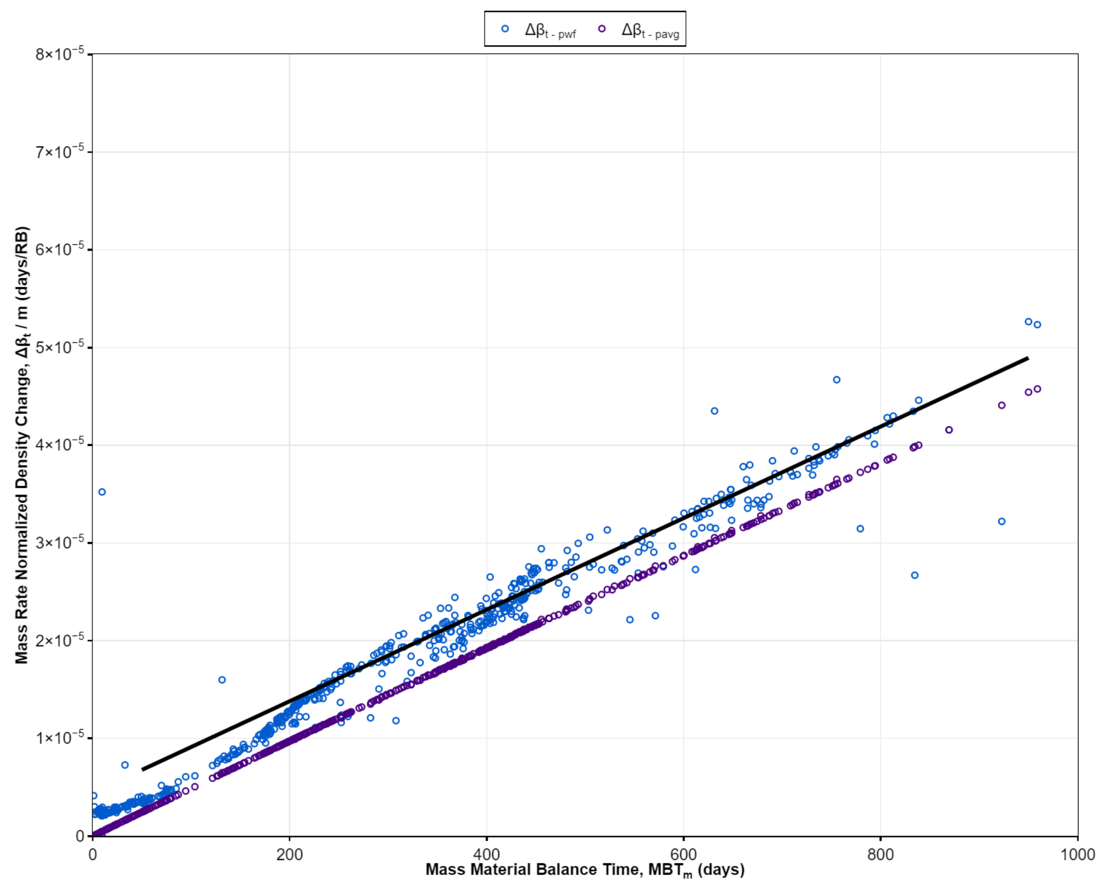
☑ Include Water

Interpretations

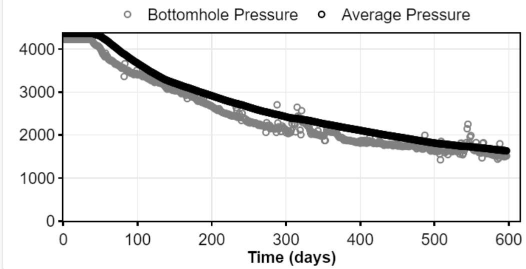
Slope
0.047 1e-6/RB

Intercept
0.044 1e-4 days/RB

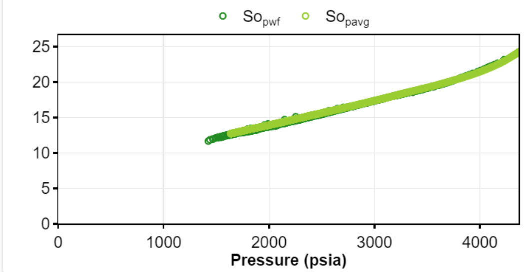
Flowing Material Balance



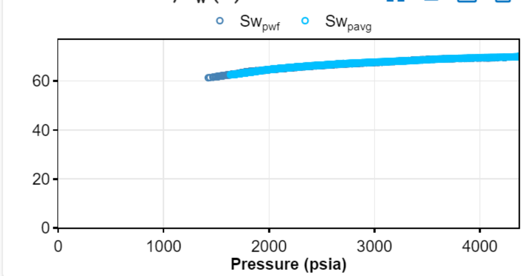
Pressure



Oil Saturation, S_o (%)



Water Saturation, S_w (%)



1 Re-evaluation – $S_{wi} = 70\%$

RUN

Estimates

Pore Volume, V_p
21341 MRB

Original Oil in Place, N
2320 MSTB

Original Gas in Place, G
7715 MMscf

Original Water in Place, W
14939 MSTB

Initial Conditions

Initial Reservoir Pressure
4370 psia

Initial Oil Saturation, S_{oi}
24.26 %

Initial Gas Saturation, S_{gi}
5.74 %

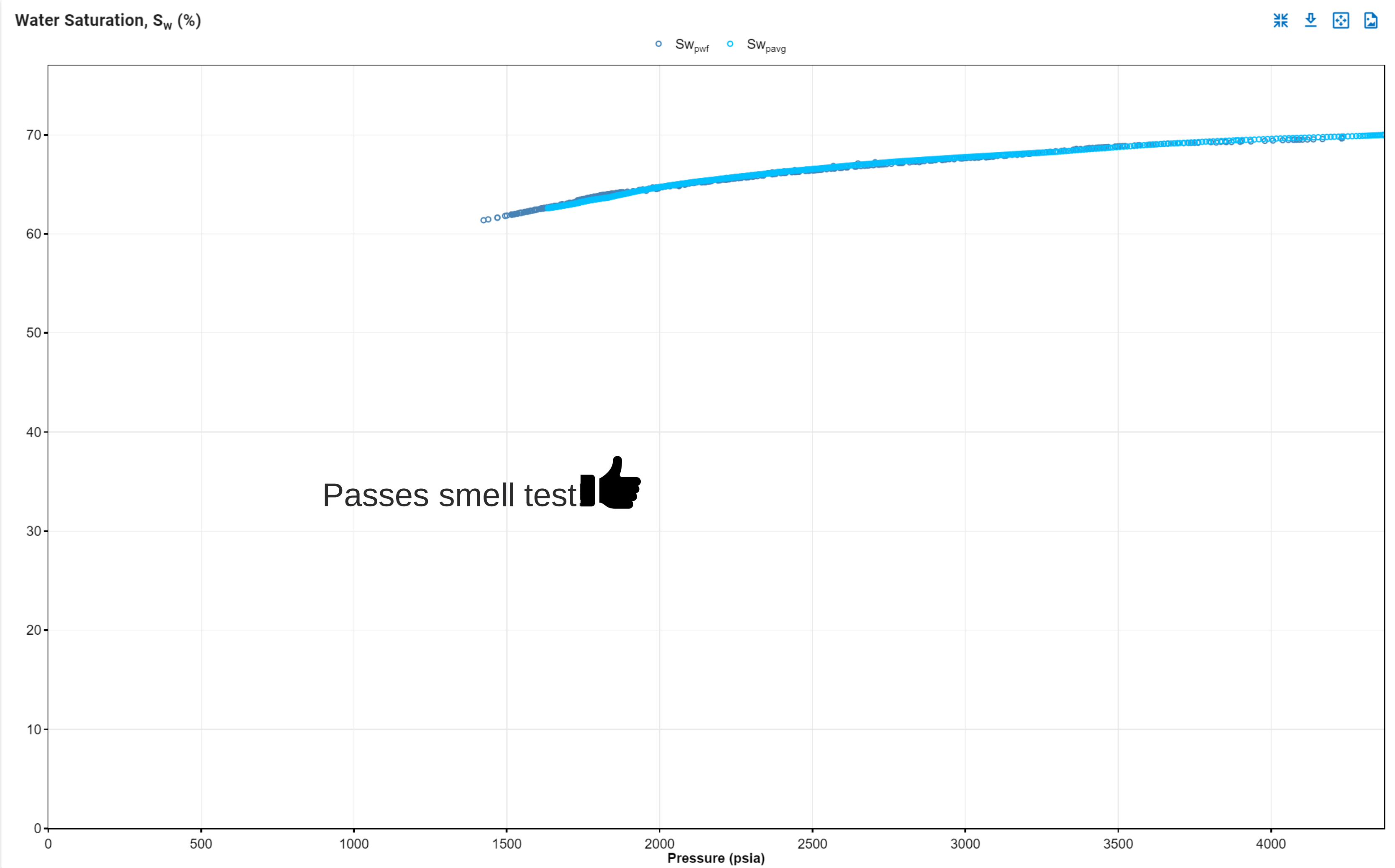
Initial Water Saturation, S_{wi}
70 %

☑ Include Water

Interpretations

Slope
0.047 1e-6/RB

Intercept
0.044 1e-4 days/RB



1

Initial Analysis – No Water

- Mass of water in tank remains constant
- No water expansion
- Water saturation will only change as a result of rock compressibility
- Provides ***most conservative estimate of hydrocarbon in place***

MPFMB – No Water

RUN ✓

Estimates

Pore Volume, V_p
19608 MRB

Original Oil in Place, N
2131 MSTB

Original Gas in Place, G
7088 MMscf

Original Water in Place, W
13725 MSTB

Initial Conditions

Initial Reservoir Pressure
4370 psia

Initial Oil Saturation, S_{oi}
24.26 %

Initial Gas Saturation, S_{gi}
5.74 %

Initial Water Saturation, S_{wi}
70 %

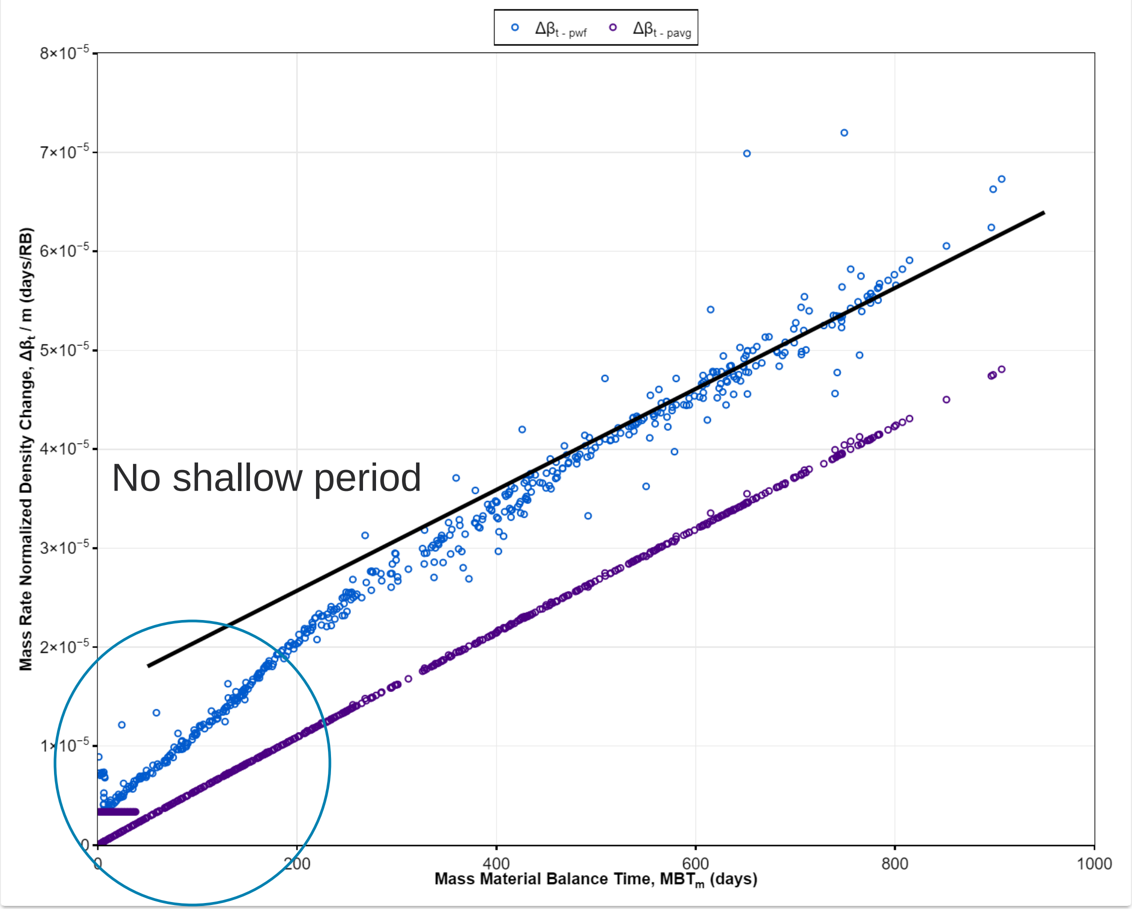
☐ Include Water

Interpretations

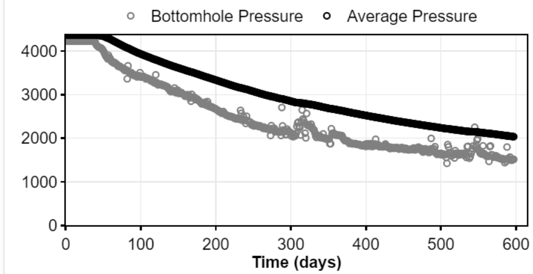
Slope
0.051 1e-6/RB

Intercept
0.155 1e-4 days/RB

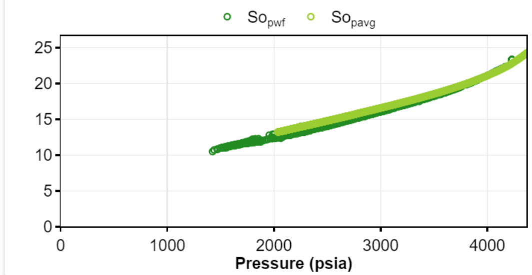
Flowing Material Balance



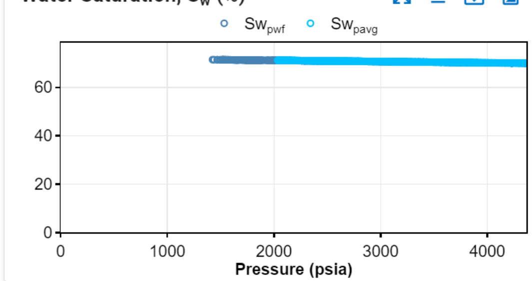
Pressure



Oil Saturation, S_o (%)

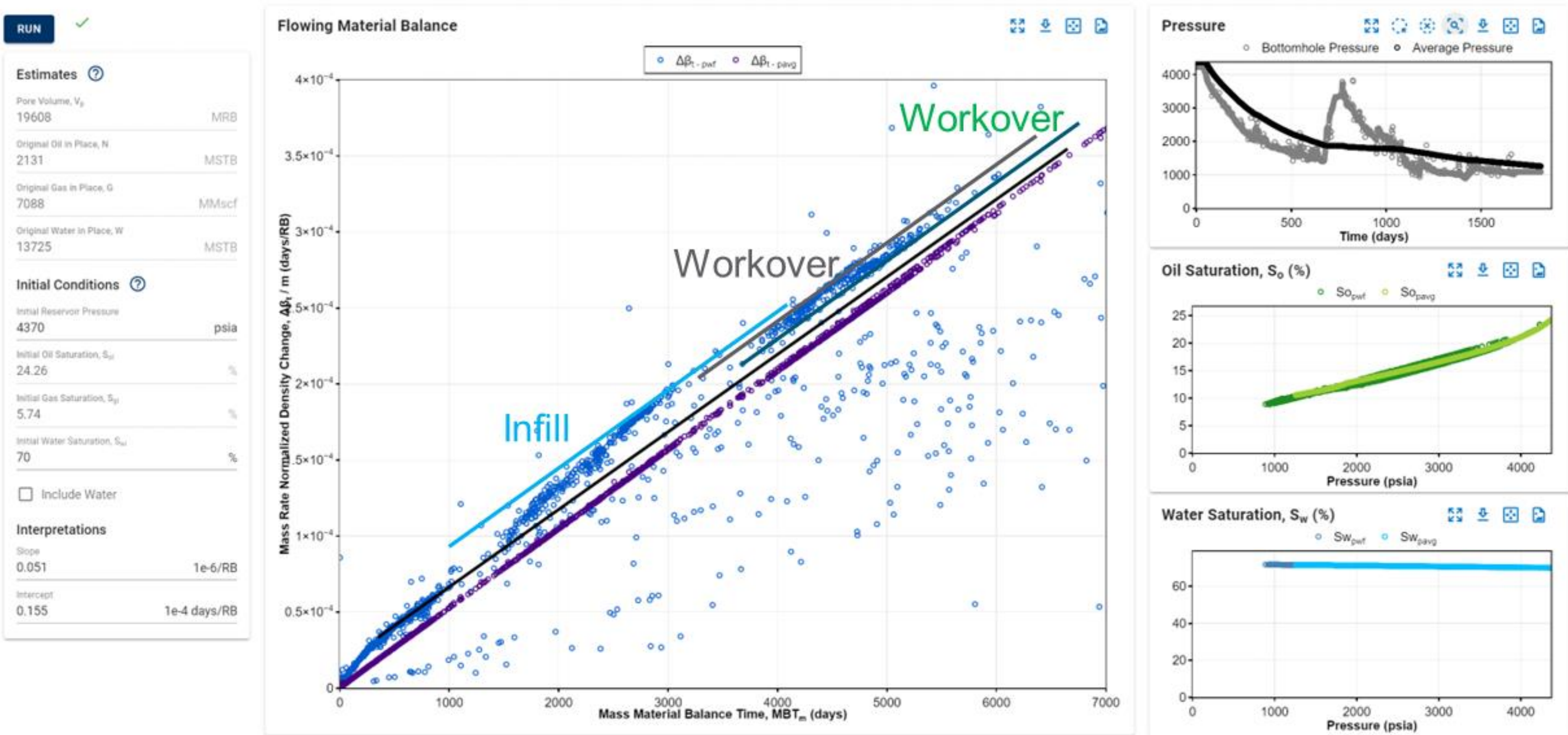


Water Saturation, S_w (%)



1

Entire Production Period



whitson

1 Average Pressure

RUN ✓

Estimates

Pore Volume, V_p
19608 MRB

Original Oil in Place, N
2131 MSTB

Original Gas in Place, G
7088 MMscf

Original Water in Place, W
13725 MSTB

Initial Conditions

Initial Reservoir Pressure
4370 psia

Initial Oil Saturation, S_{oi}
24.26 %

Initial Gas Saturation, S_{gi}
5.74 %

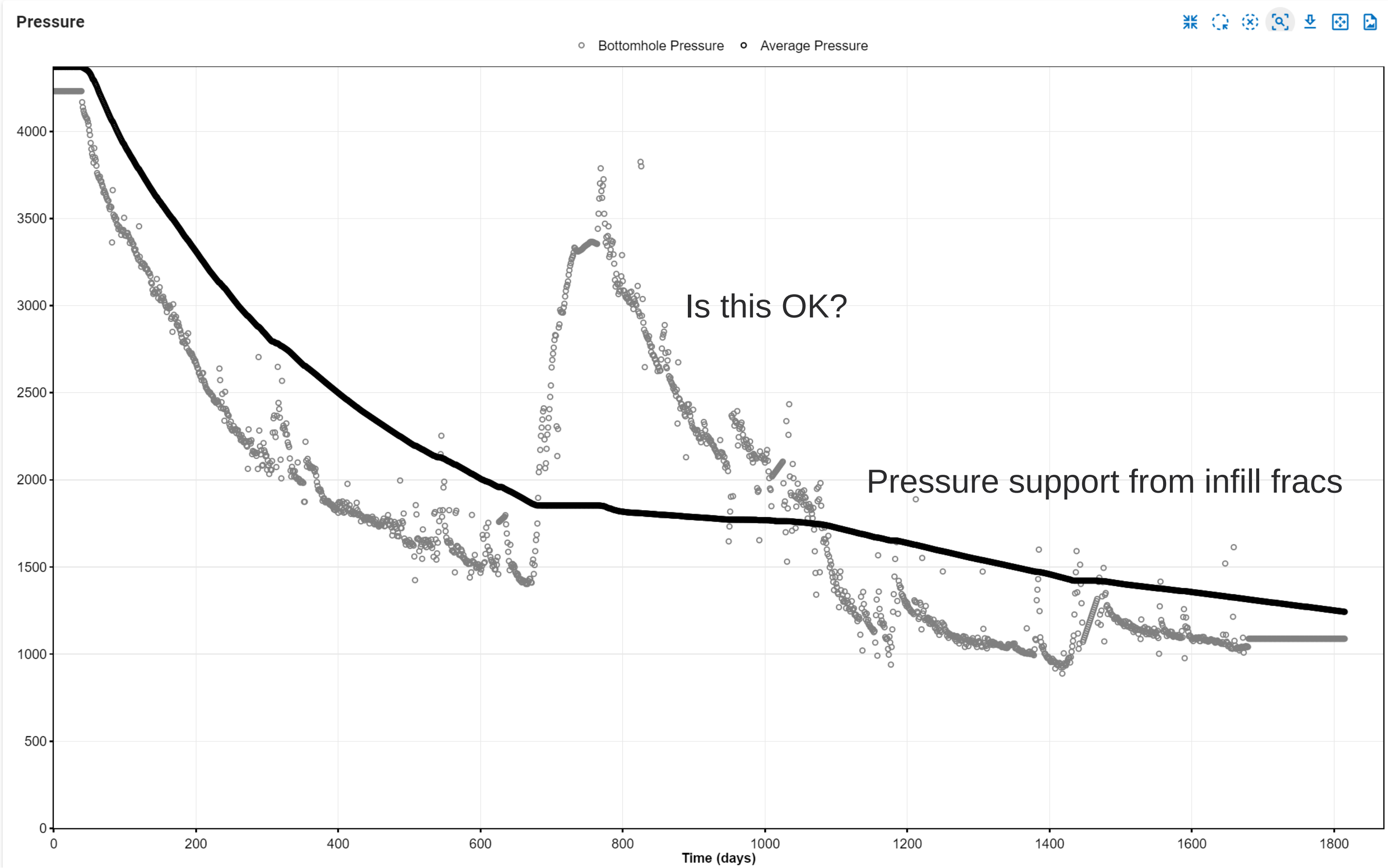
Initial Water Saturation, S_{wi}
70 %

☐ Include Water

Interpretations

Slope
0.051 1e-6/RB

Intercept
0.155 1e-4 days/RB



1 Entire Production Period

RUN ✓

Estimates ?

Pore Volume, V_p
19608 MRB

Original Oil in Place, N
2131 MSTB

Original Gas in Place, G
7088 MMscf

Original Water in Place, W
13725 MSTB

Initial Conditions ?

Initial Reservoir Pressure
4370 psia

Initial Oil Saturation, S_{oi}
24.26 %

Initial Gas Saturation, S_{gi}
5.74 %

Initial Water Saturation, S_{wi}
70 %

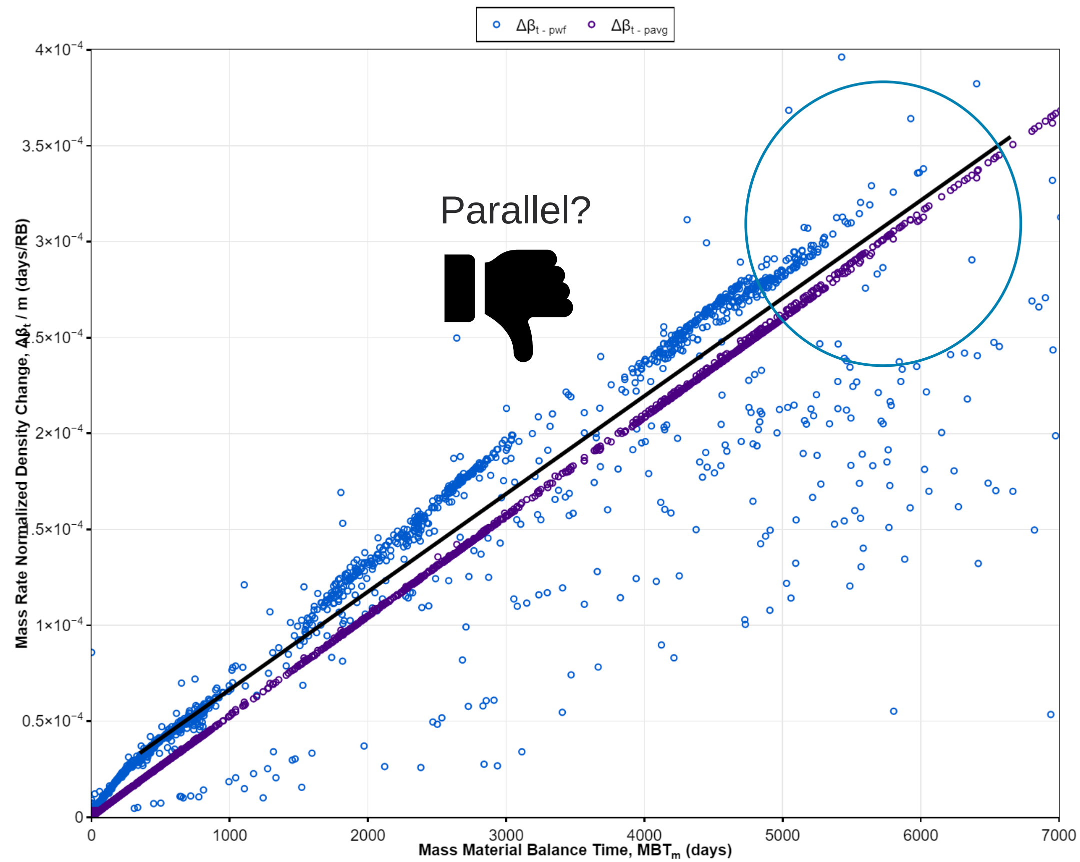
☐ Include Water

Interpretations

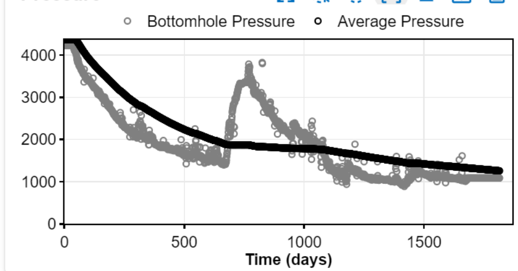
Slope
0.051 1e-6/RB

Intercept
0.155 1e-4 days/RB

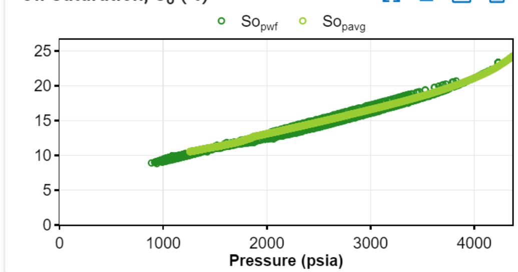
Flowing Material Balance



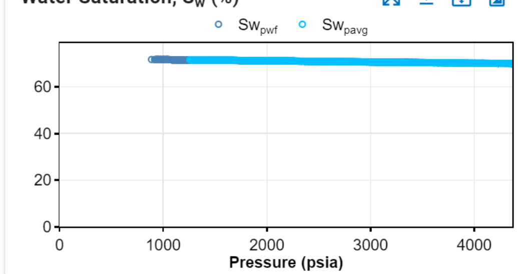
Pressure



Oil Saturation, S_o (%)



Water Saturation, S_w (%)



1 Average & Wellbore MFMB Plots not Parallel?

- Average plot too steep? Rock compressibility too large
- Average plot too shallow? Rock compressibility too small

1 Entire Production Period – No c_f

RUN

Estimates

Pore Volume, V_p
19608 MRB

Original Oil in Place, N
2131 MSTB

Original Gas in Place, G
7088 MMscf

Original Water in Place, W
13725 MSTB

Initial Conditions

Initial Reservoir Pressure
4370 psia

Initial Oil Saturation, S_{oi}
24.26 %

Initial Gas Saturation, S_{gi}
5.74 %

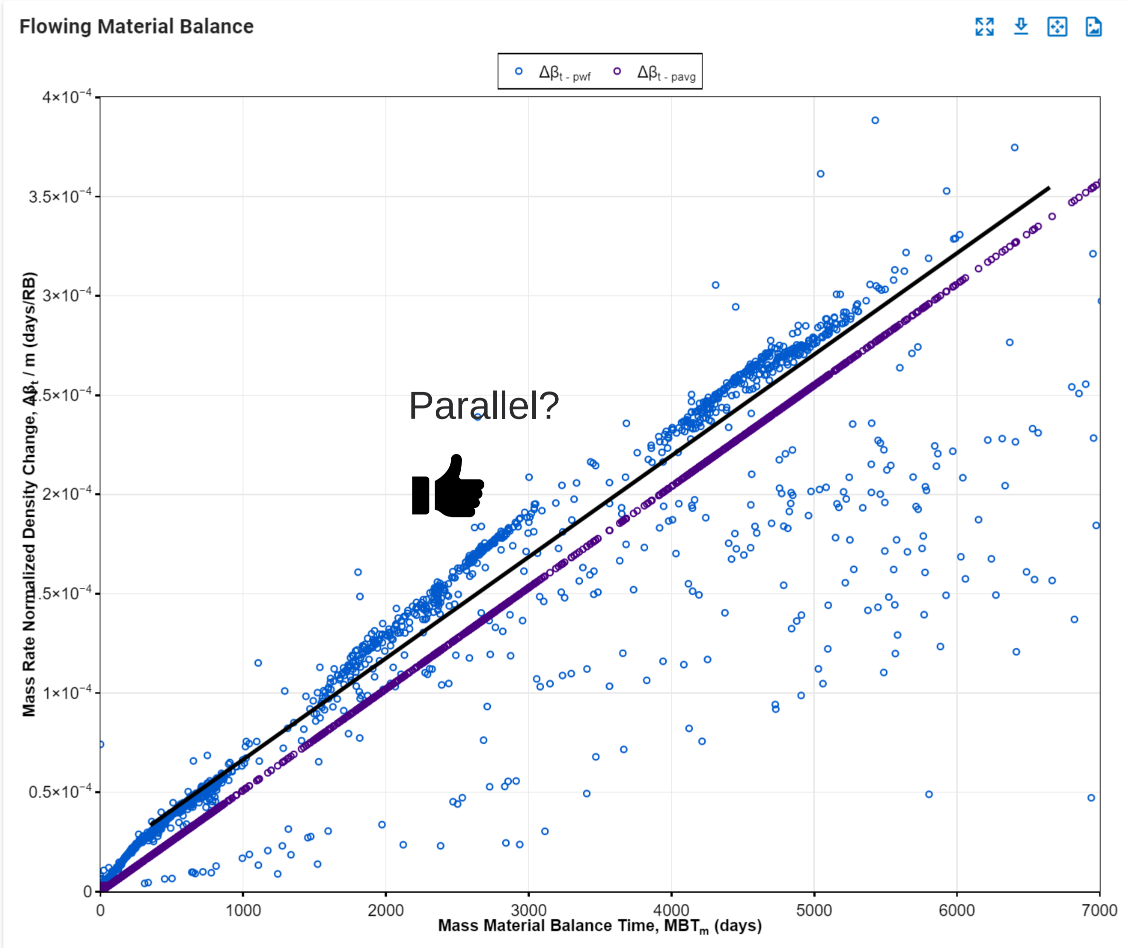
Initial Water Saturation, S_{wi}
70 %

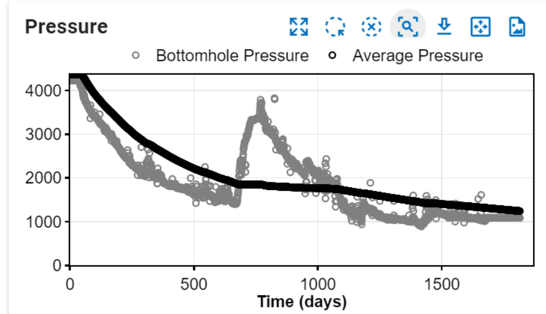
☐ Include Water

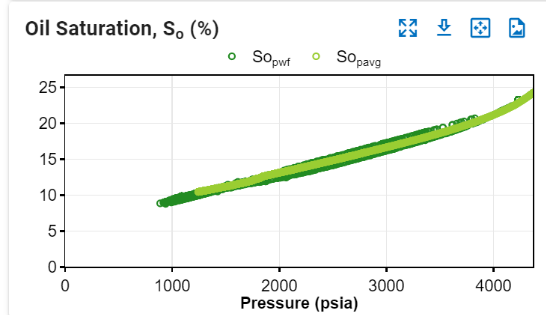
Interpretations

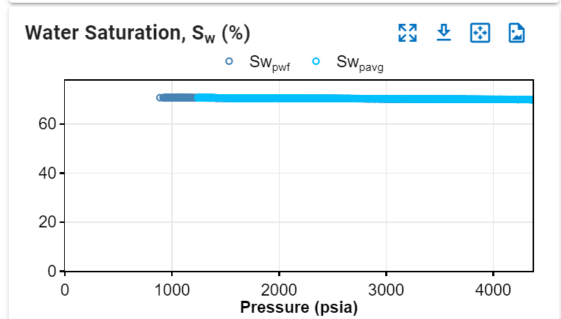
Slope
0.051 1e-6/RB

Intercept
0.155 1e-4 days/RB









1

Summary

Case	Pore Volume (MRB)	OOIP (MSTB)	OGIP (MMSCF)
S_{wi} = 30%	9588	2432	8088
S_{wi} = 70%	21341	2320	7715
No Water	19608	2131	7088

2

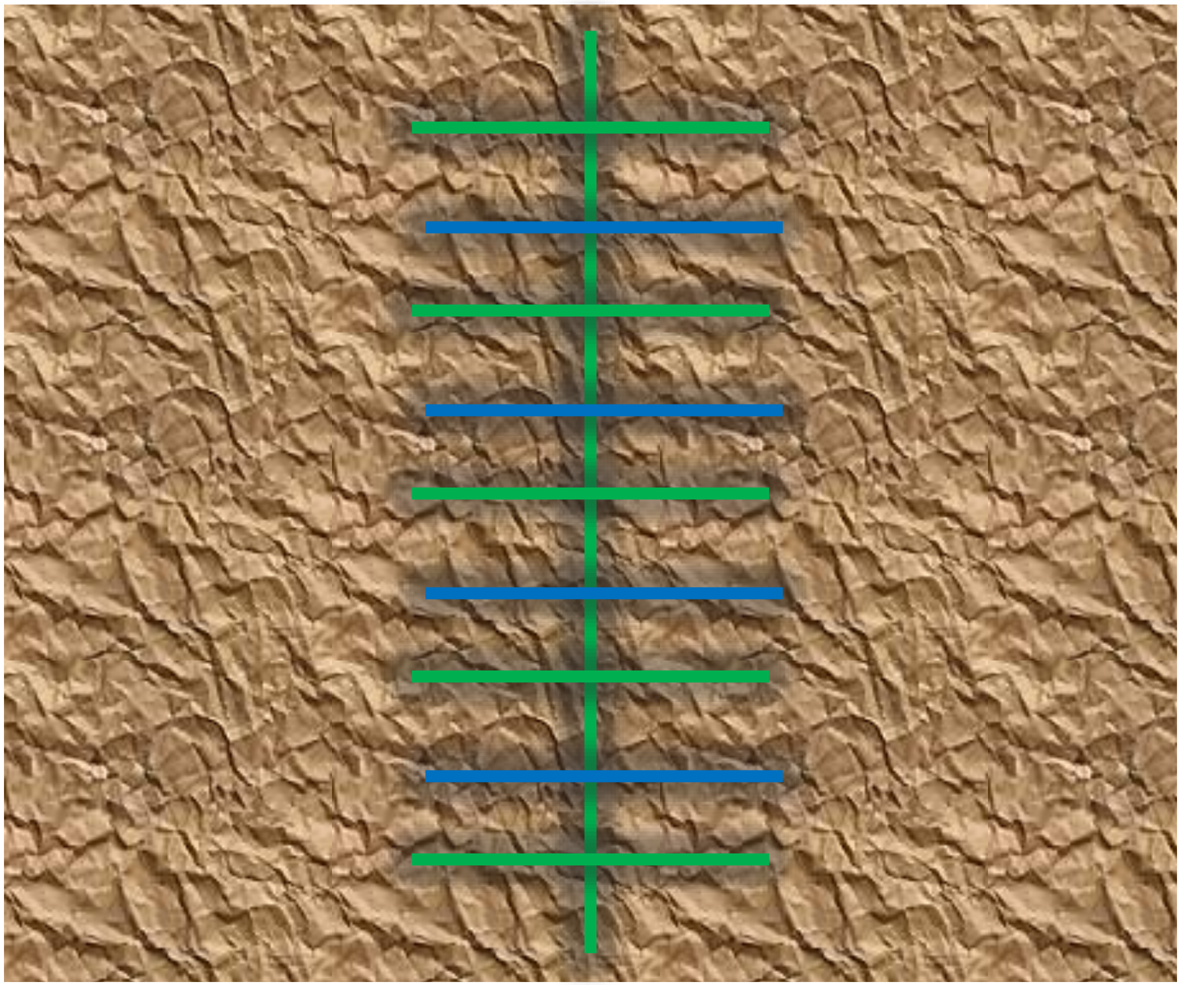
Example 2
Refracs in Eagle Ford

2

Synthetic Example

2

Simulated Case



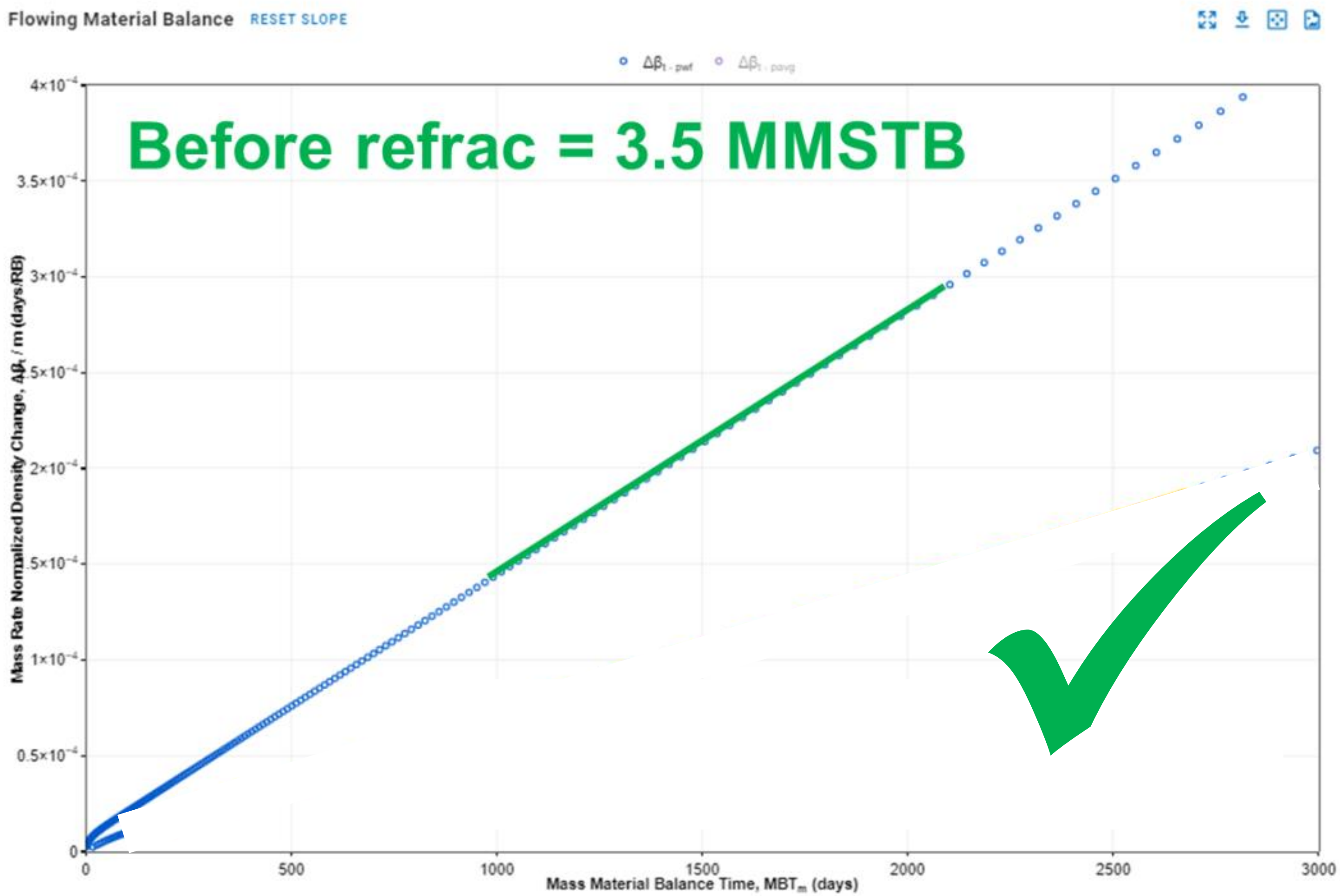
*URTeC: 3865157 - Use of Multiphase Flowing Material Balance (FMB) to evaluate Refracs in the Eagle Ford

2 Simulated Case

URTeC: 3865157 - Use of Multiphase Flowing Material Balance (FMB) to evaluate Refracs in the Eagle Ford

2

Simulated Case



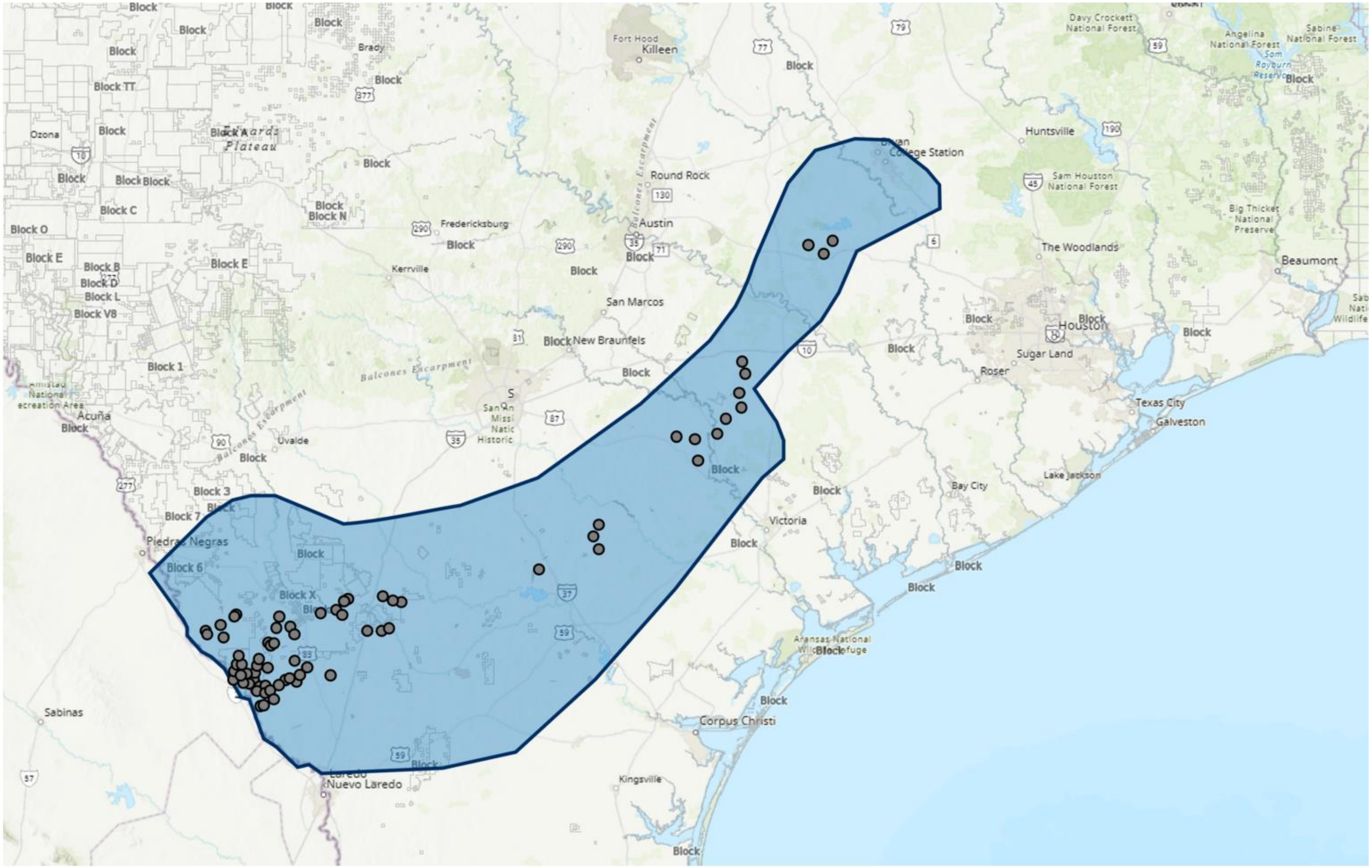
*URTeC: 3865157 - Use of Multiphase Flowing Material Balance (FMB) to evaluate Refracs in the Eagle Ford

2

Eagle Ford Example

2

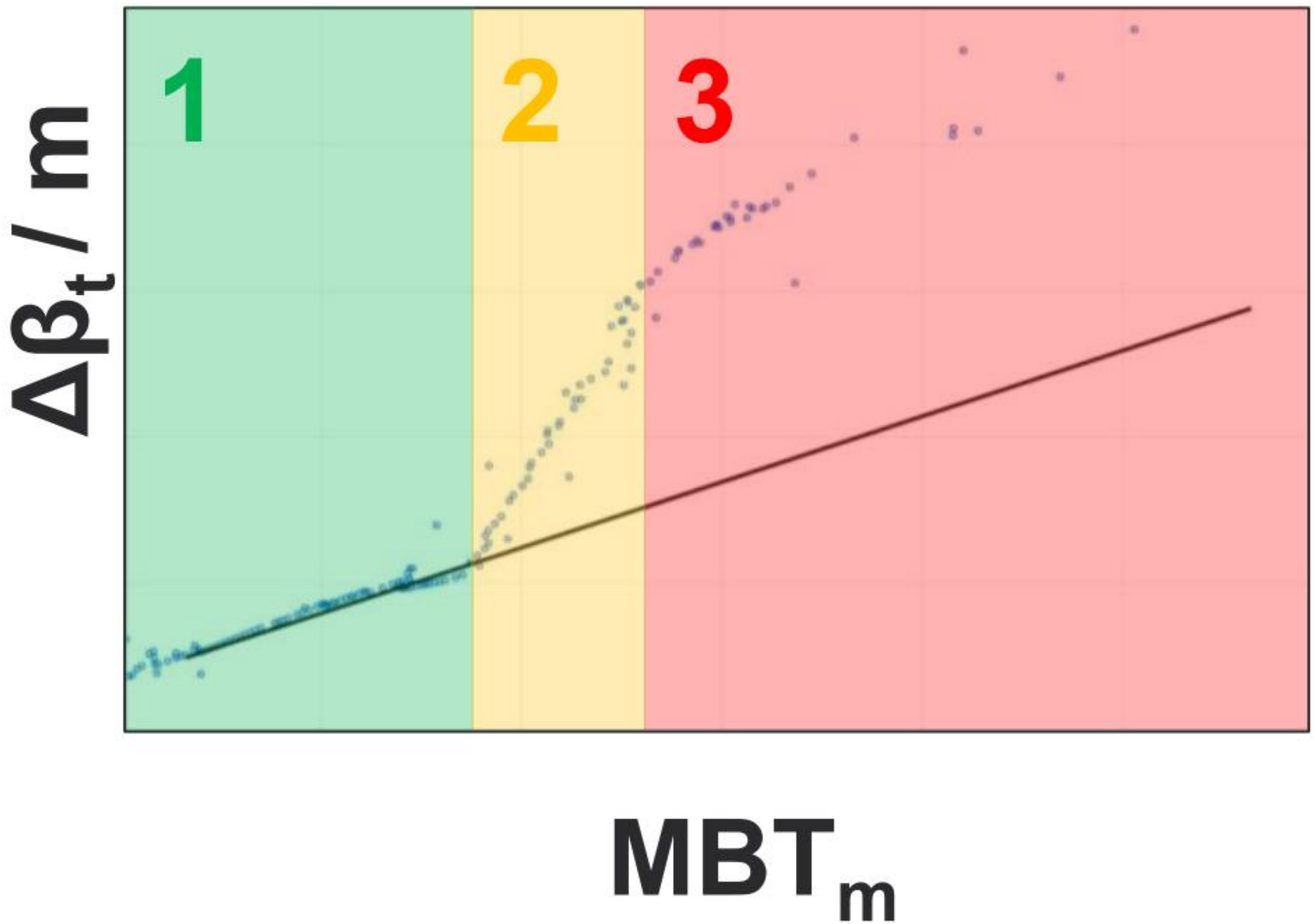
Eagle Ford Example



URTeC: 3865157 - Use of Multiphase Flowing Material Balance (FMB) to evaluate Refracs in the Eagle Ford

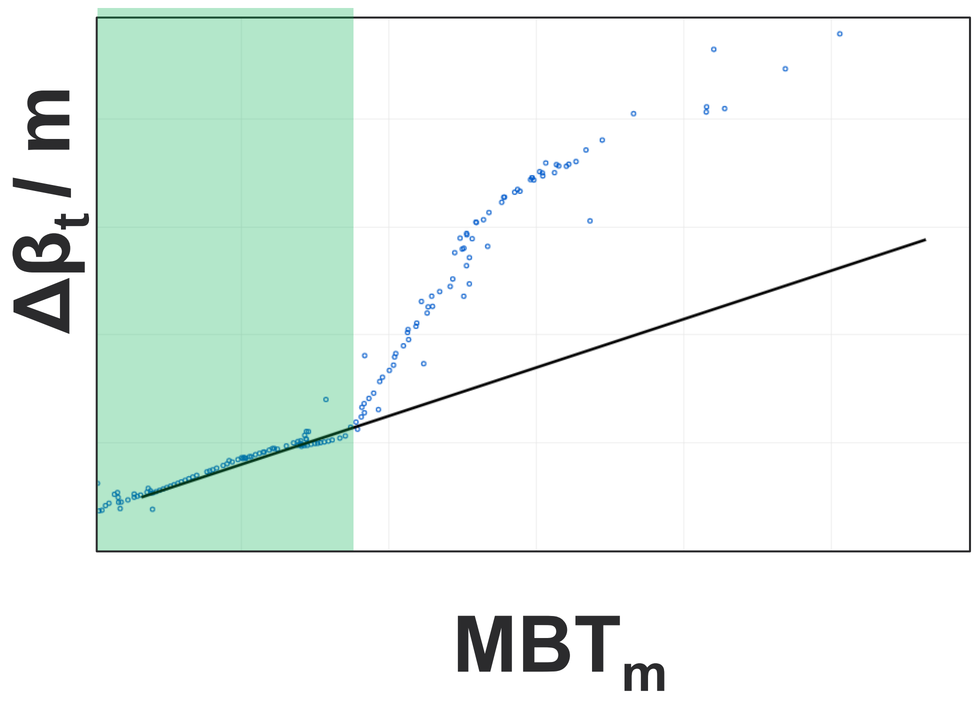
2

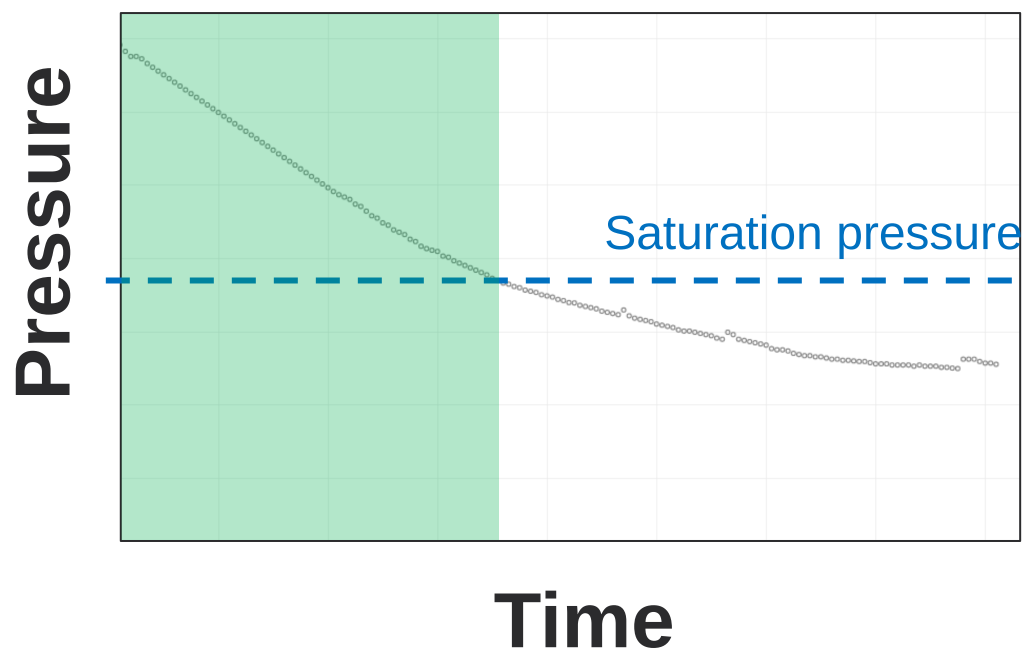
MFMB Plot – Three Key Periods



2 Multiphase FMB – Three Key Periods

Period 1: While $p_{wf} > p_{sat}$ (“single-phase flow”)

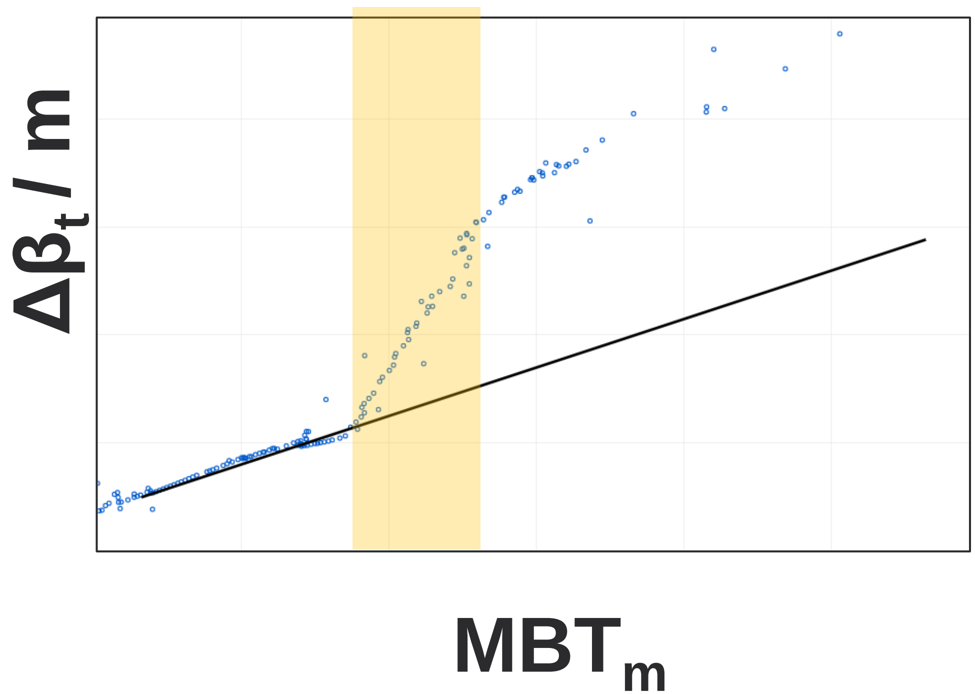


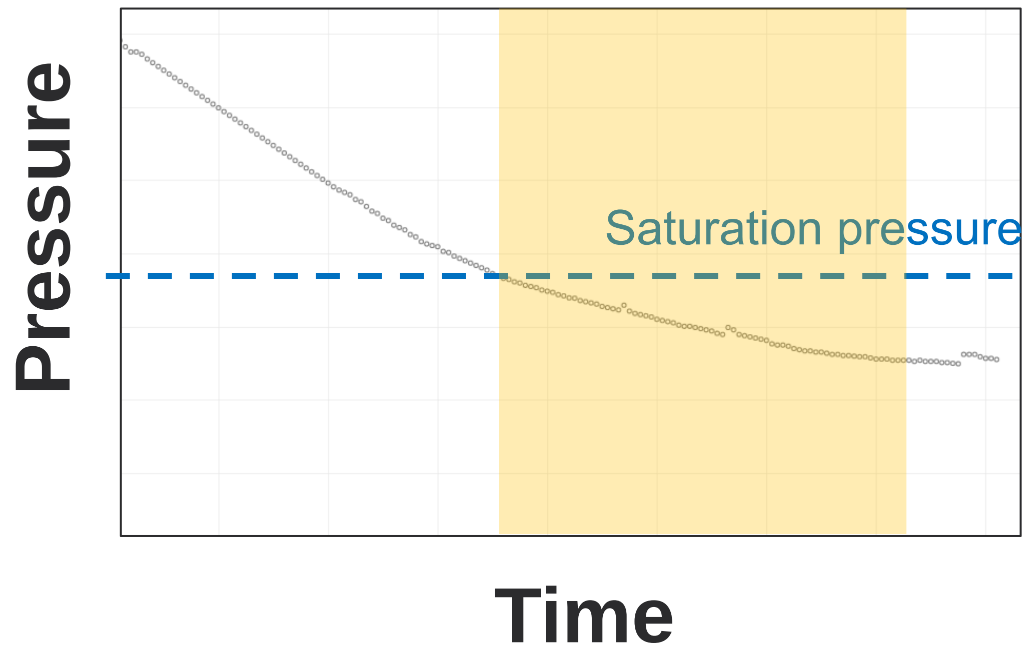


whitson

2 Multiphase FMB – Three Key Periods

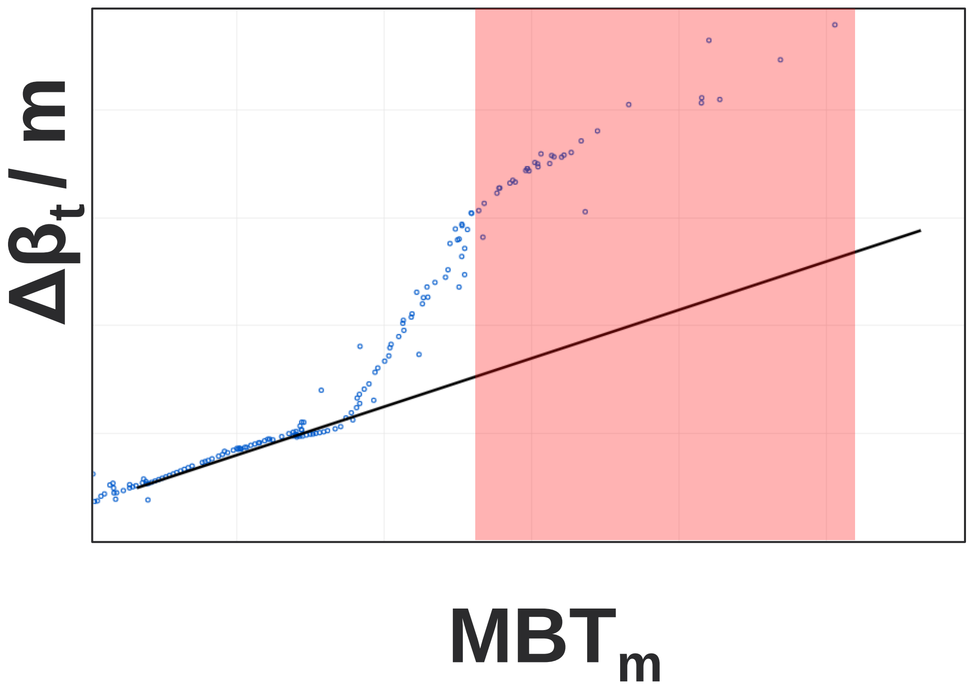
Period 2: Transition period due to multiphase flow effects (gas enters the system, and gas is more compressible)

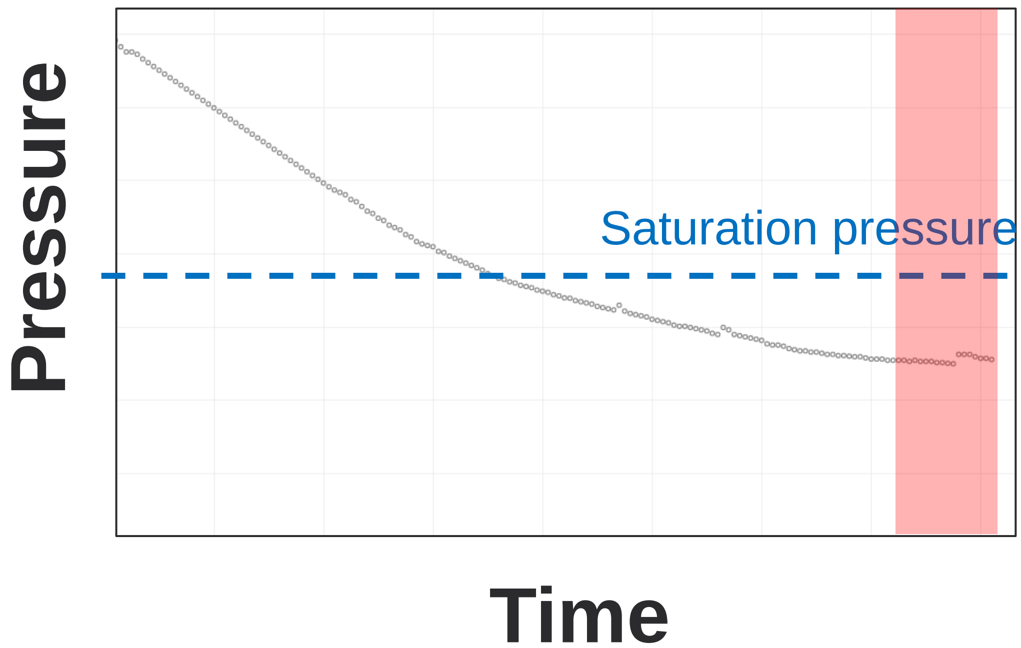




Multiphase FMB – Three Key Periods

Period 3: Second stabilized slope





2

Three Scenarios

1. Early OOIP < Late OOIP

-> Still infinite acting (IA) early

2. Early OOIP = Late OOIP

-> Contacted everything early

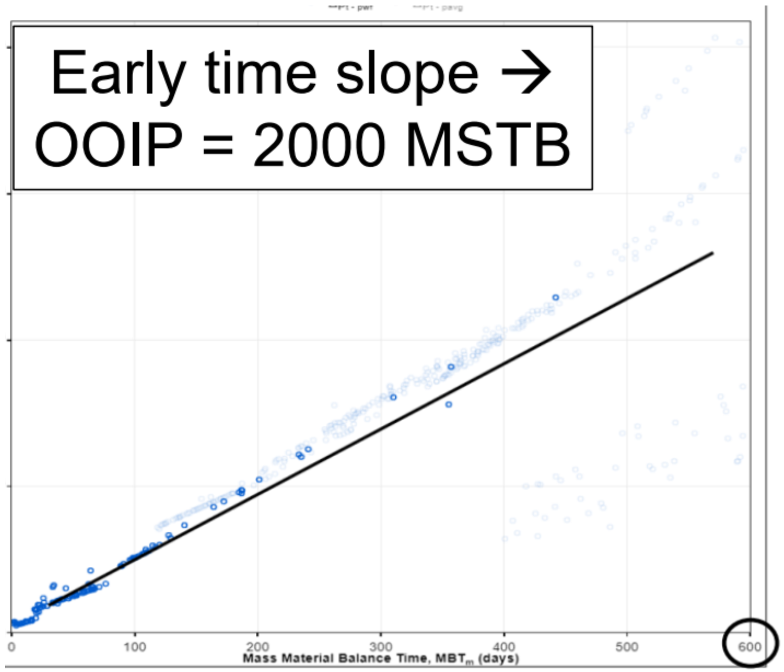
3. **Early OOIP > Late OOIP**

-> Loss of surface area with time (or strong geomechanical effects)

Field Example

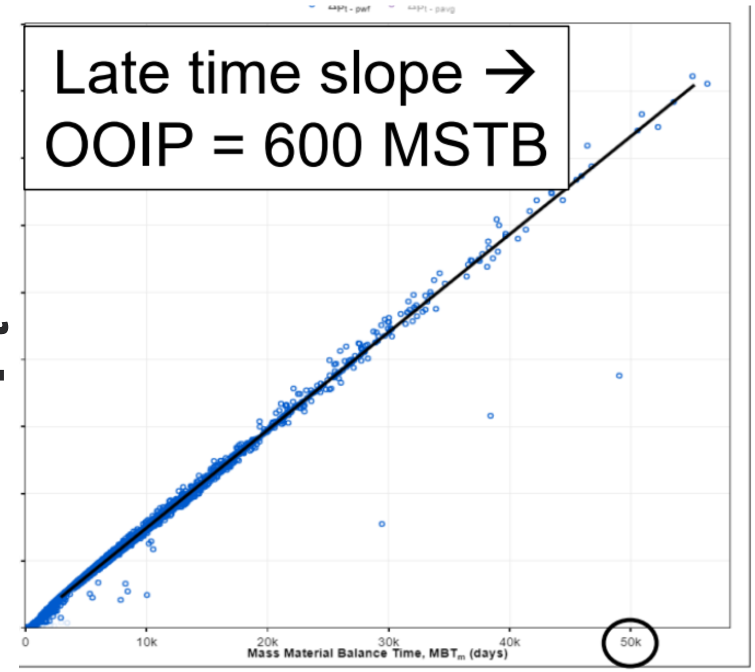
2

$\Delta\beta_t$ / m



MBT_m

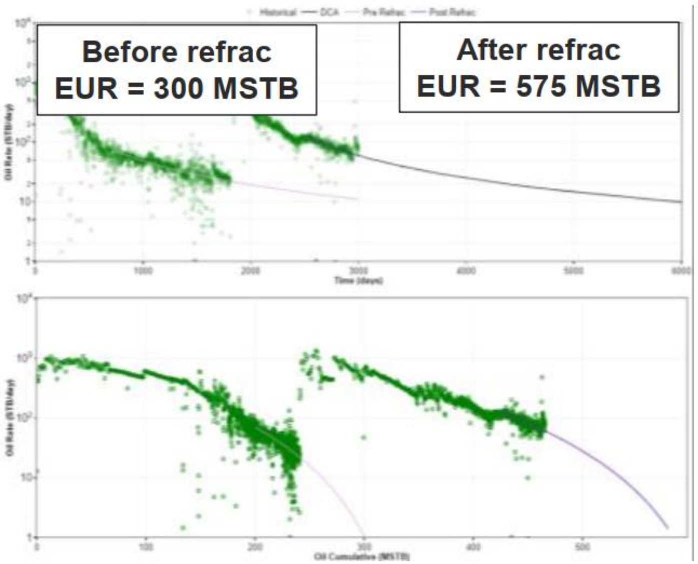
$\Delta\beta_t$ / m

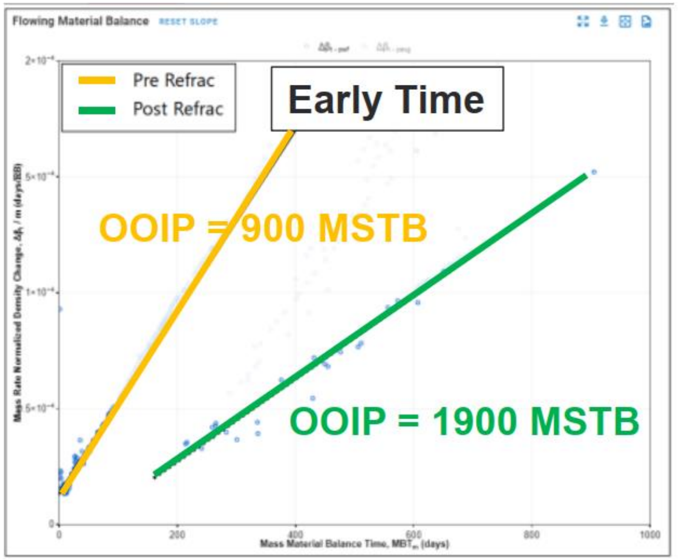


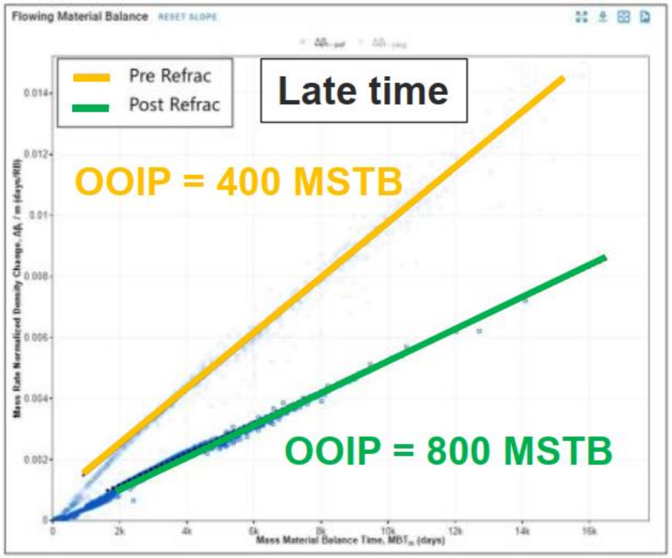
MBT_m

URTeC: 3865157 - Use of Multiphase Flowing Material Balance (FMB) to evaluate Refracs in the Eagle Ford

2 Field Example: Successful Refrac





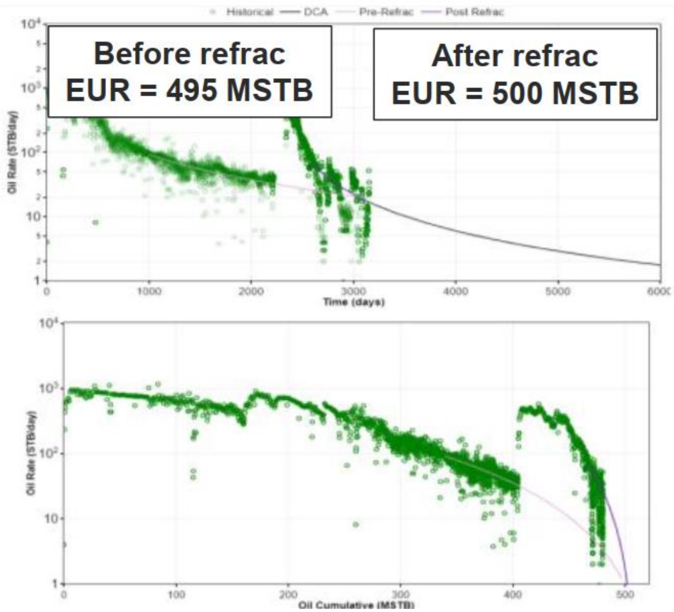


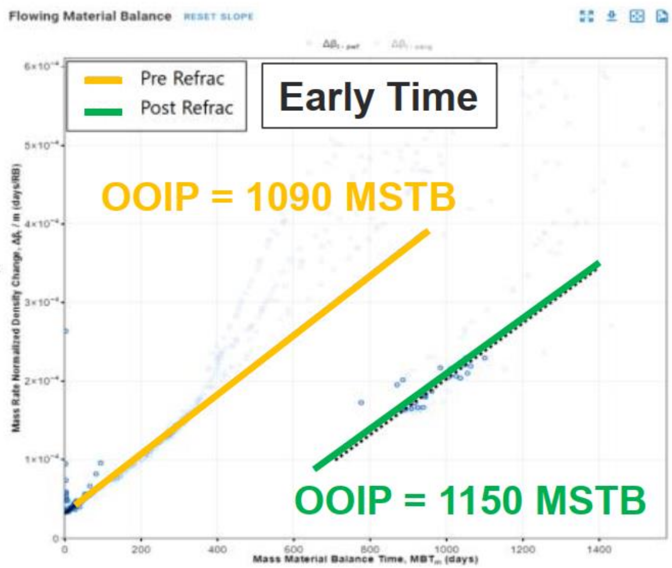
Early time OOIP using the first 15 days after refrac!

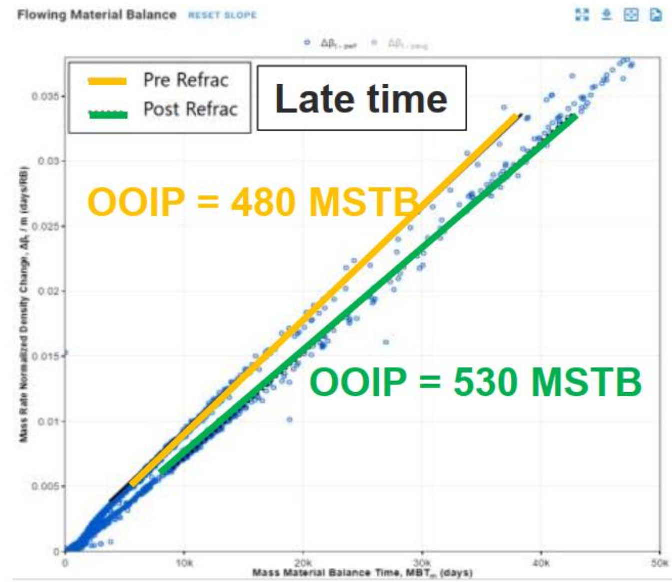
URTeC: 3865157 - Use of Multiphase Flowing Material Balance (FMB) to evaluate Refracs in the Eagle Ford

whitson

2 Field Example: Unsuccessful Refrac





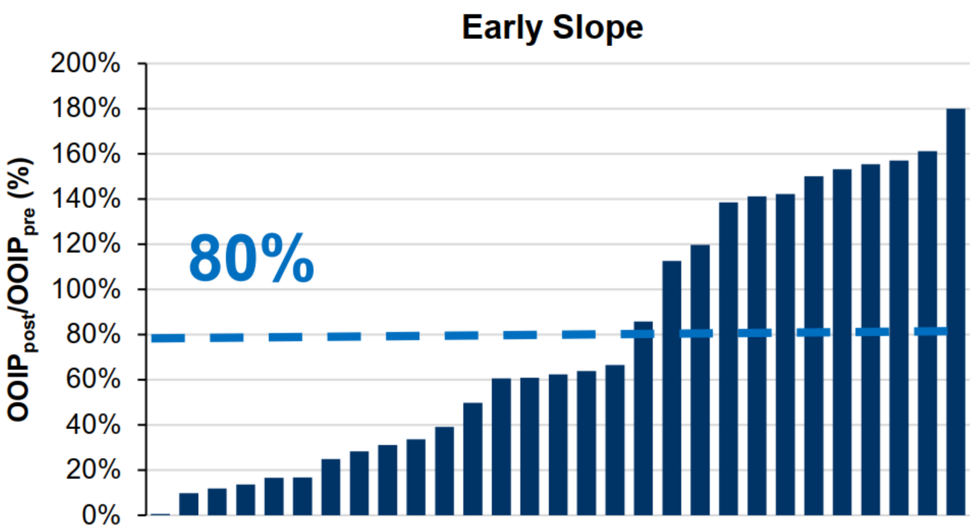


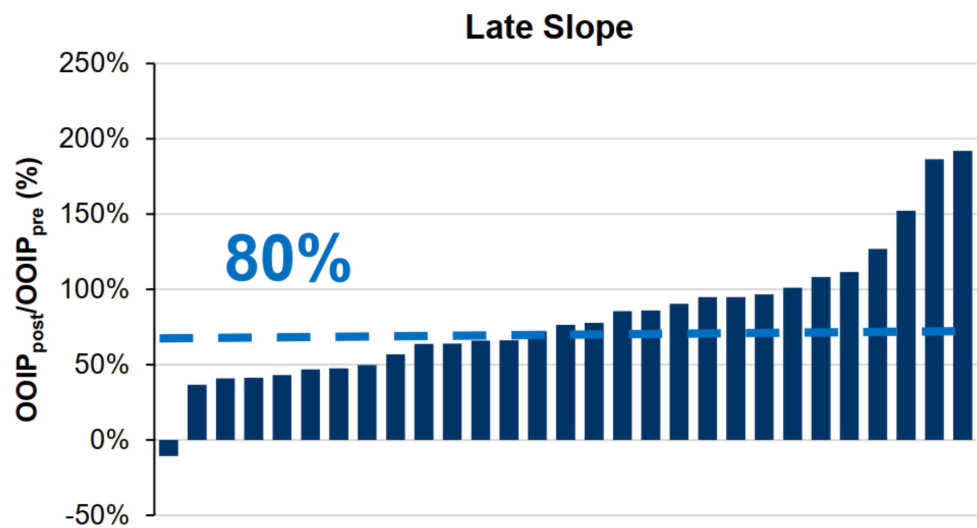
Early time OOIP using the first 15 days after refrac!

URTeC: 3865157 - Use of Multiphase Flowing Material Balance (FMB) to evaluate Refracs in the Eagle Ford

Summary: 29 Refracs – 80% Uplift

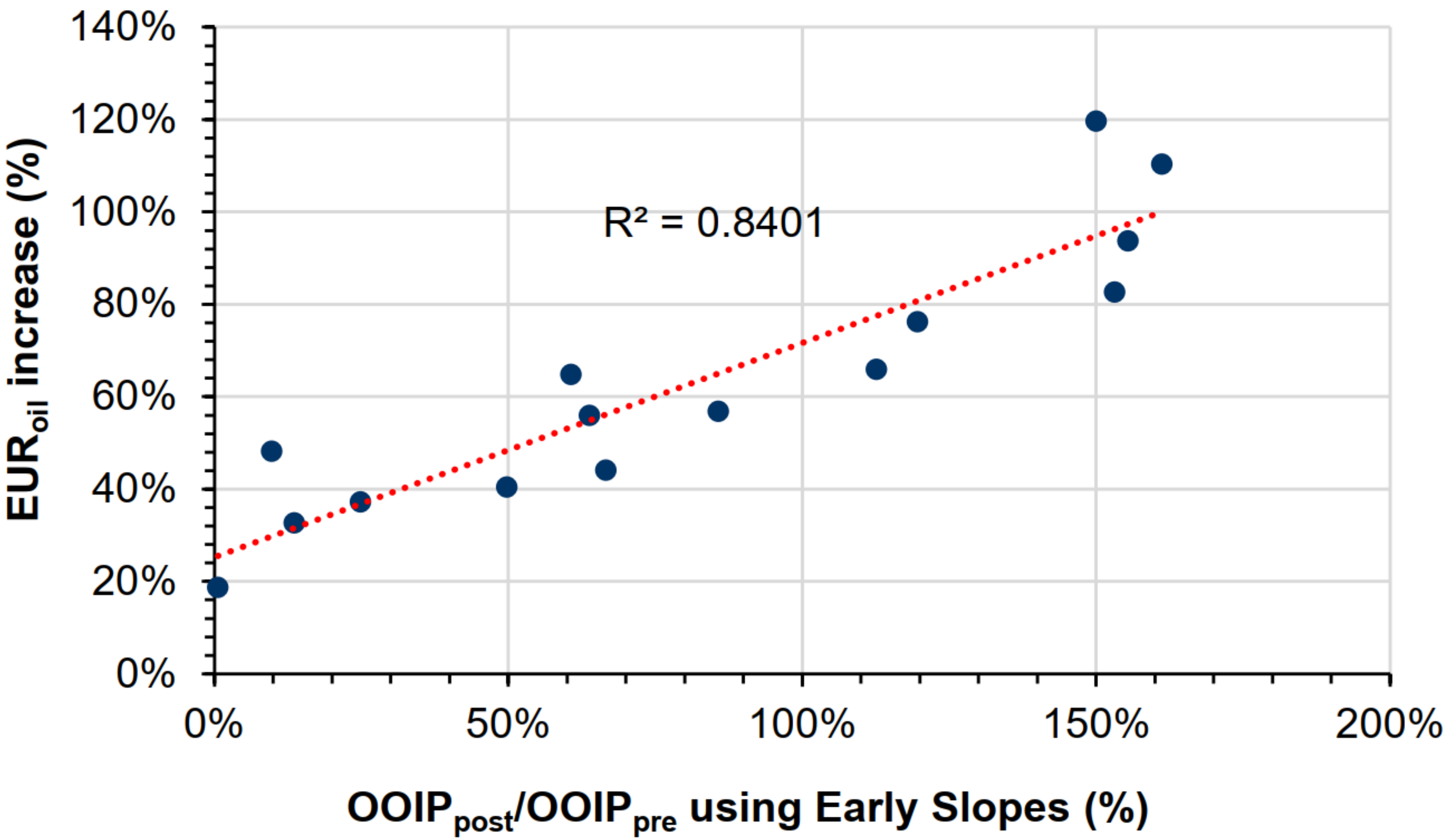
2





URTeC: 3865157 - Use of Multiphase Flowing Material Balance (FMB) to evaluate Refracs in the Eagle Ford

2 Increase in EUR vs Increase in OOIP



URTeC: 3865157 - Use of Multiphase Flowing Material Balance (FMB) to evaluate Refracs in the Eagle Ford

2

Summary

1. **Early time diagnostic of refrac**

    -> 15 first days after refrac

2. **Accounts multiphase flow & superposition**

    -> Refracs are done below p_{sat}

3. **Quantifies added reserves**

    -> … vs just is accelerating production

URTeC: 3865157 - Use of Multiphase Flowing Material Balance (FMB) to evaluate Refracs in the Eagle Ford

whitson

3

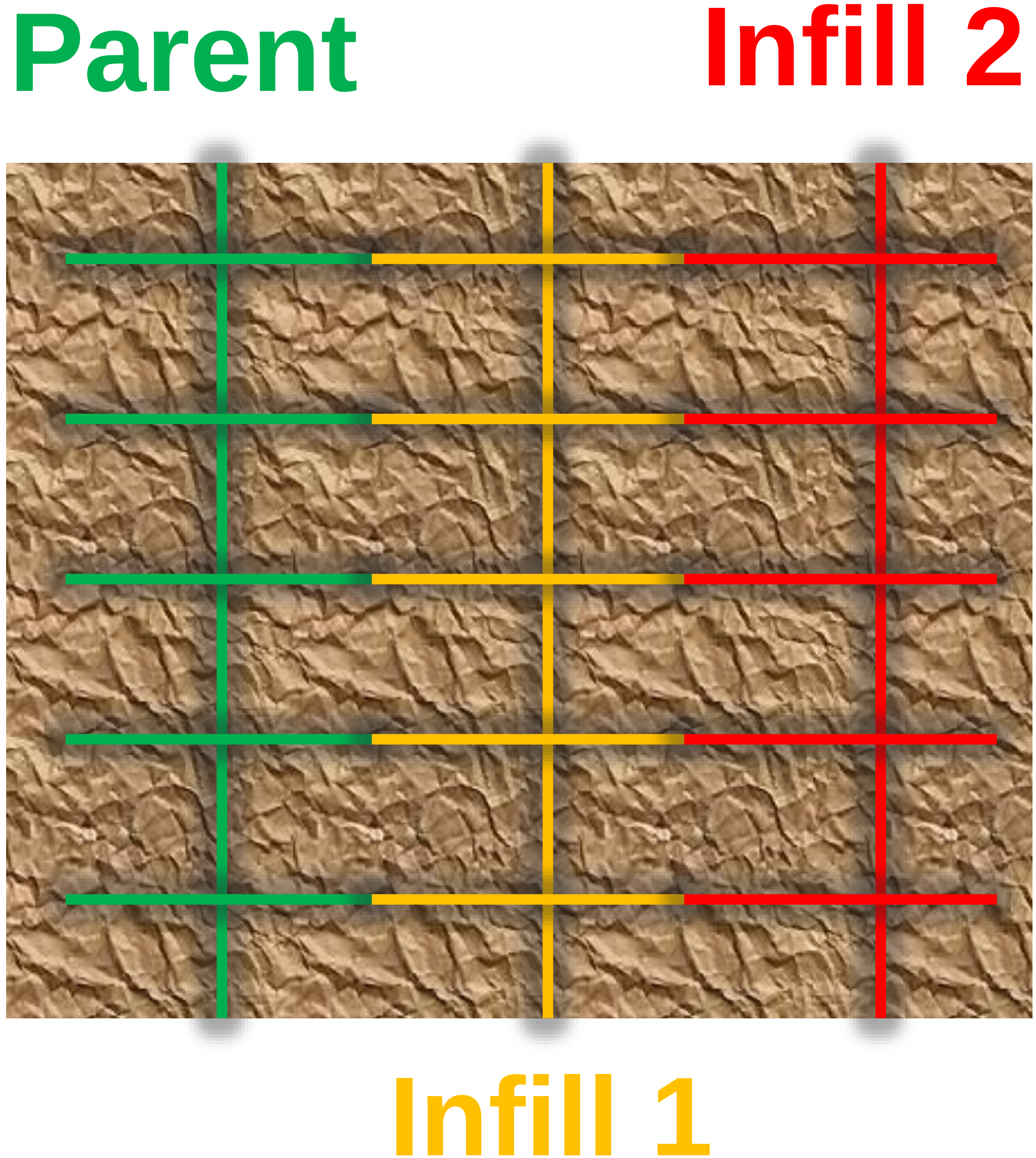
Example 3

MFMB on Well Groups in the Permian

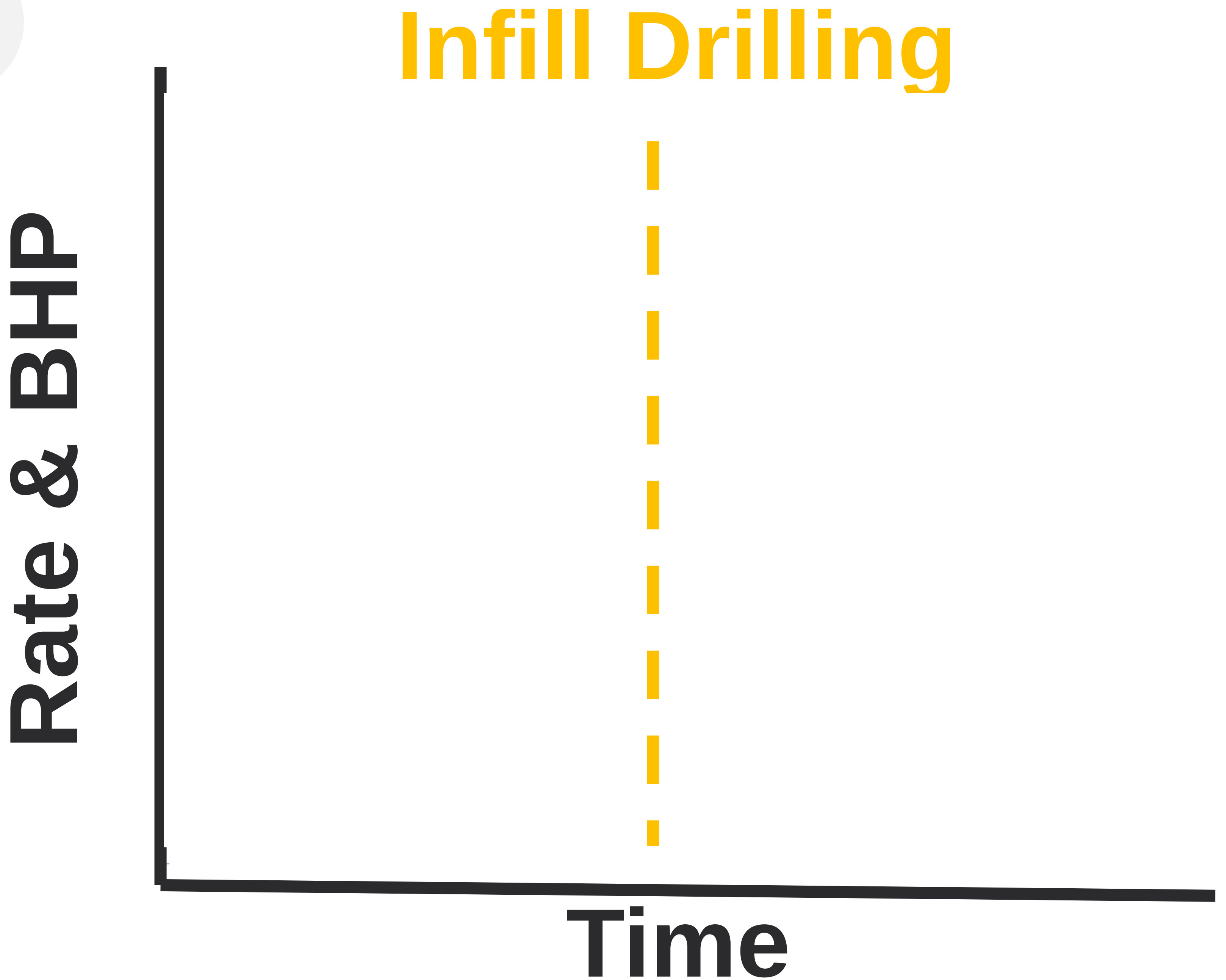
3

Synthetic Example

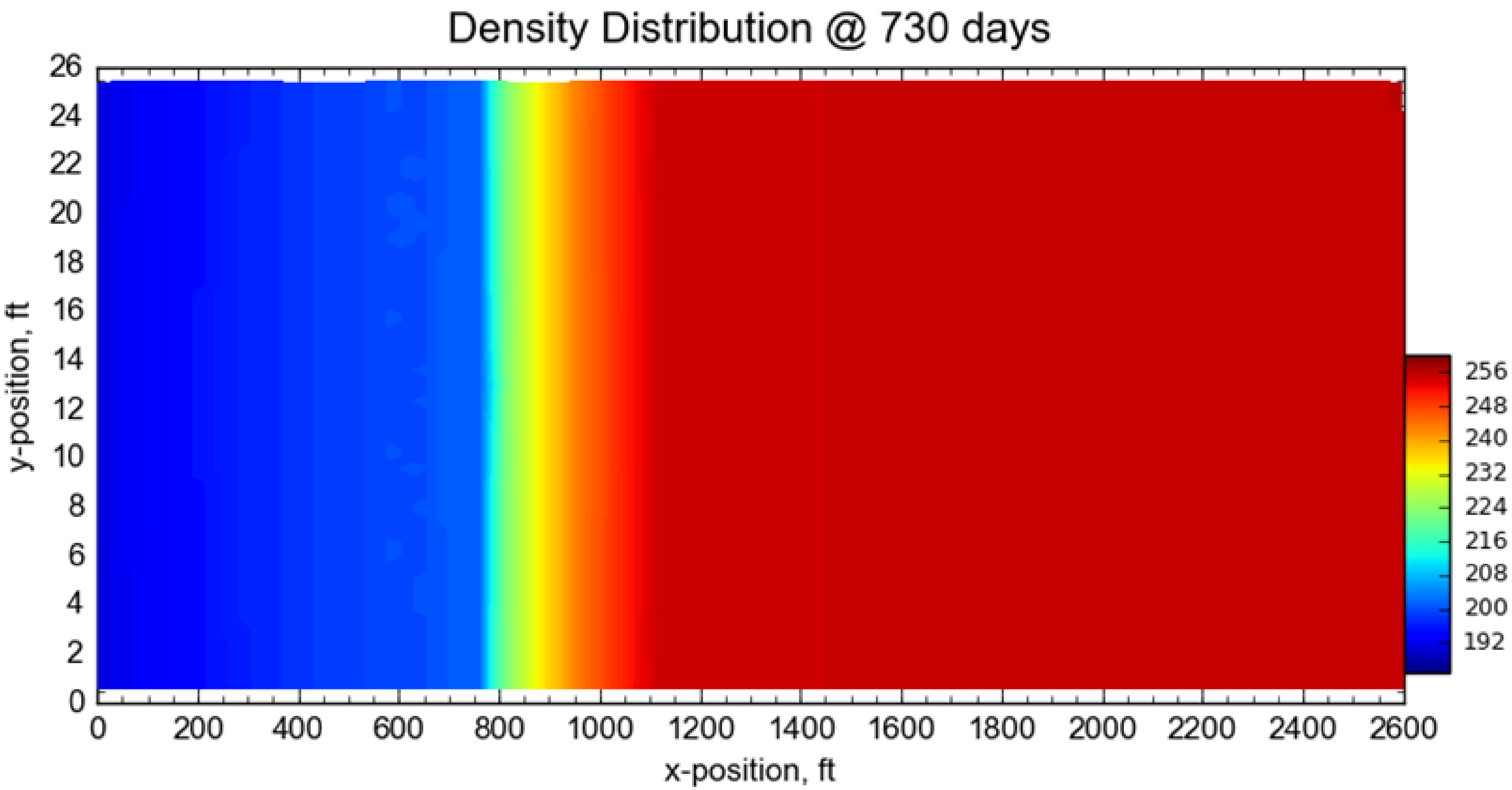
3

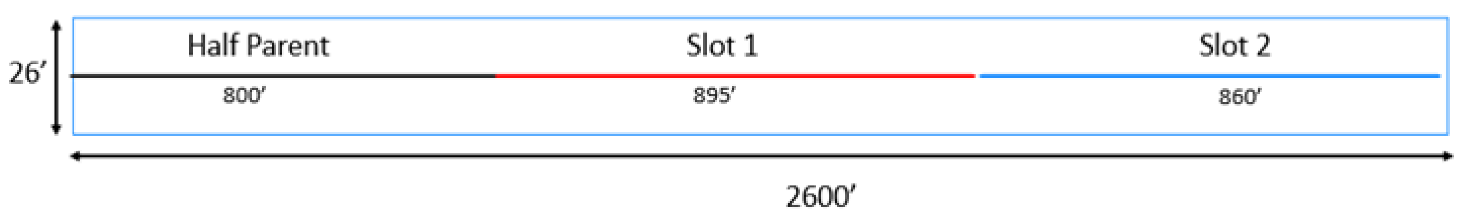


3



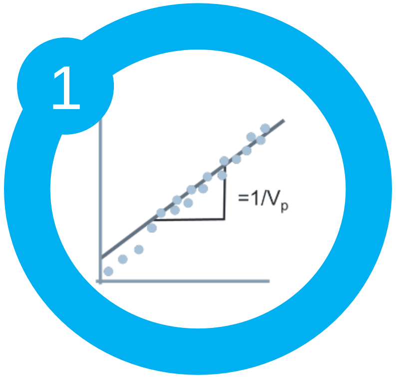
3 Density distribution @ 730 days

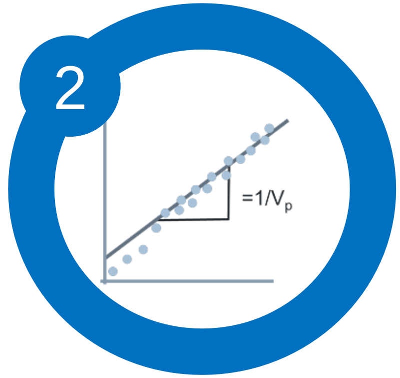


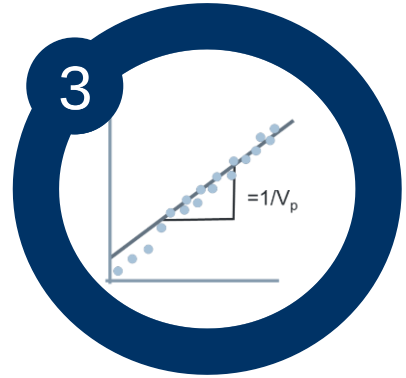


3

Alternative 1: Sum Individual Analysis





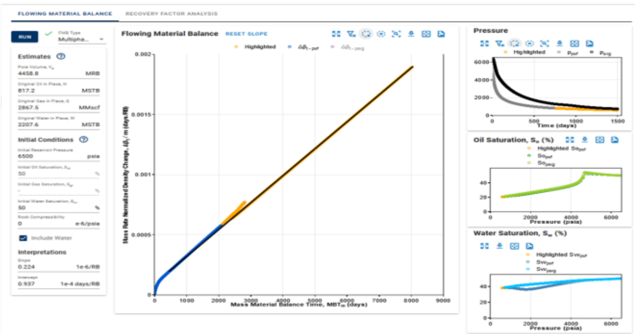
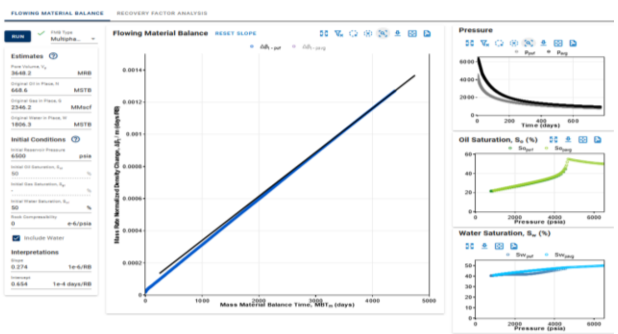
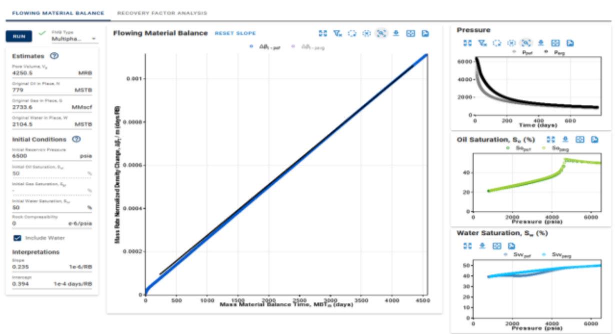


Vp_A Vp_B Vp_C

Vp_{total}

whitson

3 Alternative 1: Sum Individual Analysis

Parent	Infill 1	Infill 2
		
V_p = 4.5 MMRB	V_p = 3.7 MMRB	V_p = 4.3 MMRB

$V_{p,tot}$ = 12.4 MMRB
(3% off)

Alternative 2: “Pseudowell”

Create a “pseudo-well”

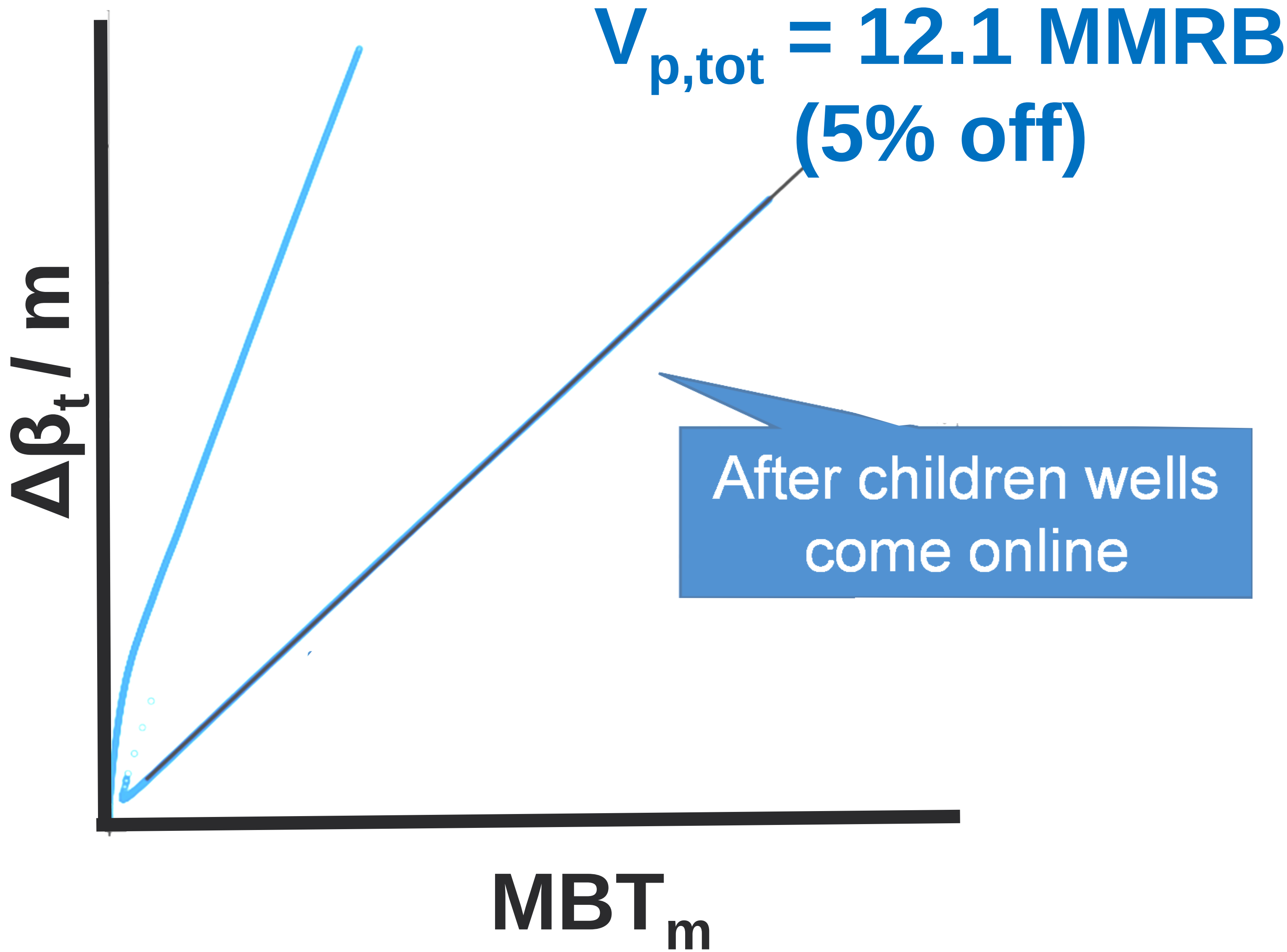
1. Rates: sum for all three wells

2. BHPs: mass-weighted average

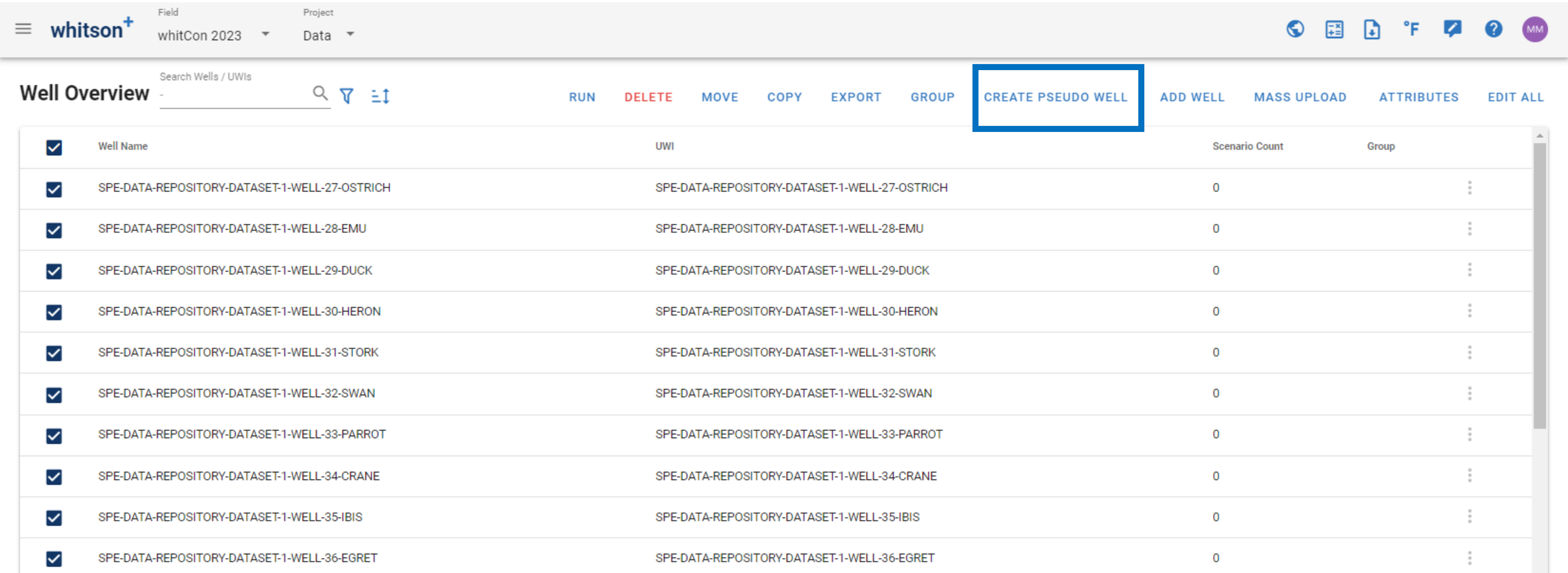
Else use the method as usual, now for a single pseudo-well

3

Alternative 2: "Pseudowell"



3 Alternative 2: “Pseudowell”



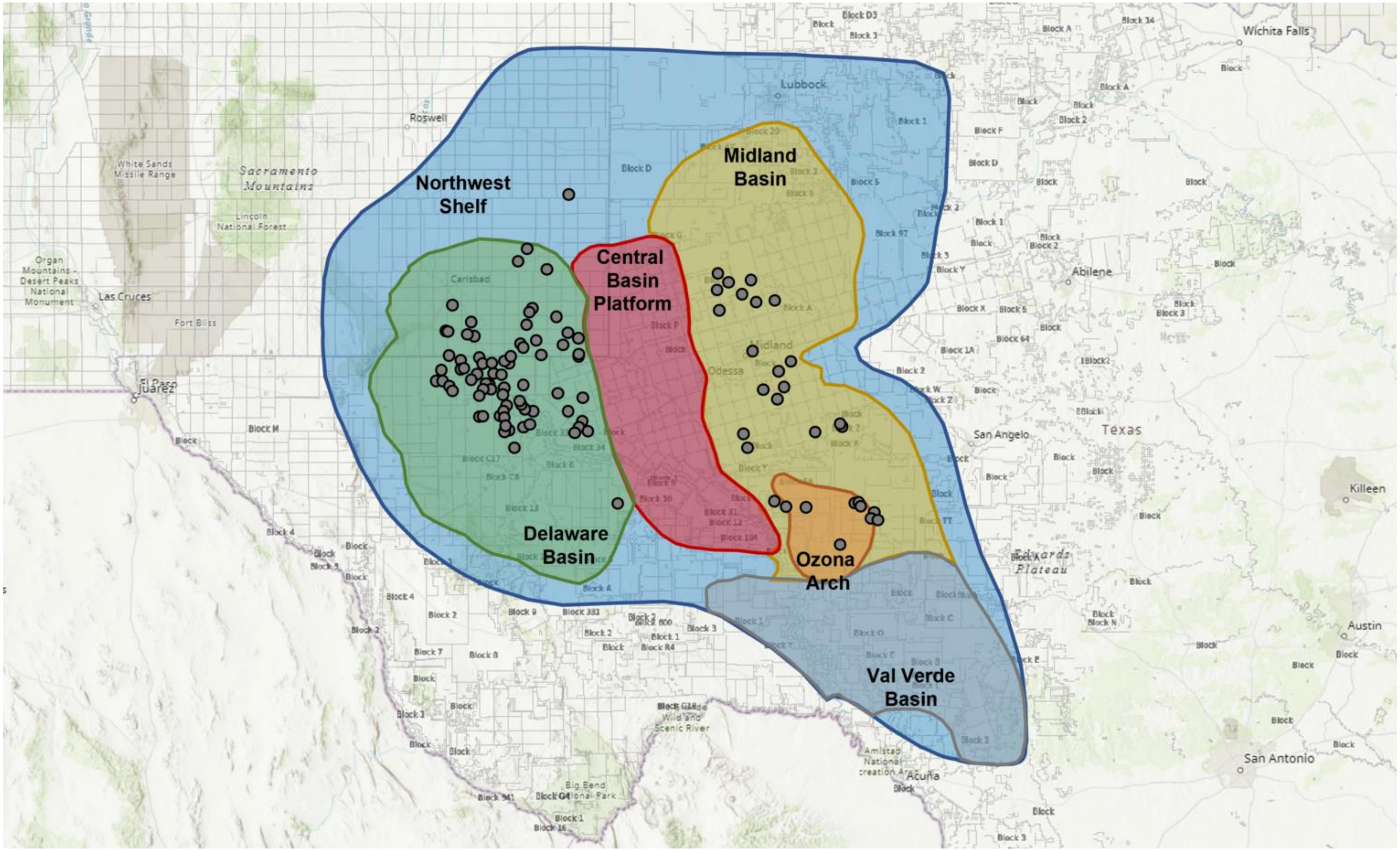
✔ **All wells need to have PVT and MFMB run**

3

Permian Example

3

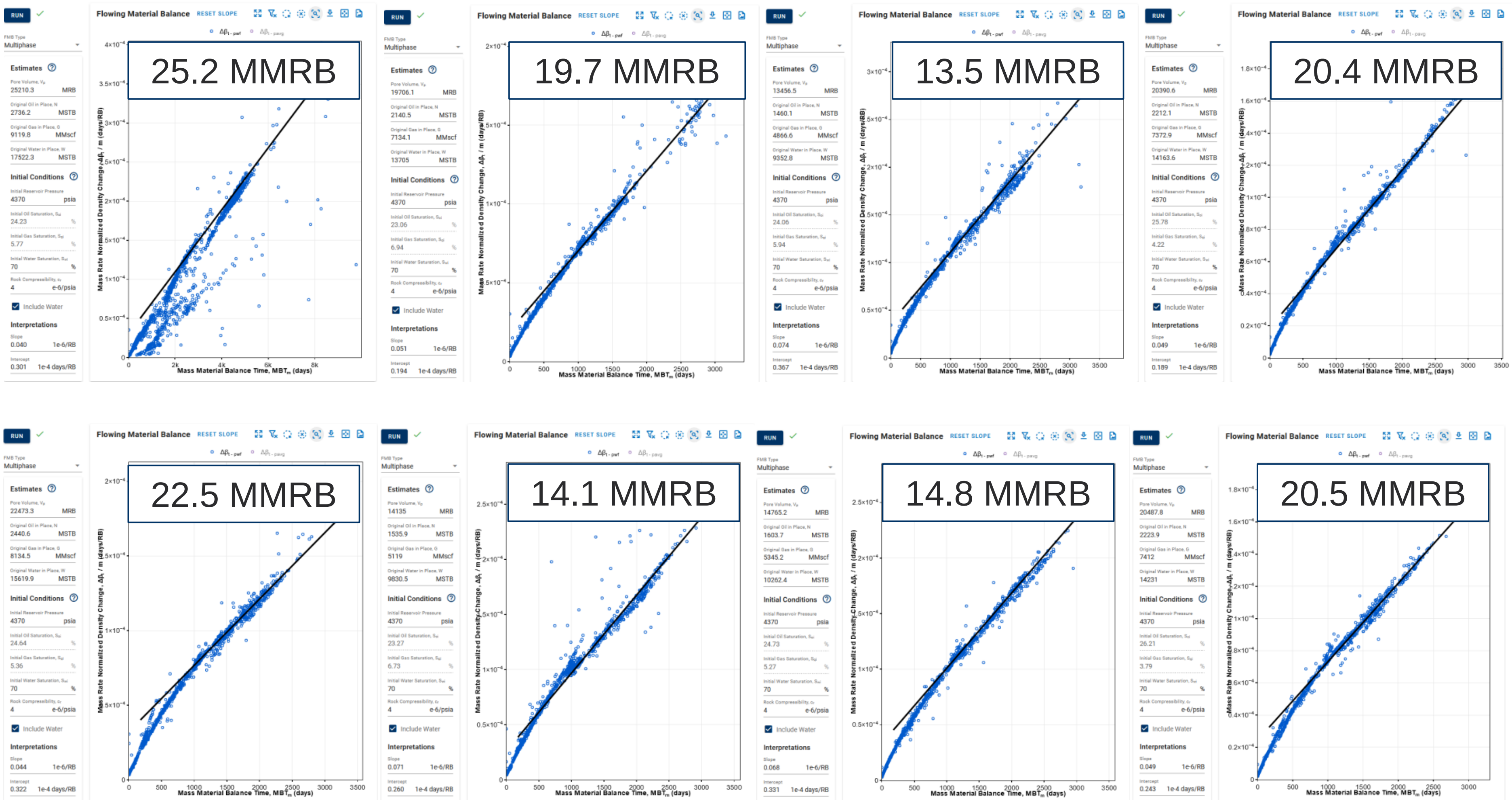
Permian Case Study



*URTeC: 3870320: Multiphase Flowing Material Balance for Well Groups

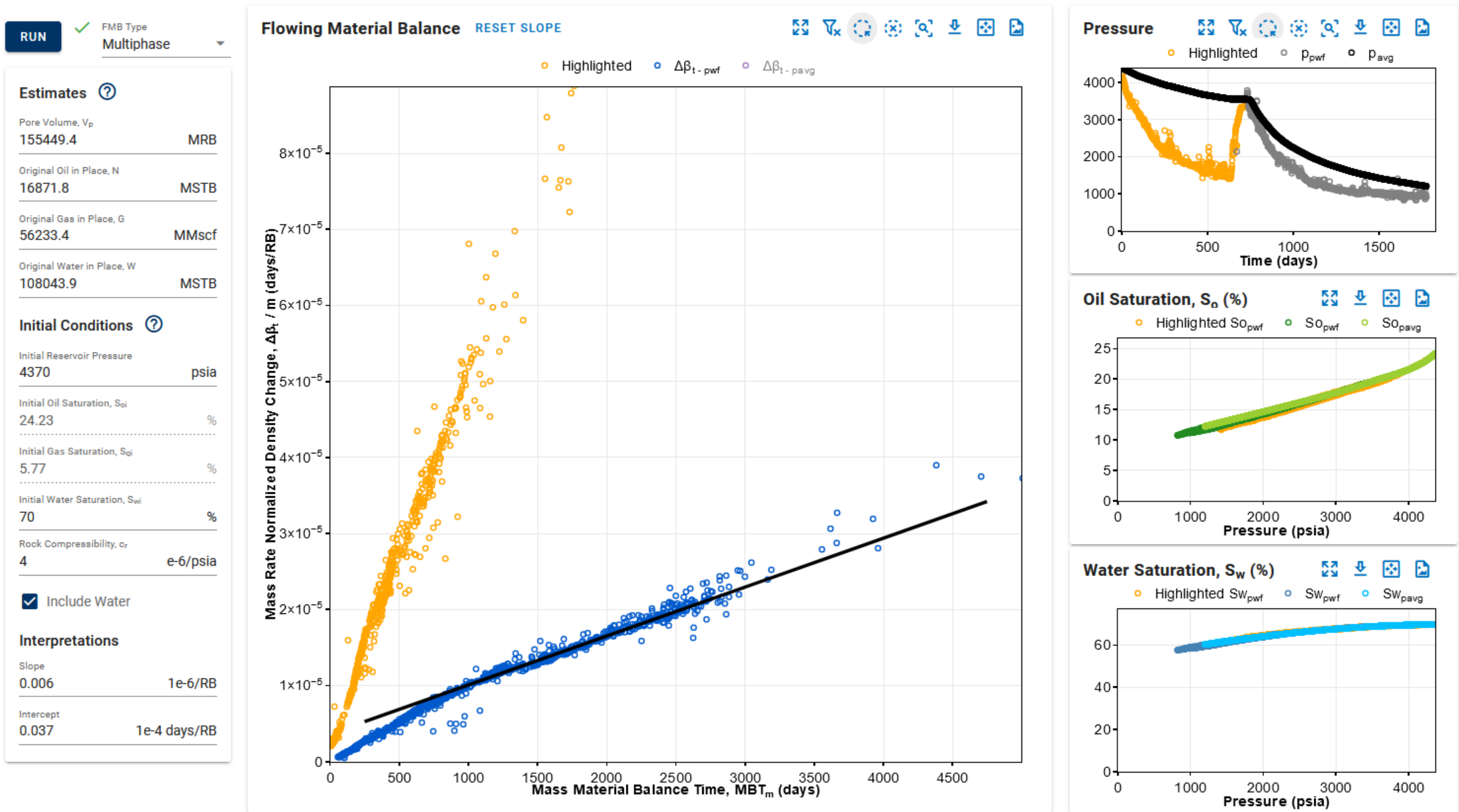
3

Alternative 1



**URTeC: 3870320: Multiphase Flowing Material Balance for Well Groups*

Alternative 2



**URTeC: 3870320: Multiphase Flowing Material Balance for Well Groups*

Comparison

Well	Pore Volume (MMRB)
F-1 (Parent)	26.4
F-2	19.7
F-3	22.5
F-4	14.1
F-5	13.5
F-6	20.4
F-7	14.8
F-8	20.5
Sum	**151.9**
Pseudowell	**155.4**

**URTeC: 3870320: Multiphase Flowing Material Balance for Well Groups*

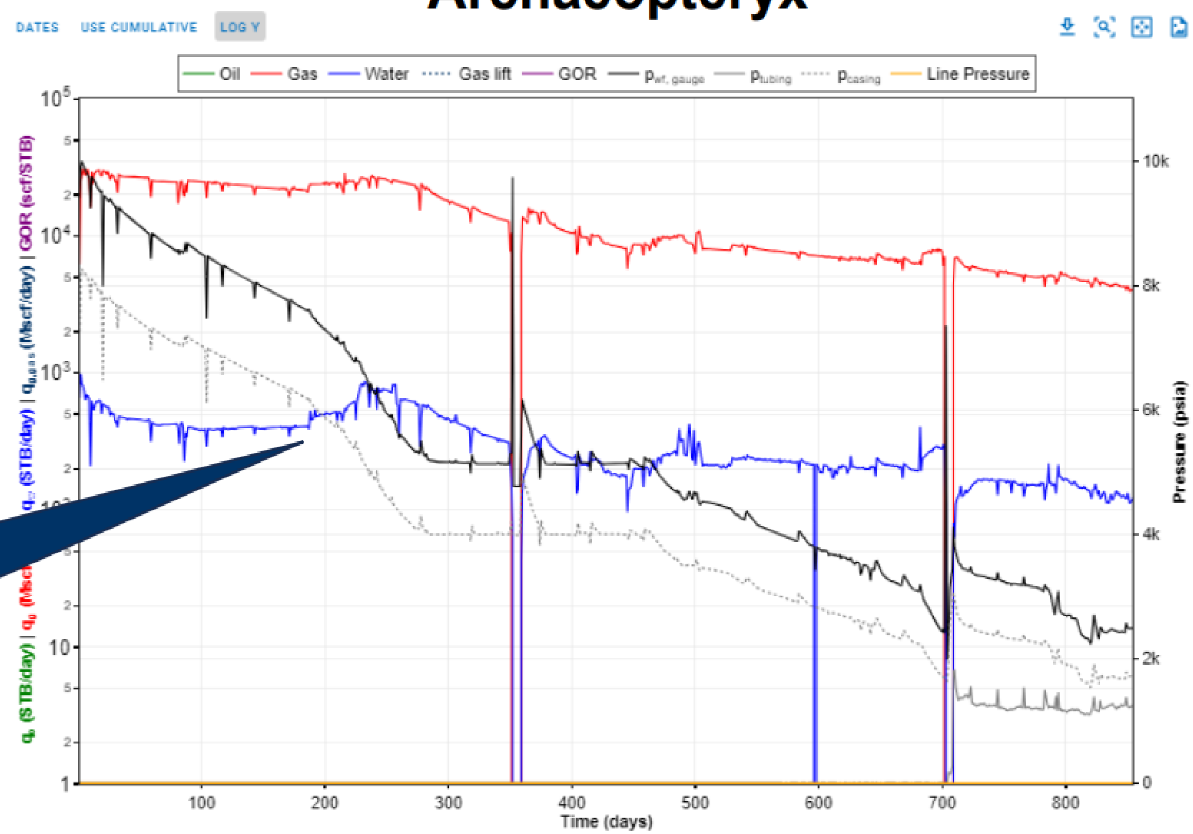
Example 4
Frac Hits

4

Problem Statement

Pore Volume Reduction after Frac Hit?

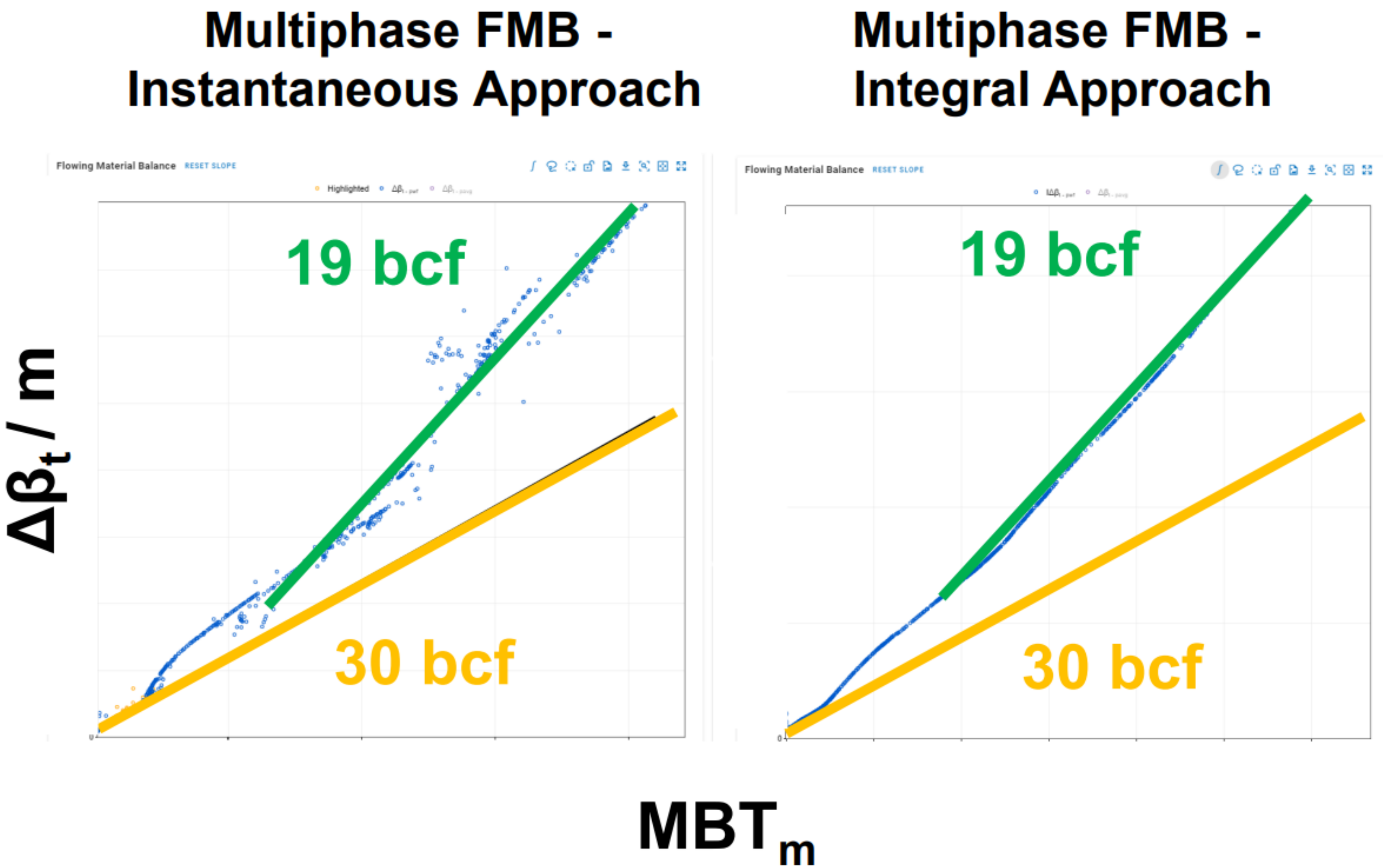
Archaeopteryx[1]



Frac-hit?

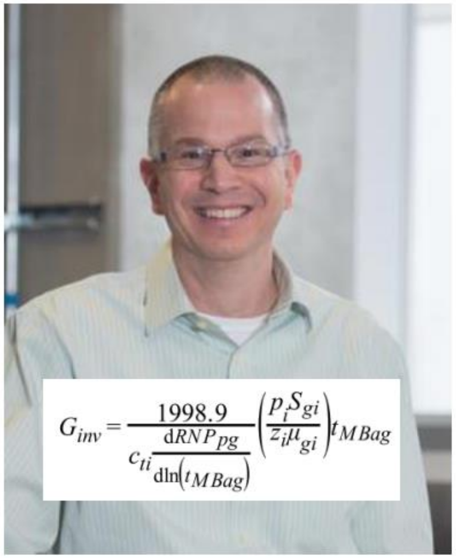
Pore Volume Reduction~36-37%

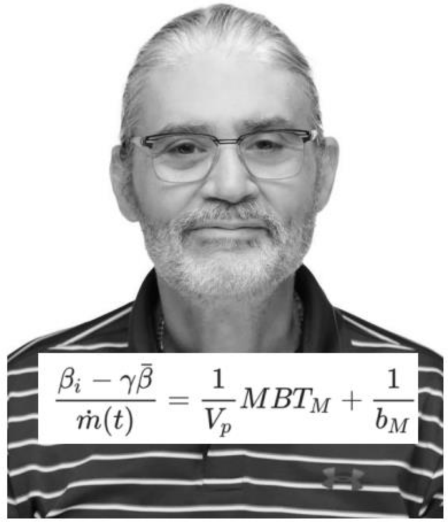
4

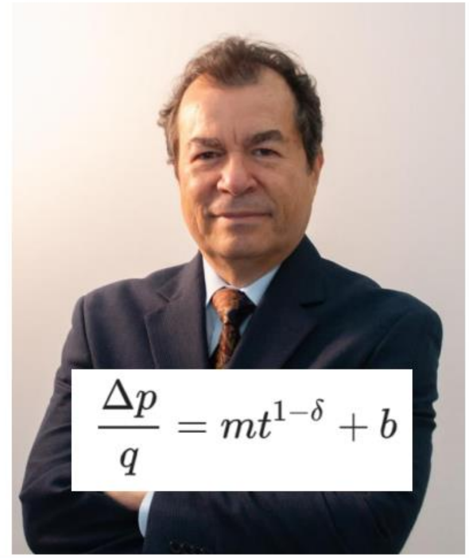


whitson

4 Comparison to Other Techniques





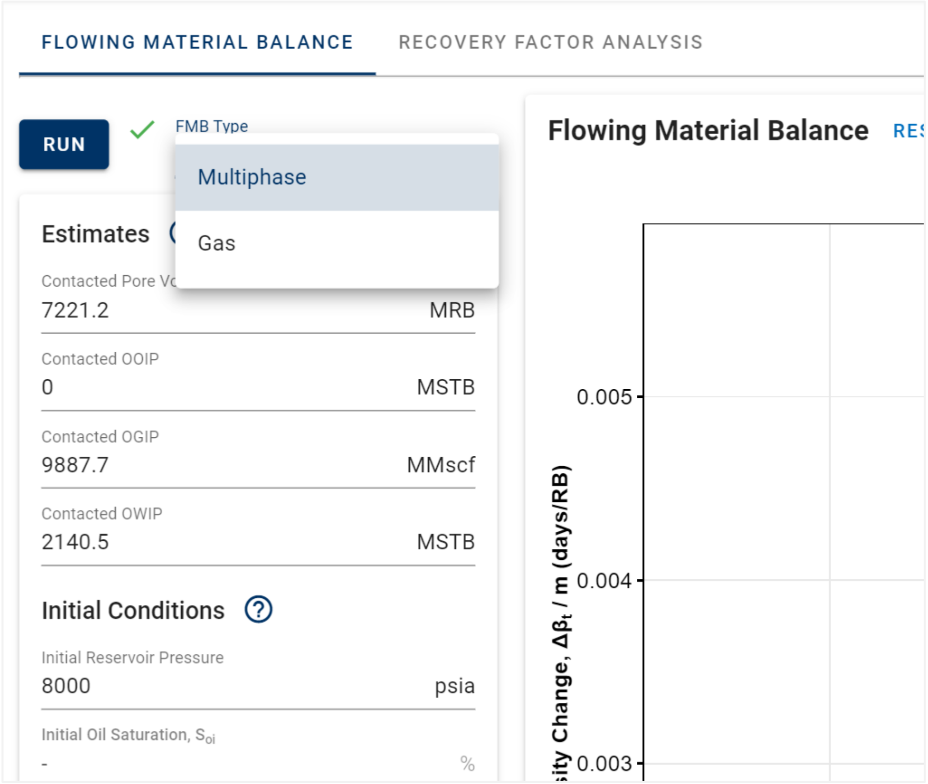


	Dynamic Fluid-in-Place (CFIP) SPE 217760 MS, 2024	Multiphase Flowing Material Balance URTeC 3854304, 2022	Fractal-Dimension RTA History-Matching URTeC 3718045, 2023
Pore Volume Reduction	**~37-38 %**	**~36-37 %**	**~35 %**

FAQ

What about Dry Gas FMB?

- You can still use the MFMB method for a dry gas
- That said, the "dry gas" (Agarwal) FMB is also in **whitson⁺**
- All concepts are the same.
  - There is one practical difference, i.e. that it's an iterative method
- I'll demo it for reference

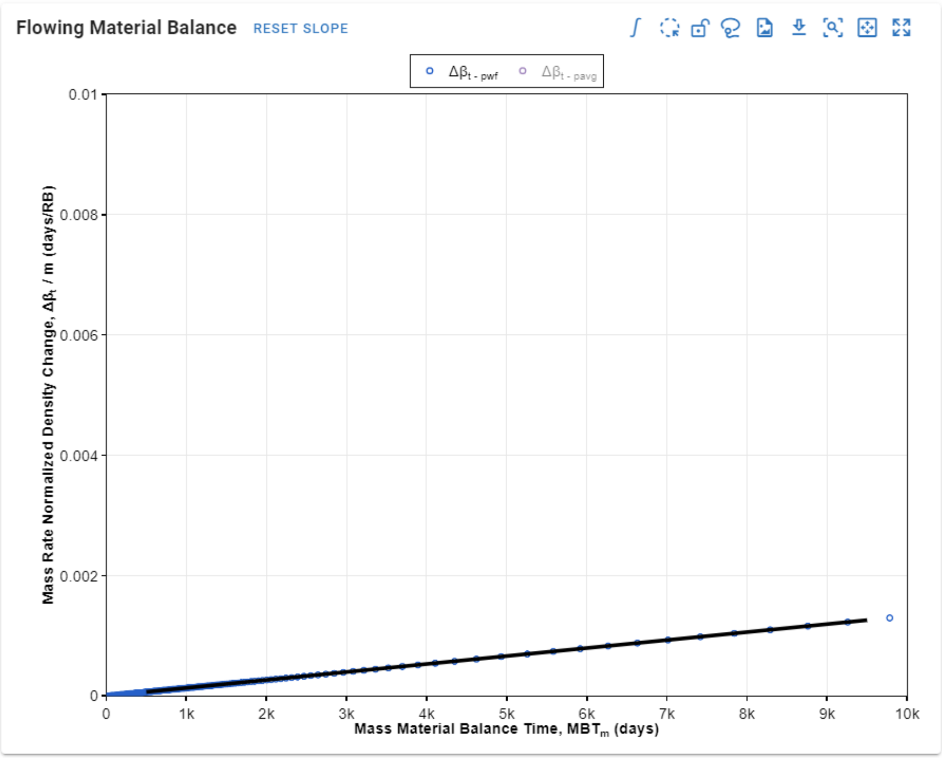


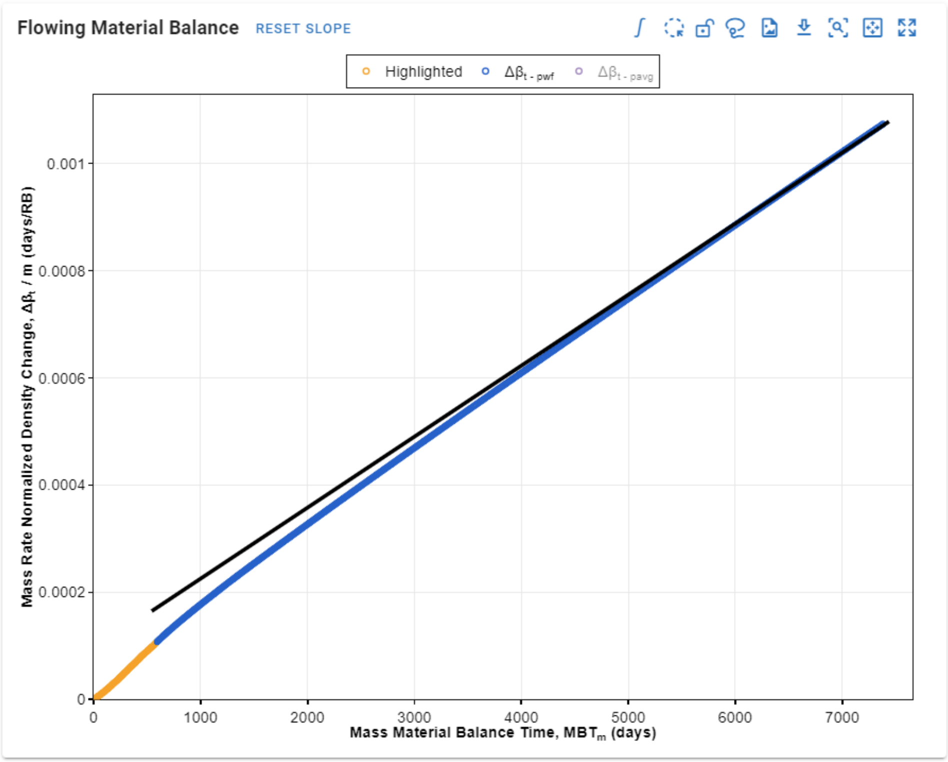
Effect of Pressure Dependent Permeability?

Effect of Pressure Dependent Permeability?

- Delays the time to reach boundary dominated flow

- Delays the time to see the correct contacted pore volume





Without Matrix Gamma

With Matrix Gamma

whitson

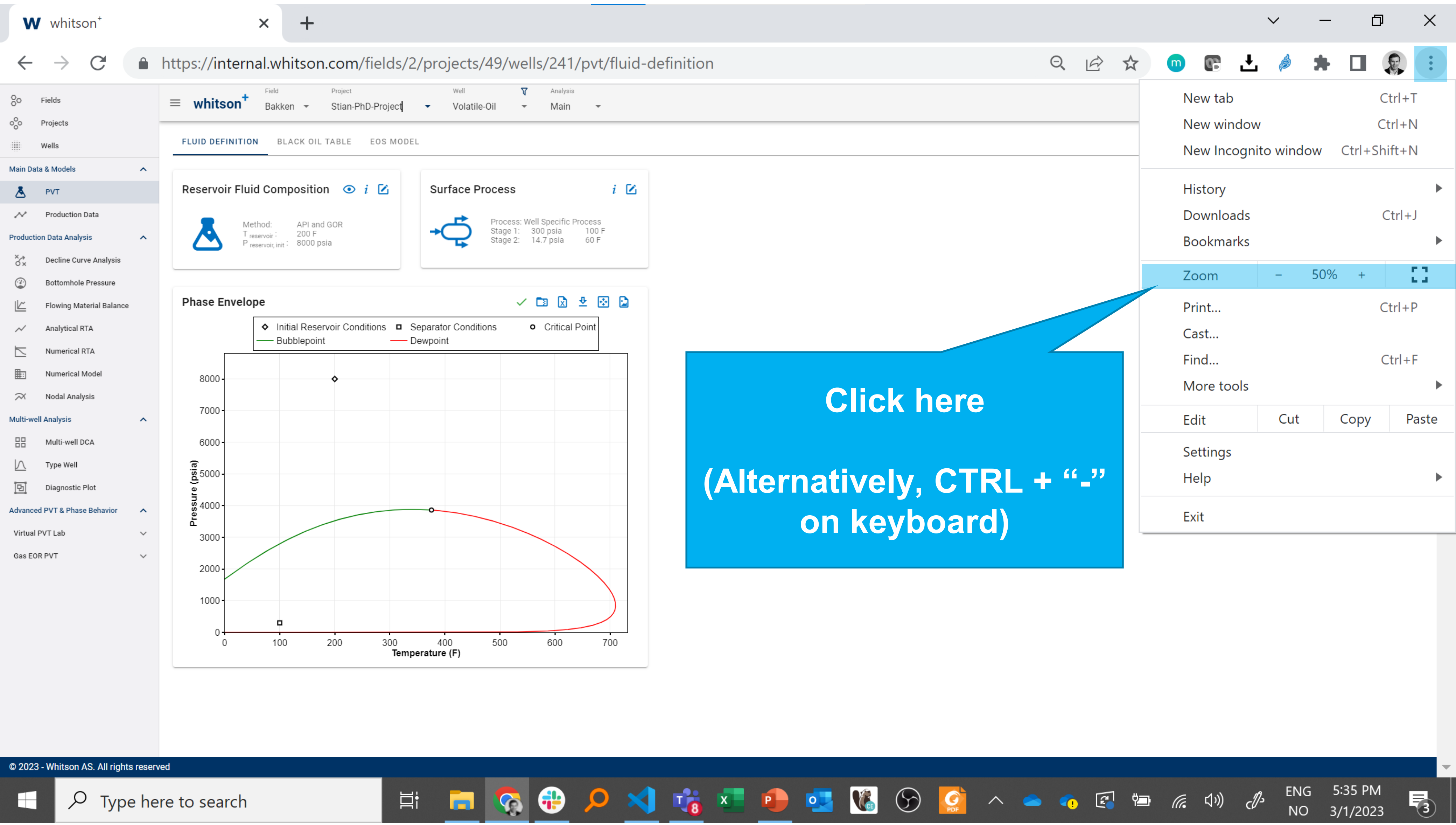
Effect of Pressure Dependent Permeability?

> **Why doesn't the multiphase FMB method require inputted pressure dependent permeability (if relevant)?**
>
> "All transport dependent terms (permeability, relative permeability, etc.) are built in to the rates. They never appear explicitly."
>
> Leslie Thompson

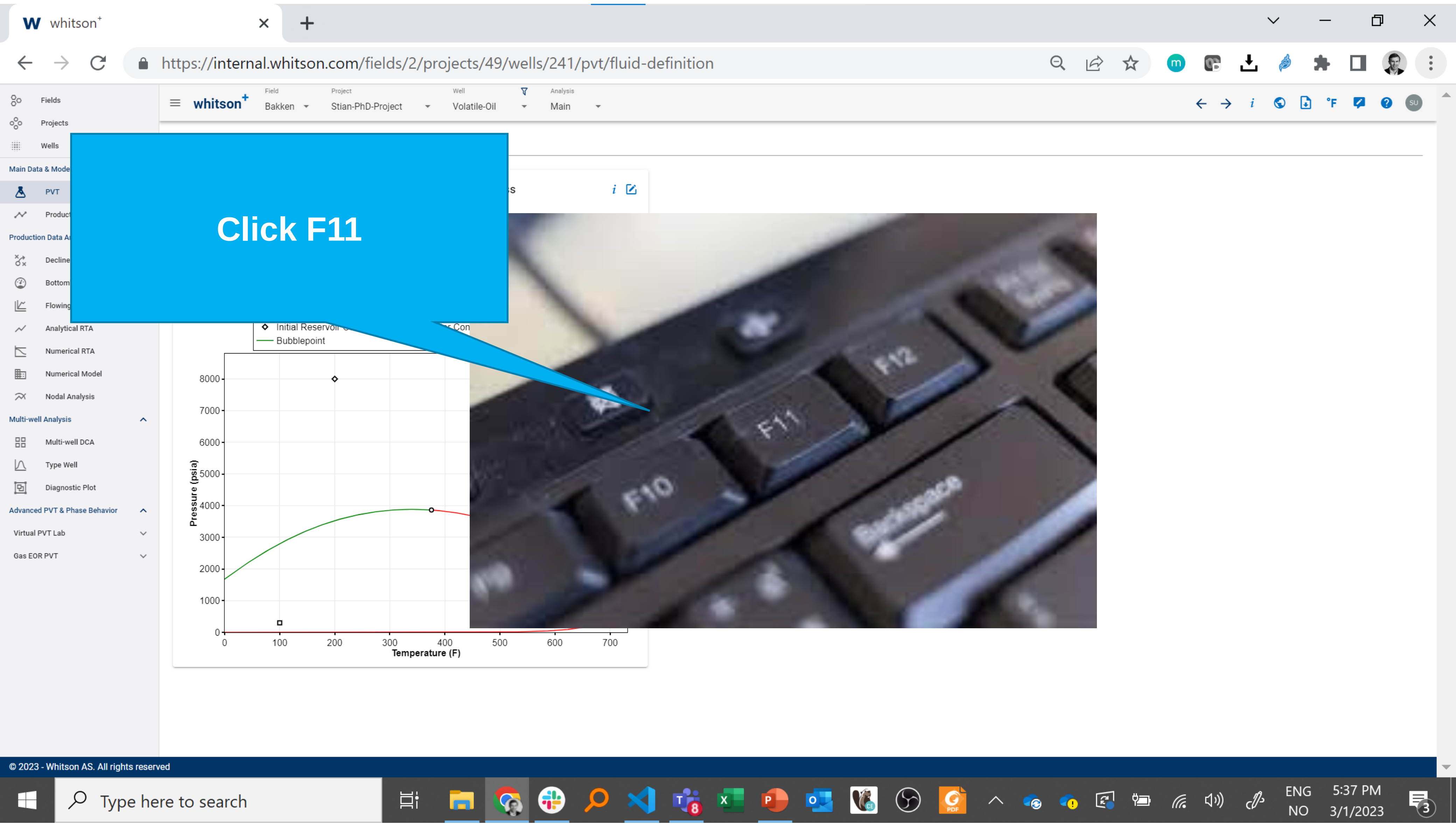
Exercises

Software Basics

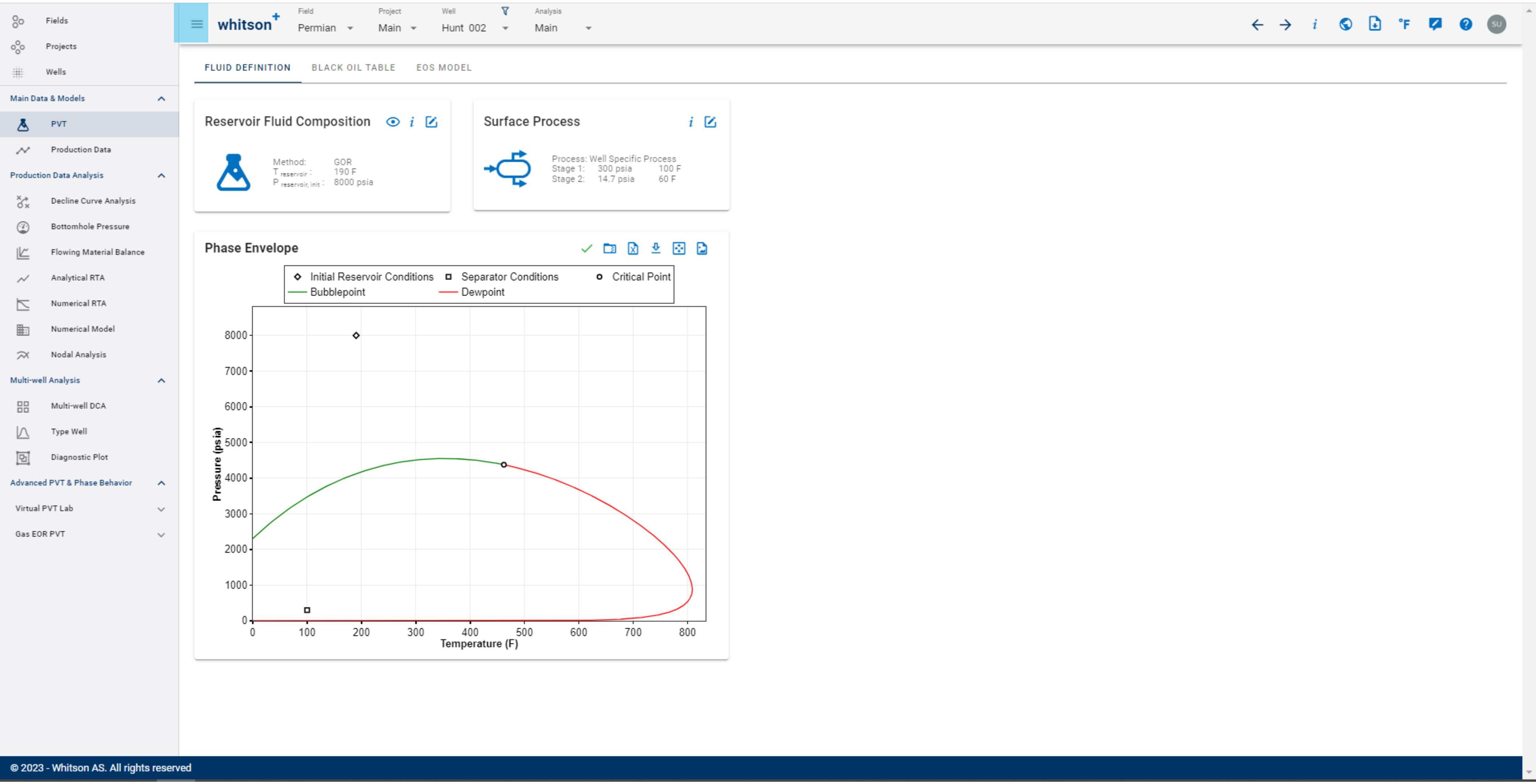
whitson+: Set Zoom to 70-80%



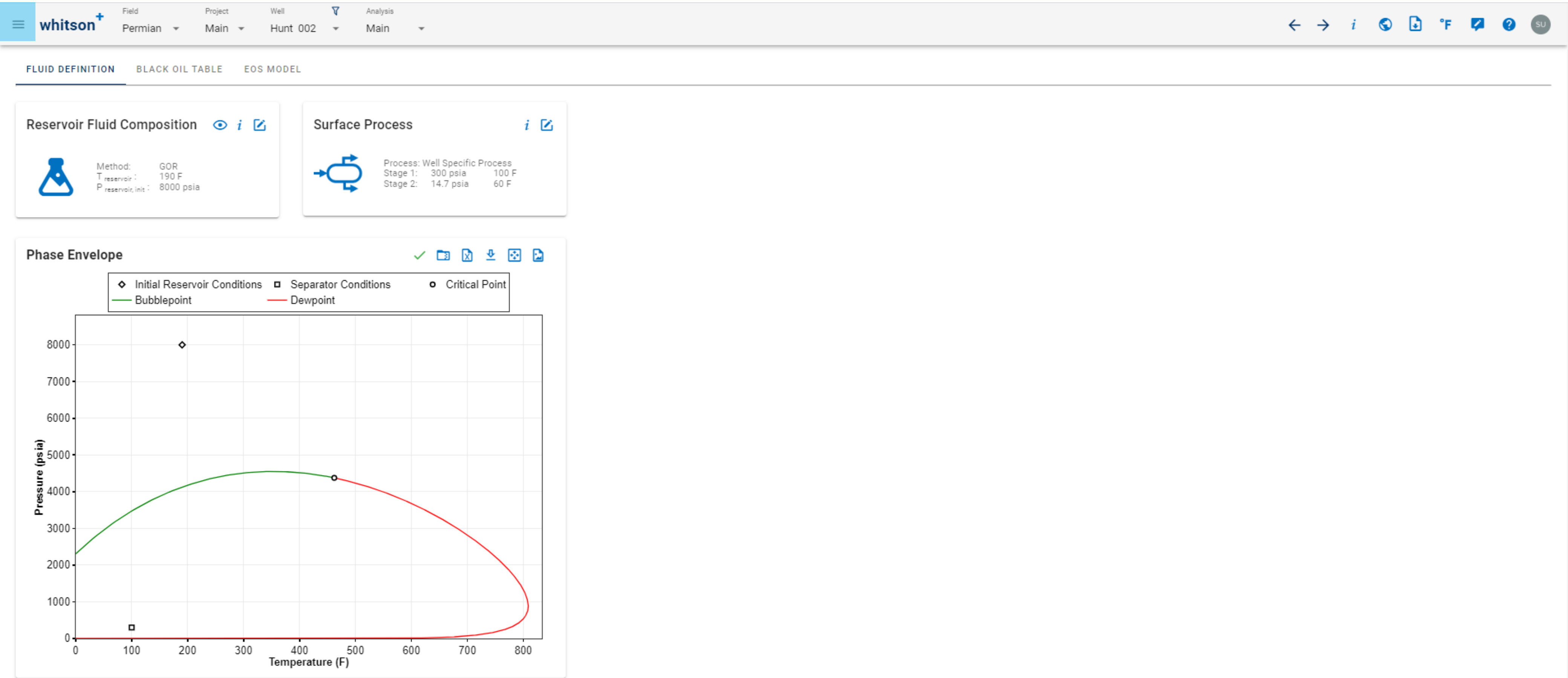
whitson+: Maximize Screen by “F11”



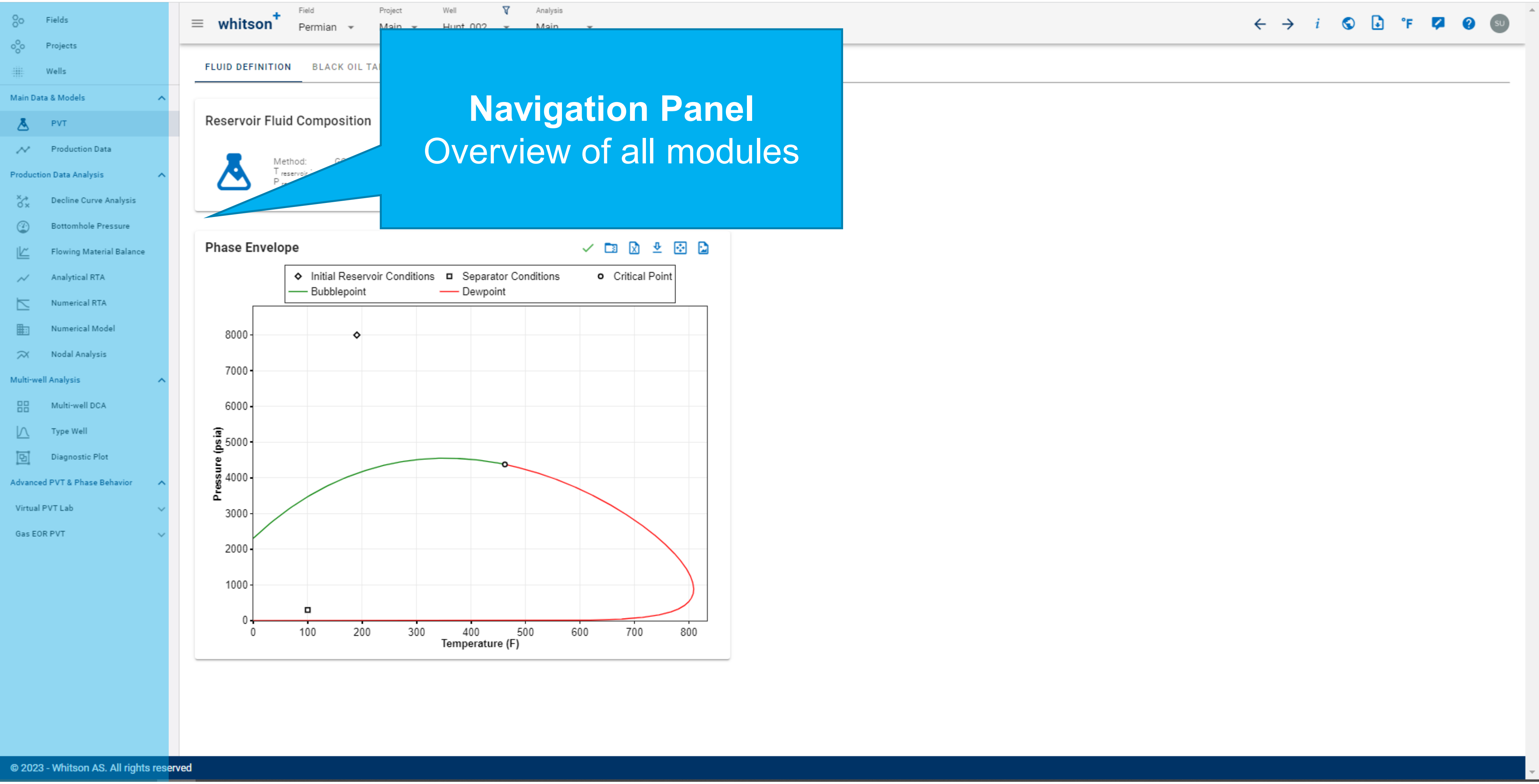
whitson+: More Screen Real Estate



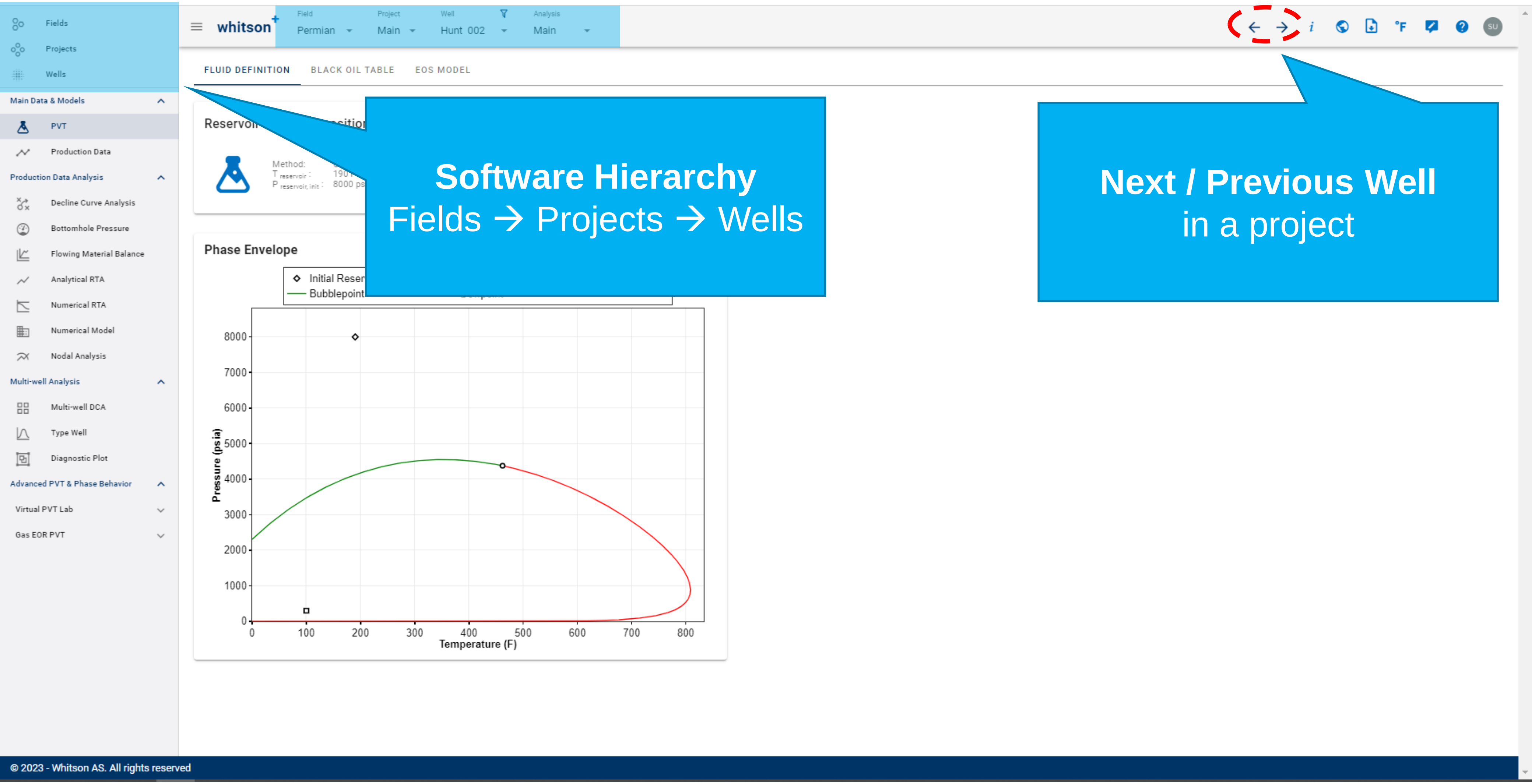
whitson⁺: More Screen Real Estate



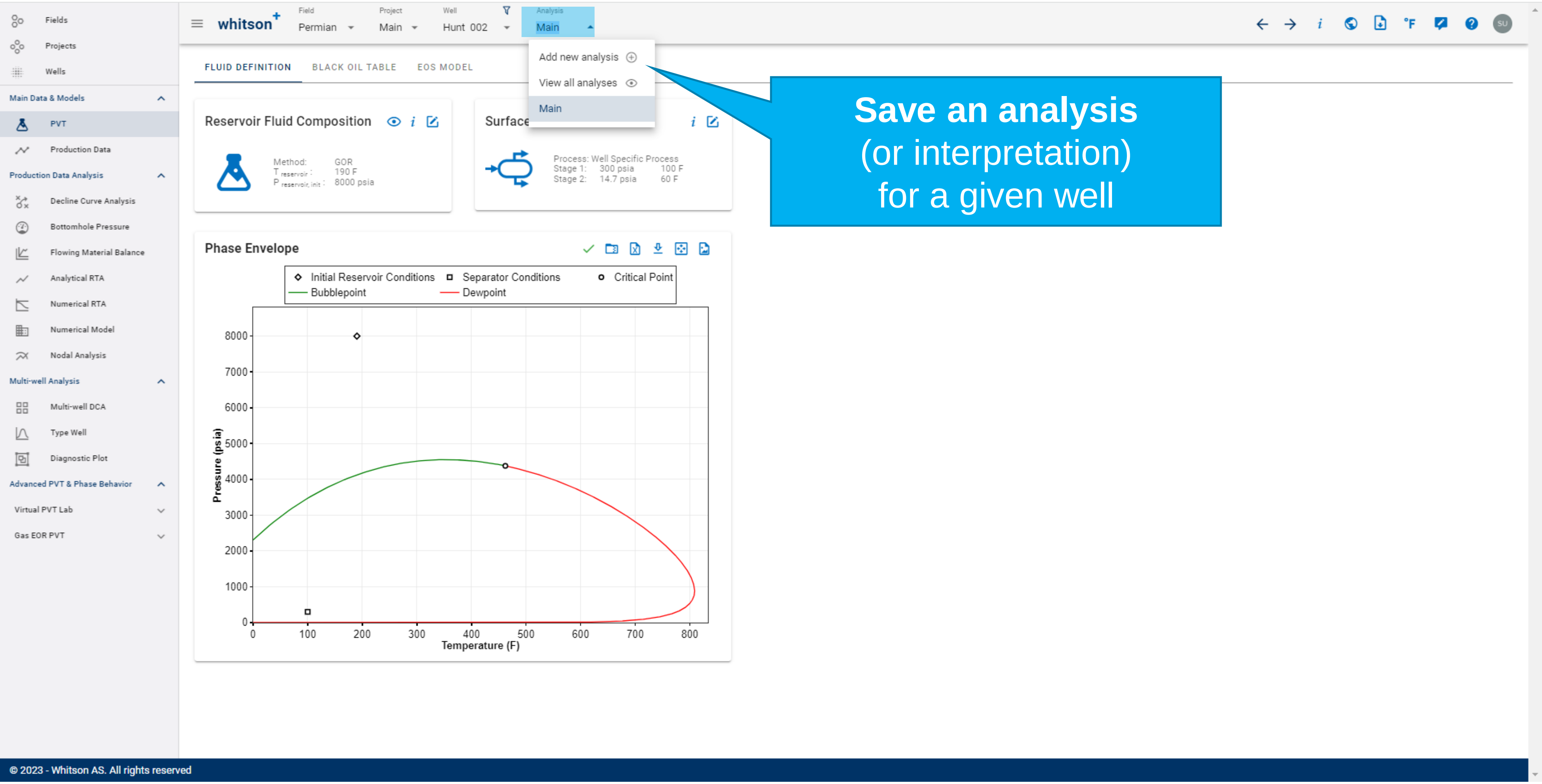
whitson⁺: Navigation Panel



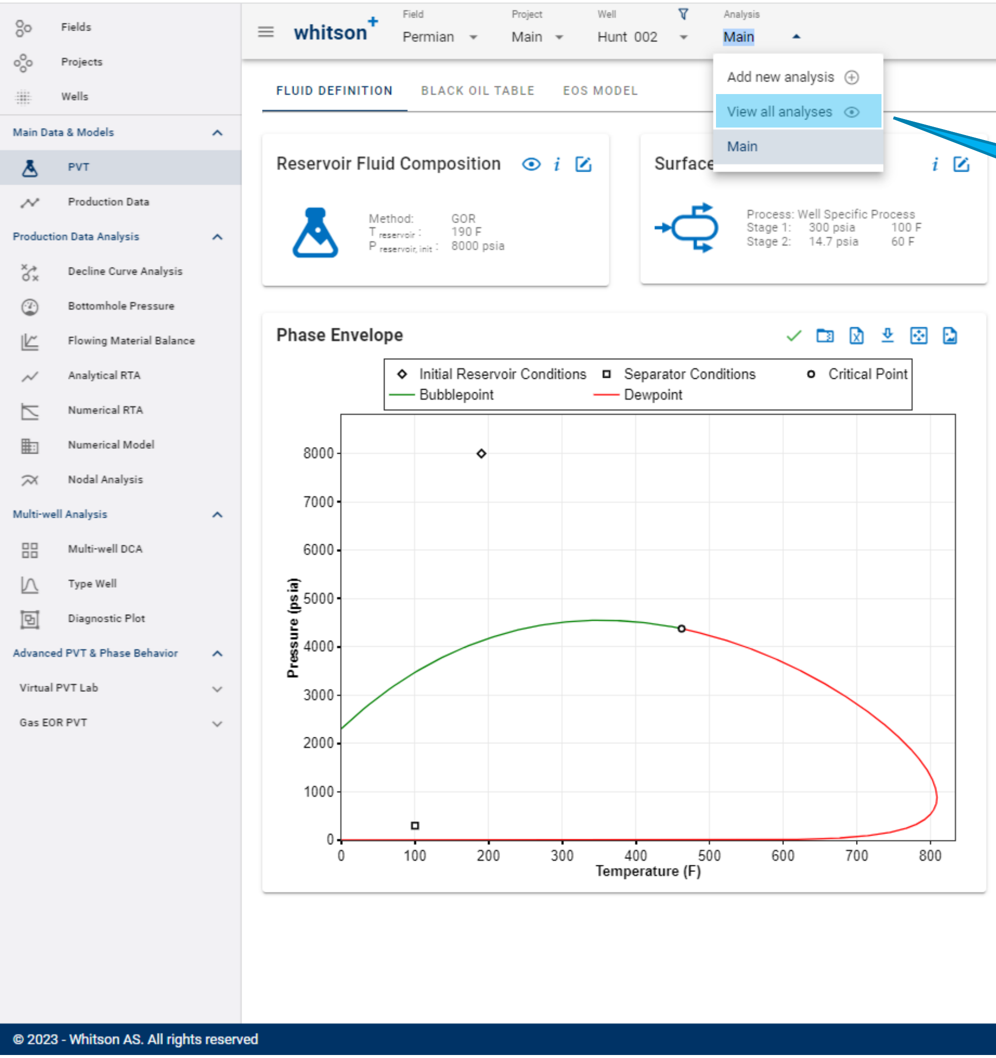
whitson+: Software Hierarchy



whitson⁺: Create Multiple Analyses for a Well

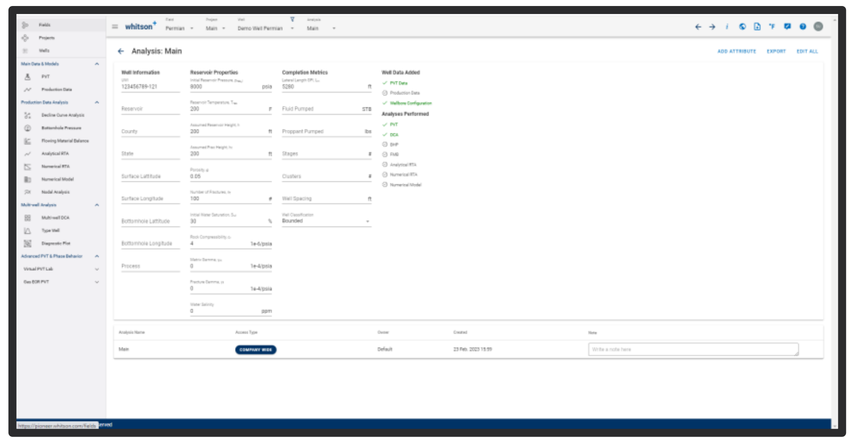


whitson+: Create Multiple Analyses for a Well

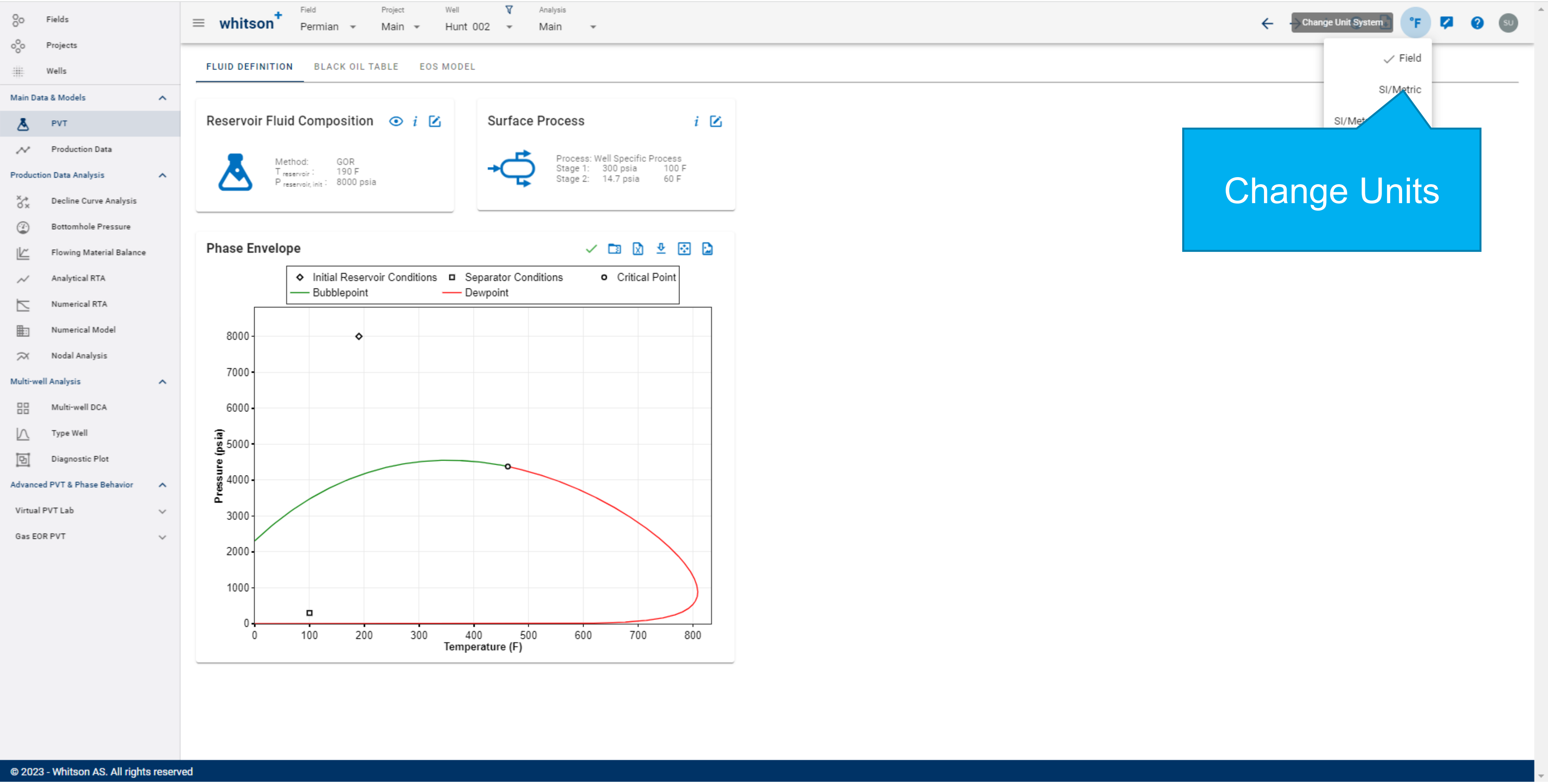


Click here and it will bring you to the well overview page

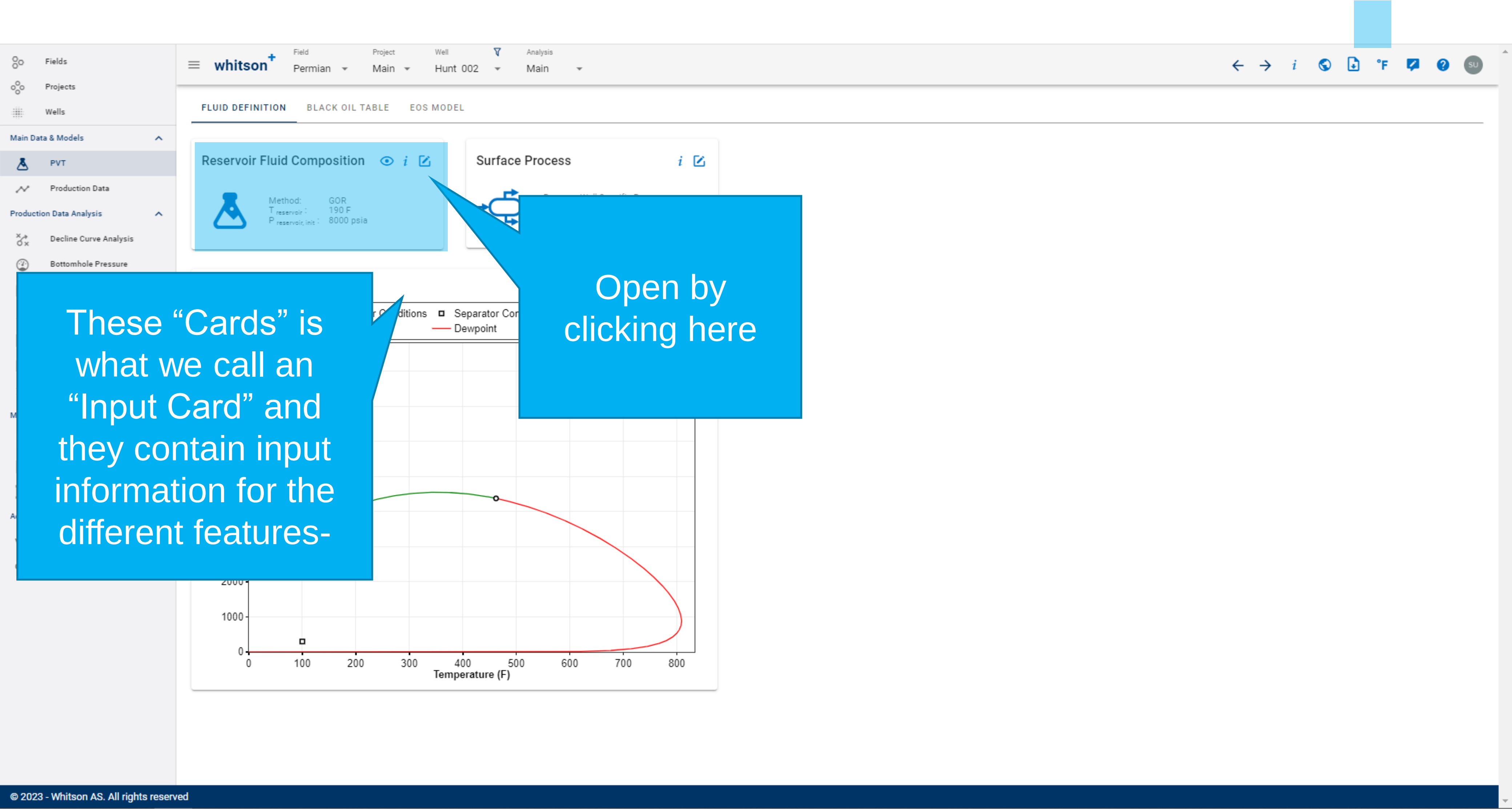
Well Overview page



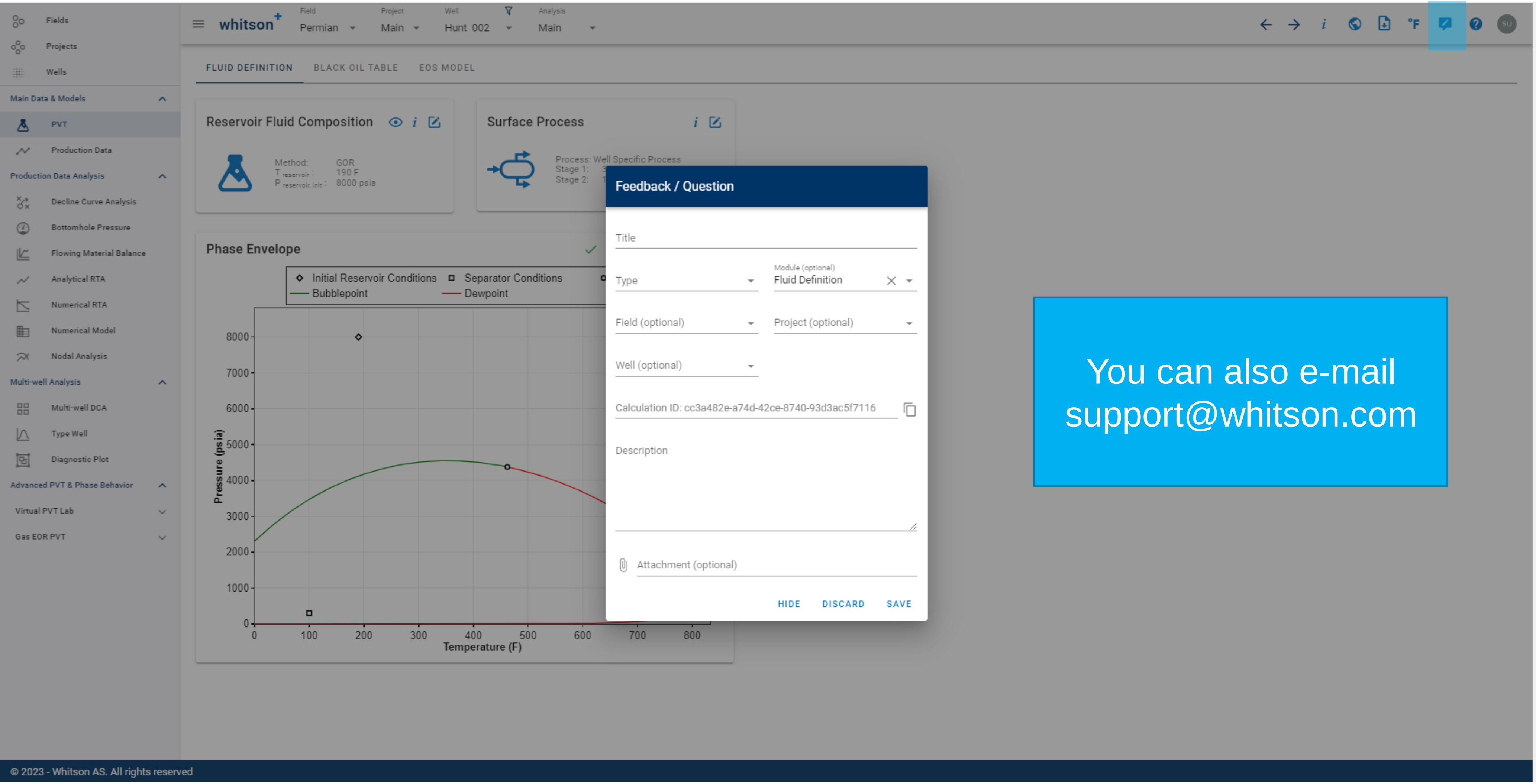
whitson+: Change Units



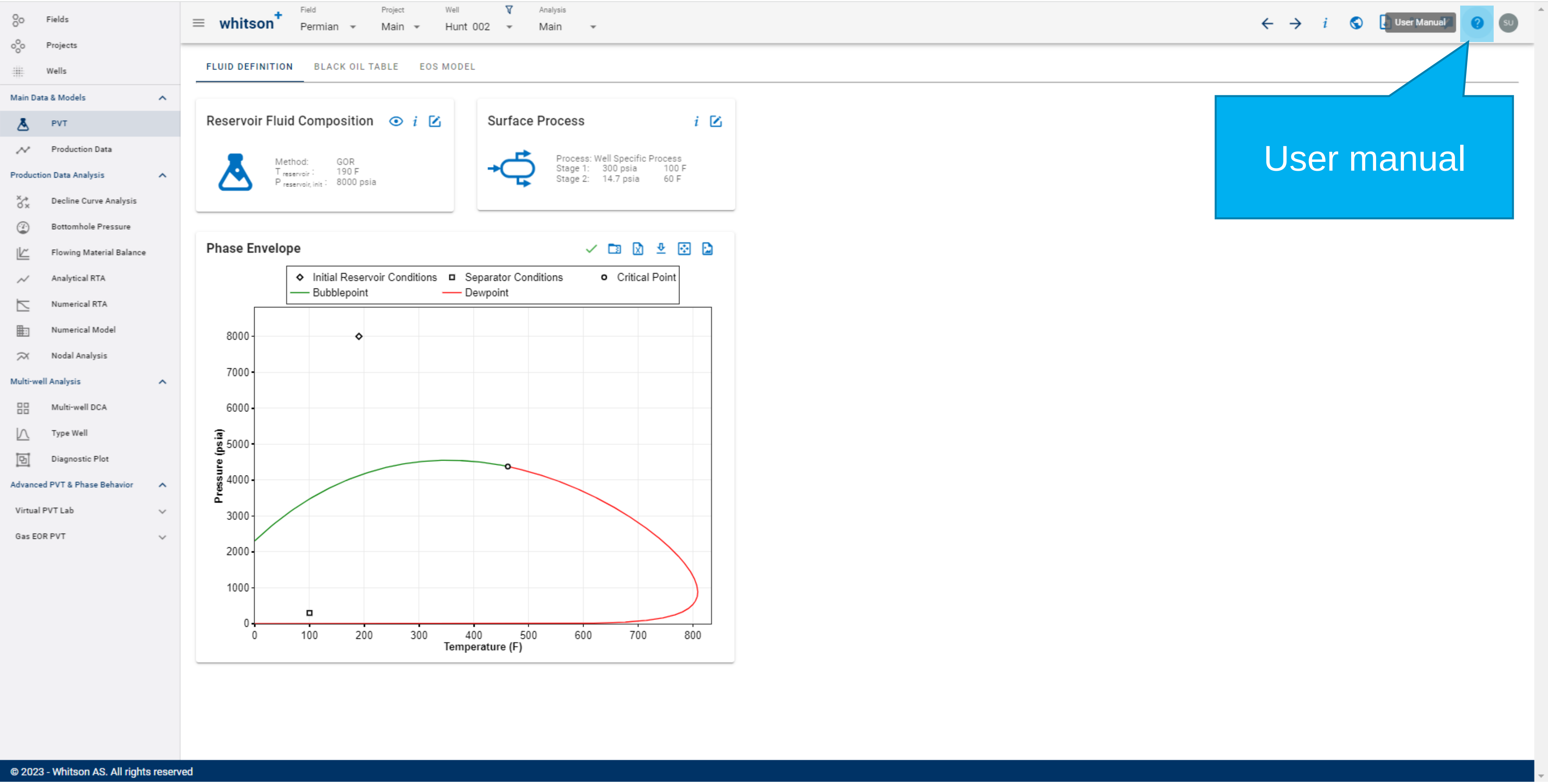
whitson⁺: Input Card



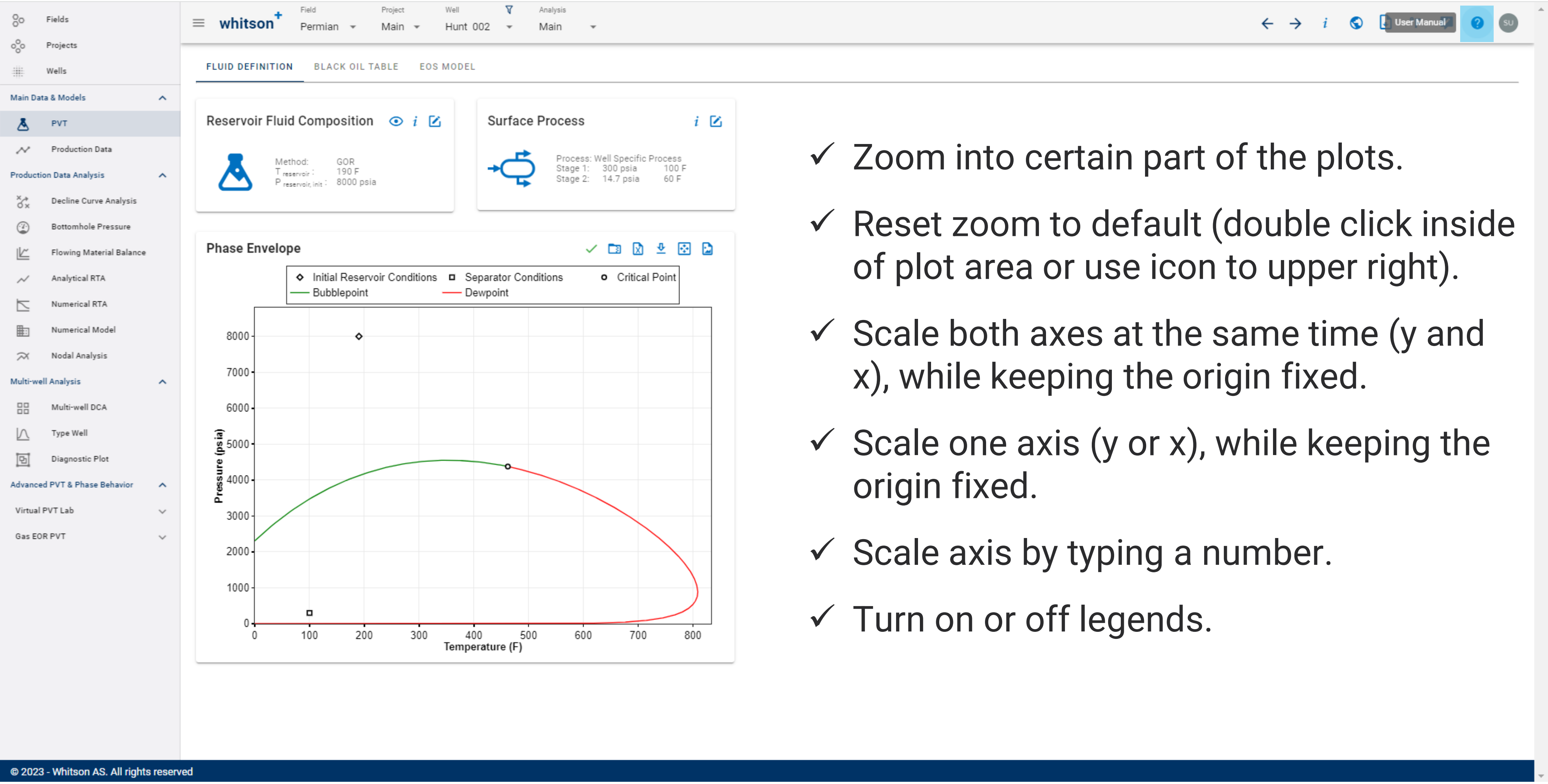
whitson+: Support Ticket



You can also e-mail support@whitson.com


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 reservoir : 190 F
P reservoir, init : 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
Pressure (psia)
Temperature (F)
User manual
© 2023 - Whitson AS. All rights reserved

whitson+: Zooming Plots



- ✓ Zoom into certain part of the plots.
- ✓ Reset zoom to default (double click inside of plot area or use icon to upper right).
- ✓ Scale both axes at the same time (y and x), while keeping the origin fixed.
- ✓ Scale one axis (y or x), while keeping the origin fixed.
- ✓ Scale axis by typing a number.
- ✓ Turn on or off legends.

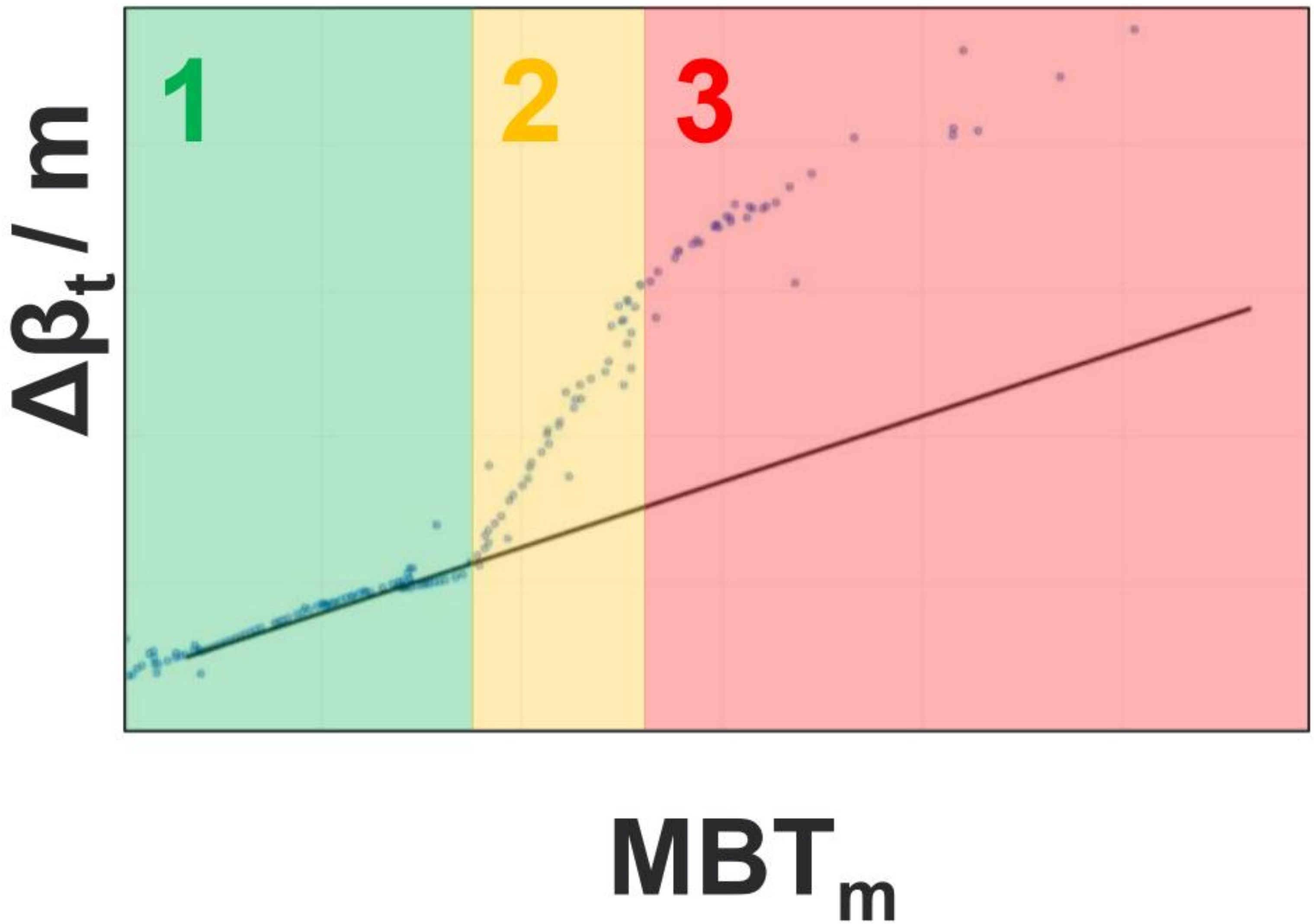
Important Shortcut: Refresh

- Refresh shortcut: “CTRL + R”

- Use if you experience
  - Bad connection
  - The browser is “stuck”

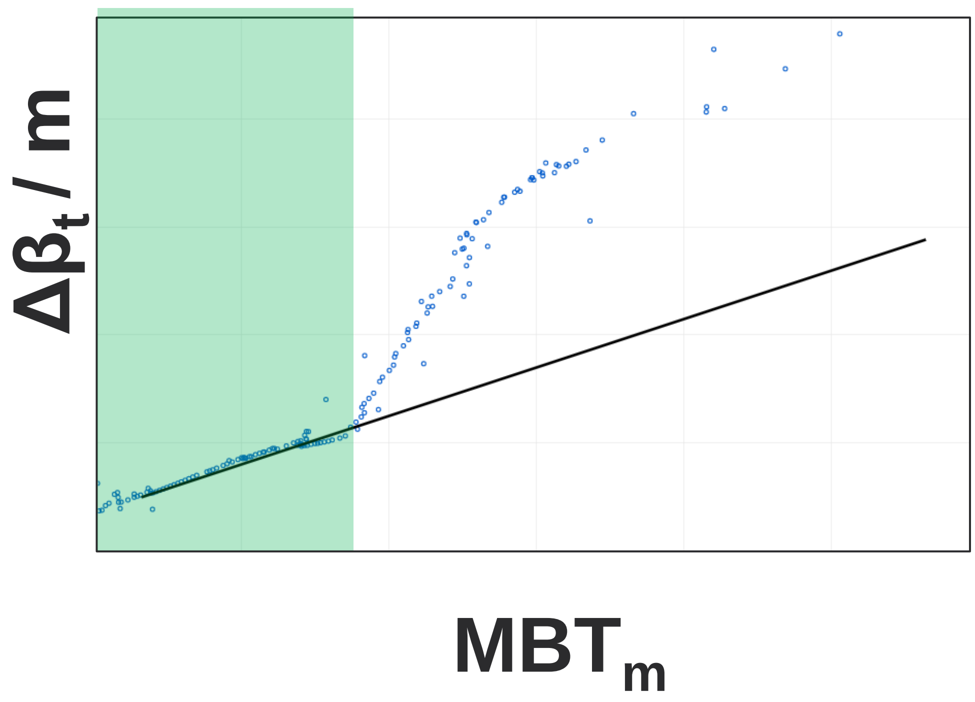
REMINDER

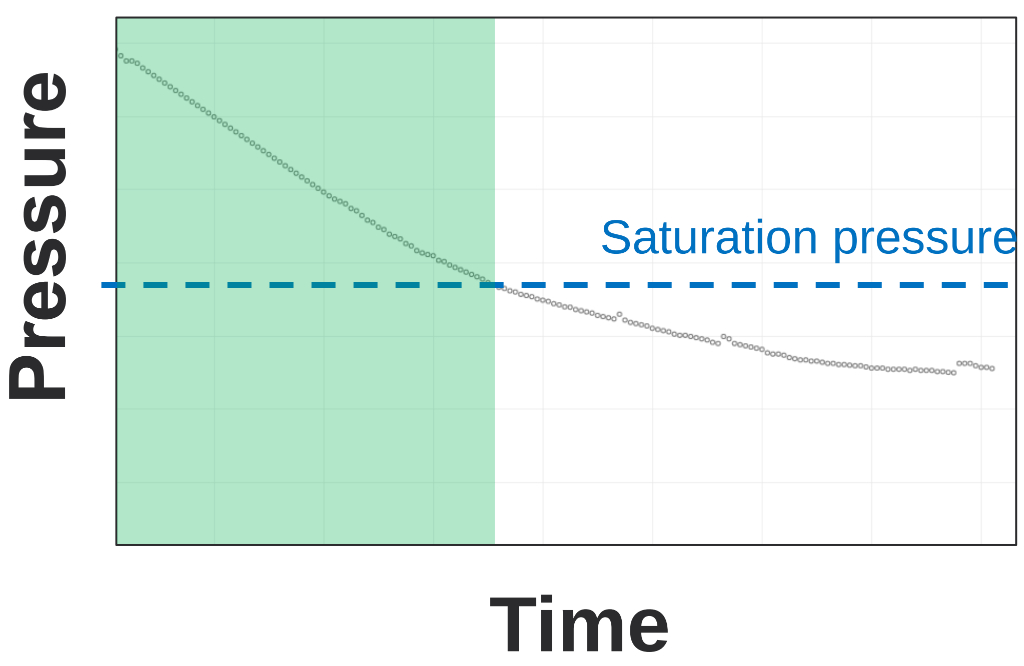
MFMB Plot – Three Key Periods



Multiphase FMB – Three Key Periods

Period 1: While $p_{wf} > p_{sat}$ (“single-phase flow”)

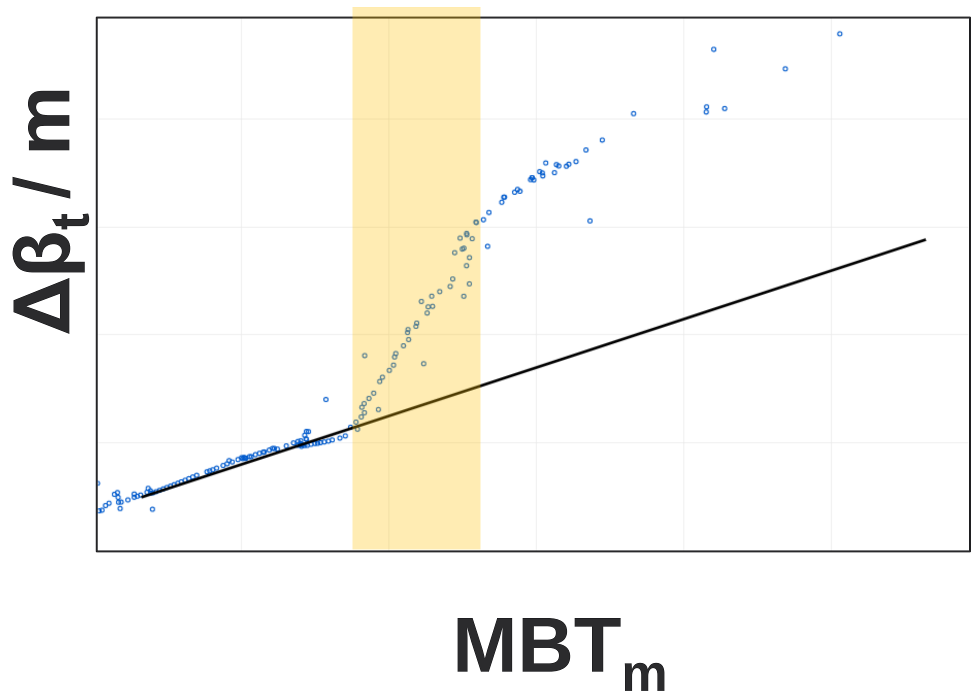


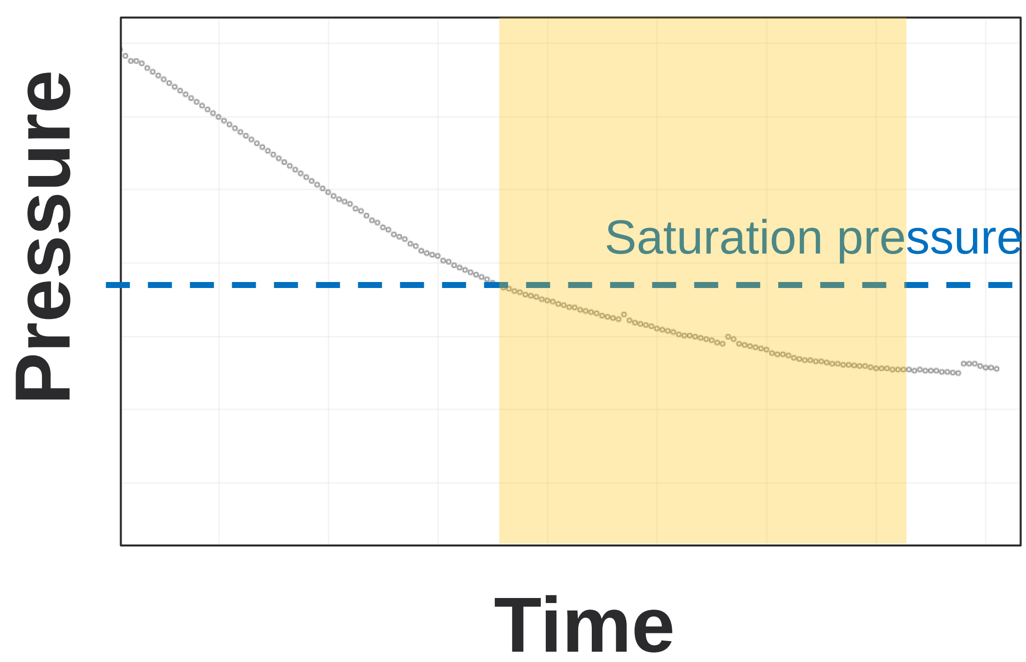


whitson

Multiphase FMB – Three Key Periods

Period 2: Transition period due to multiphase flow effects (gas enters the system, and gas is more compressible)



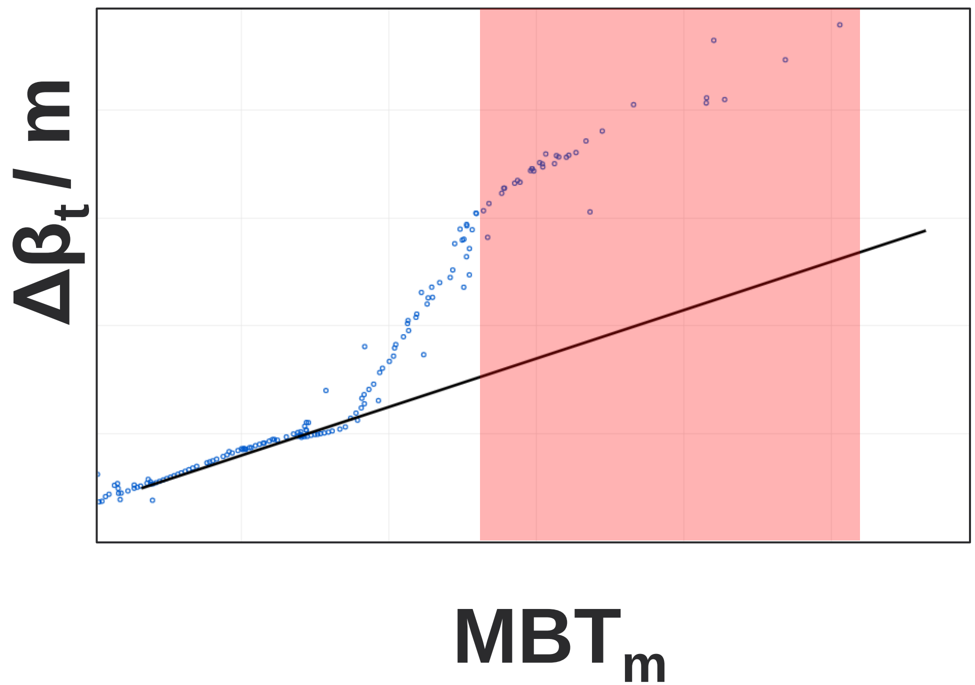


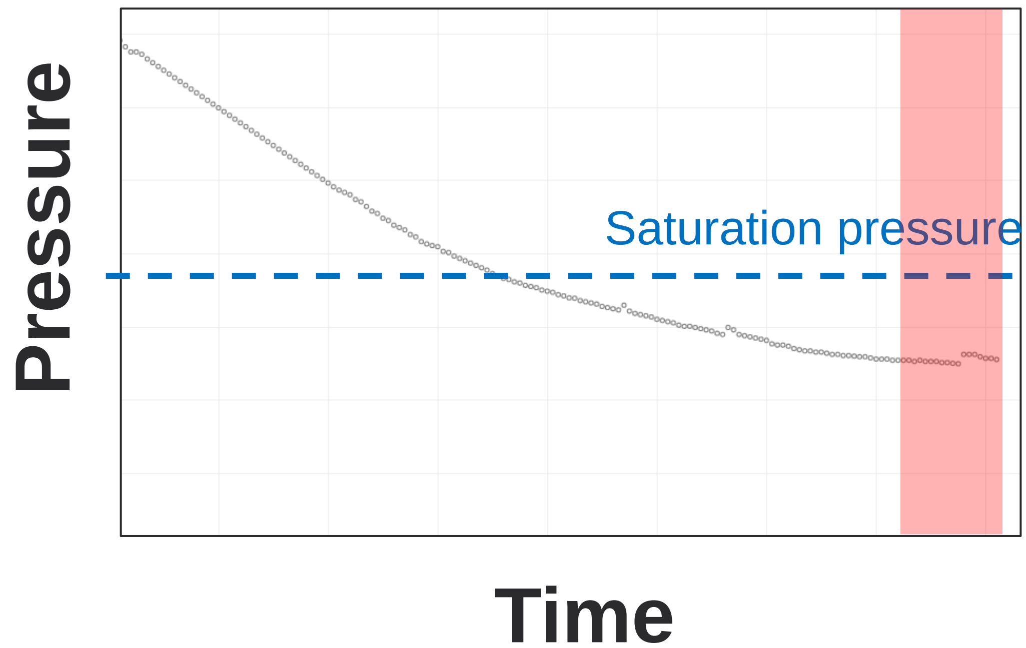
whitson

REMINDER

Multiphase FMB – Three Key Periods

Period 3: Second stabilized slope



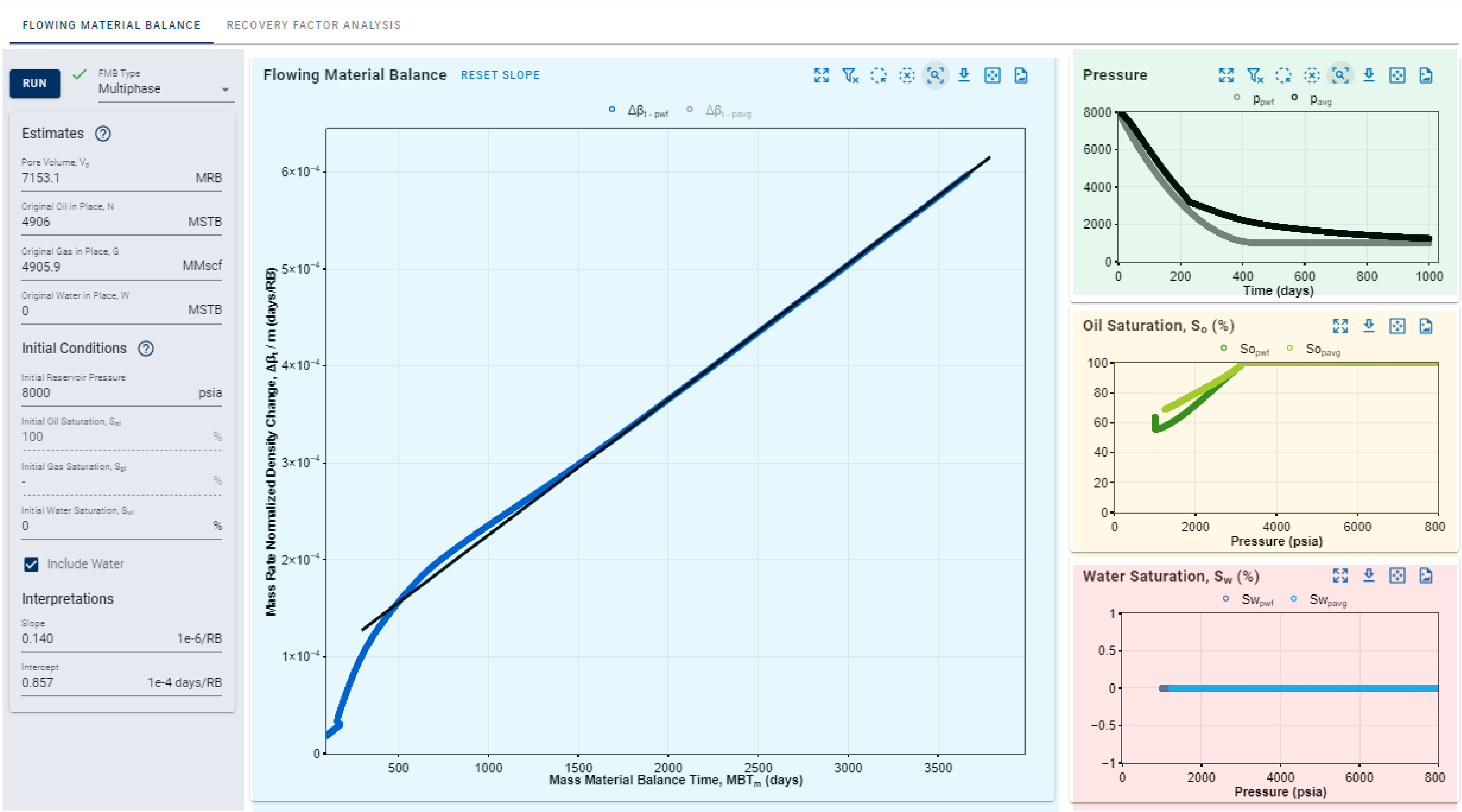


whitson

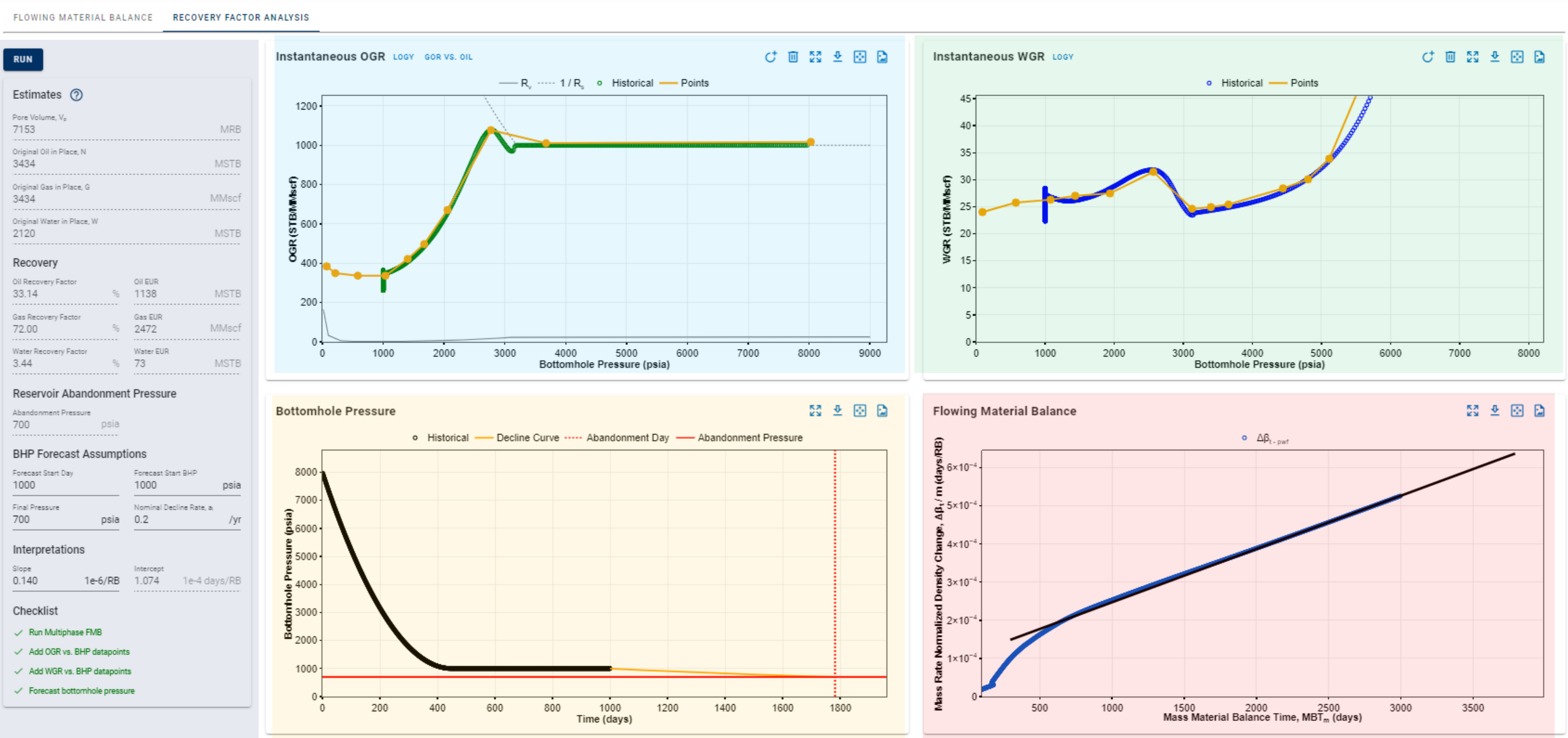
Practice

Multiphase FMB & Recovery Factors in whitson$^+$

Multiphase FMB



RF Analysis in whitson+



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	Asia-Pacific	Middle East	Americas
Curtis Hays Whitson, PhD	Kameshwar Singh, PhD	Ahmad Alavian, PhD	Mathias Carlsen, MSc
curtishays@whitson.com	singh@whitson.com	alavian@whitson.com	carlsen@whitson.com

Whitson AS	Whitson USA LLC
Skonnertvegen 7, 7053	3410 W Dallas St.
Trondheim, Norway	Houston, TX 77019, US

www.whitson.com