Horizontal Fractured Wells

Flowback and Initial Production Analysis
Minimum Frac Volumes
Likely Recoverable Oil/Gas
Gas Lift Calculations/Optimization
Benefits of Tubing/Annulus DHPGs

Outline

- What Does ODSI Do? Where'd this come from?
- What Makes this so friggin' special? Huh?
  - ODSI's 3-phase wellbore model

- Min/Max Recoverable Oil Example
- Gas Lift Example
- Additional Calculations with DHPG
- Additional Calc's with DHPG (Tubing & Annulus)

Possible Instrumentation Configurations

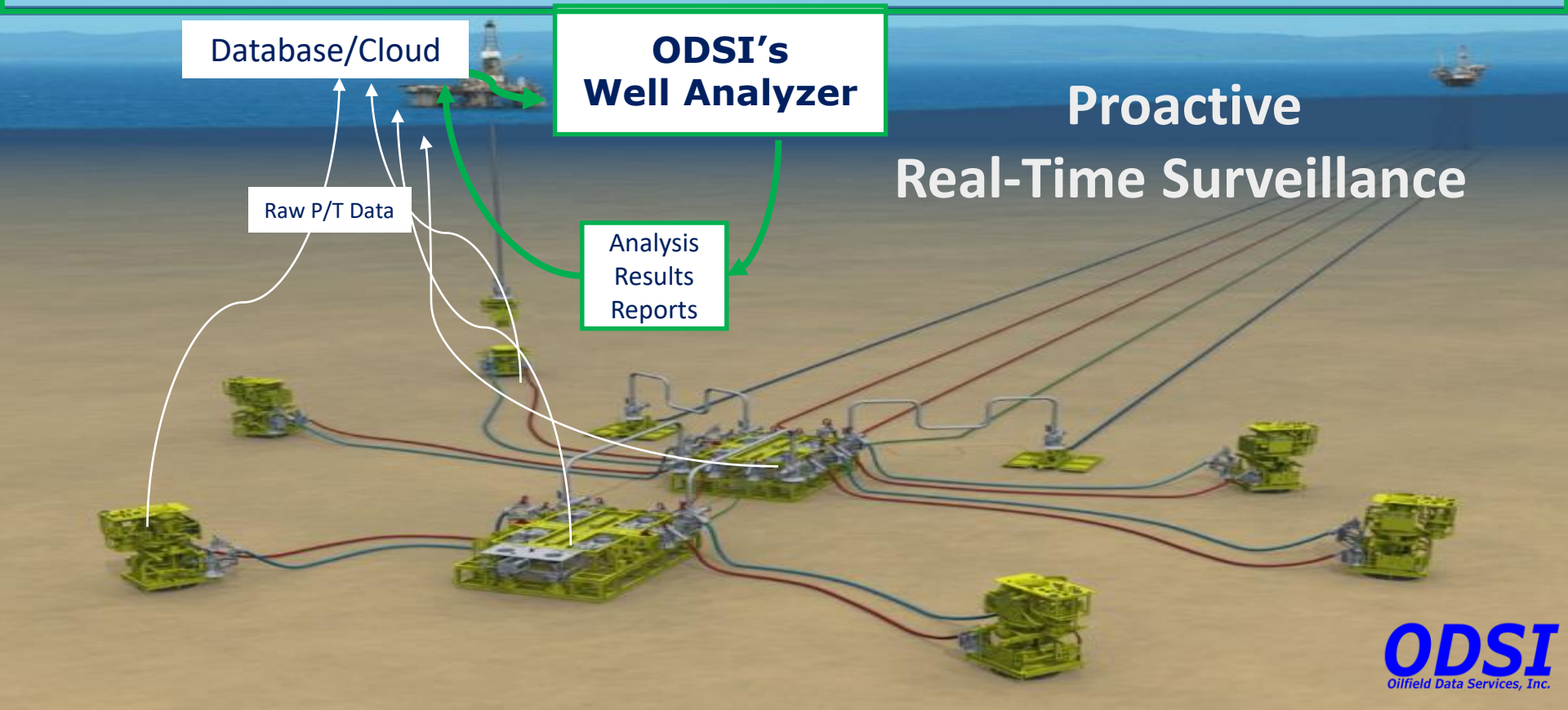
- WHP Gauge, Flow Rates & GLG Rates
- WHP Gauge, DHPG & GLG Rates
- WHP Gauge & DHPG (Tubing & Annulus)

Wellbore Solutions

- **Rate Calculation/Validation**
  - Multiphase Rate Calculation
  - Metered rate validation
  - Detects errors in allocation/meter calibration
  - Backup if MPFM fails
- **BHP Conversion**
  - From tree or DHGP data
  - Backup if PDHG fails

Reservoir Solutions

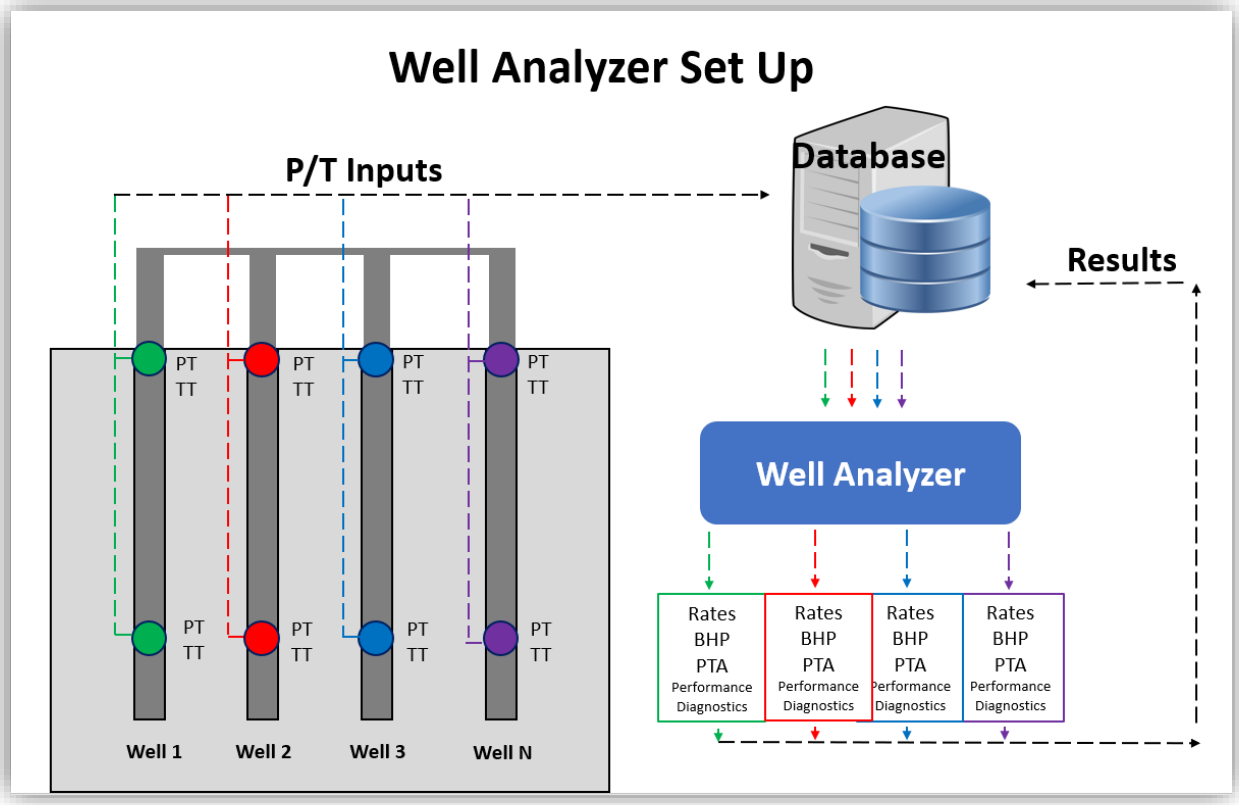
- **GL rate Calculation/Optimization**
  - Inefficient Lift and Loading Flags
- **Auto PTA (Buildups and Drawdowns)**
  - Skin
  - Permeability
  - Reservoir Pressure
  - Productivity (PI)
- **Reservoir Volume Calculations**
  - In-place, Hydraulically Connected and Mobile HC Volume



Well Analyzer - Real-Time Set Up

Well Analyzer works both in Real-Time and on Historic data

It polls the required data tags from the client's database/historian, performs the calculations, validates the results and writes them back to the database



Well Analyzer Wellbore Model

- The only existing software based on a direct numerical integration to the Mechanical Energy Balance (MEB) eq.
  - Does not rely on correlations (uses Peng-Robinson EOS)
  - Provides **more accurate** and **reliable results**
  - **Works for 3-phase + gas lift**
- The wellbore model
  - Accounts for dynamic temperature behavior
  - Adjusts the fluid properties accordingly
  - Performs wellbore flash calculations to determine the composition of the fluid in the wellbore
    - Changing GOR?
    - Changing Yo?
    - Changing WC?

"It is a capital mistake to theorize before one has data. Insensibly one begins to twist facts to suit theories, instead of theories to suit facts."

Sir Arthur Conan Doyle, Author of Sherlock Holmes stories

Well Analyzer Real-Time Features

- ODSI's Rate Calculations
  - More accurate than MPFM for multiphase flow
  - Self-calibrating & Independent
  - Backup if MPFM fails
- Mid-completion or "sweet spot" BHP
  - Mid-perf BHP from surface data
  - Backup if PDHG fails
- Auto PTA (Buildups and Drawdowns)
  - Skin
  - Permeability
  - Avg.P_{res}/P*
  - Productivity Index (PI)

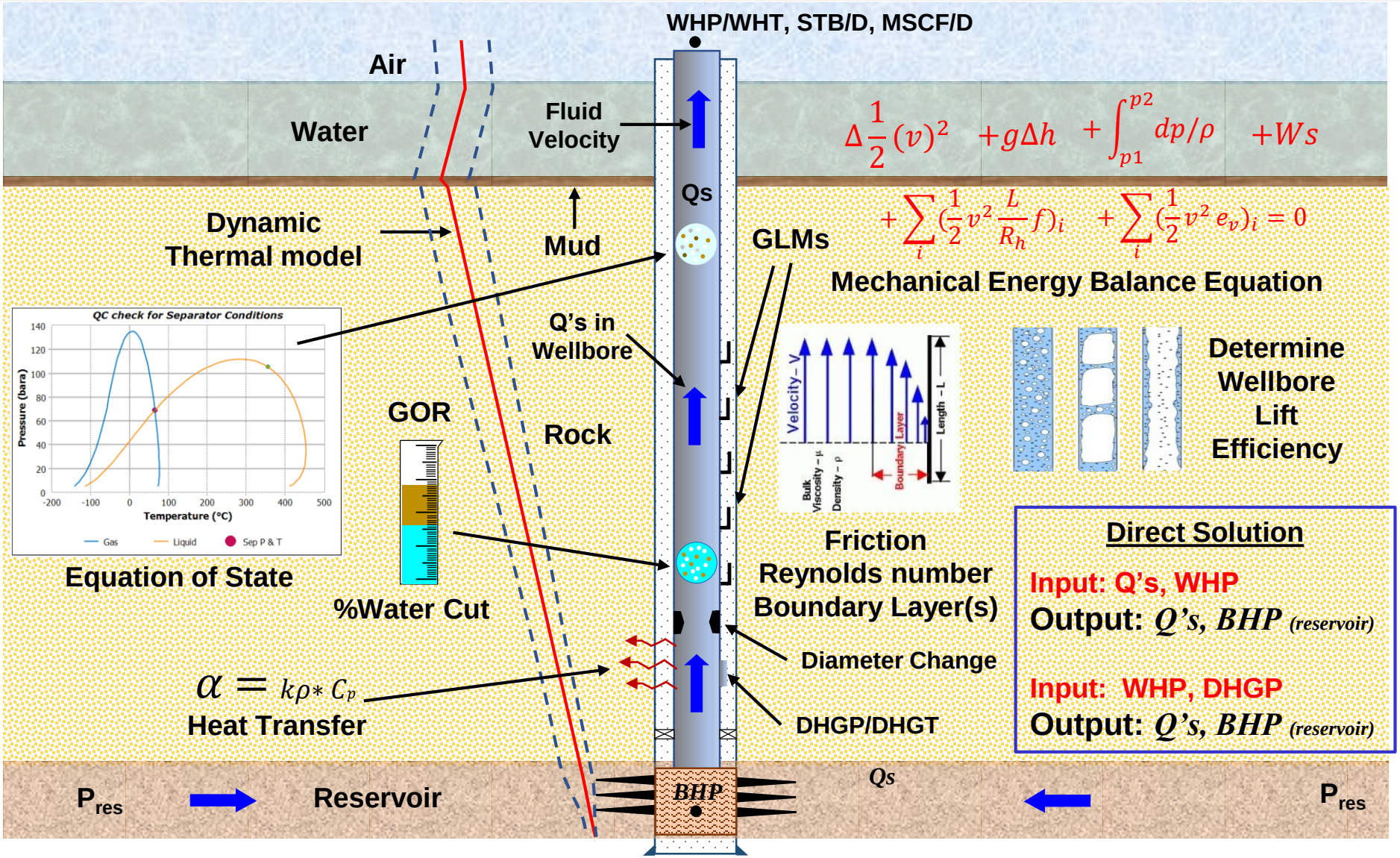
Well Analyzer Real-Time Features

- Continuous Observed HC Volume calculations
  - How much of the apparent reservoir volume is:
    - Hydrocarbons?
    - Water?
    - How much is due to formation compression/compaction?
    - How much of the total volume is connected to the well?
    - How much of the total volume is actually mobile (recoverable)?
    - How much is likely to be produced?
- Accurate and fast results updated in real-time
- Proactive surveillance on a well's performance and changes in the apparent volumes with time

ODSI's 3-Phase flow model (Wellbore Physics + Good PVT)

- Developed on high rate wells in the North & Norwegian Sea in 2017
- Applied to Frac Flowbacks with shockingly good results
  - **Accurate BHPs!!!**
- With Accurate BHPs (and modeled rates), most Frac Flowbacks can be analyzed for **minimum recoverable oil volume**
- Usually, the first 6 weeks of a well's production life can be analyzed to determine the **total likely recoverable oil volume**

ODSI's Wellbore Solution, 1, 2, & 3-Phase

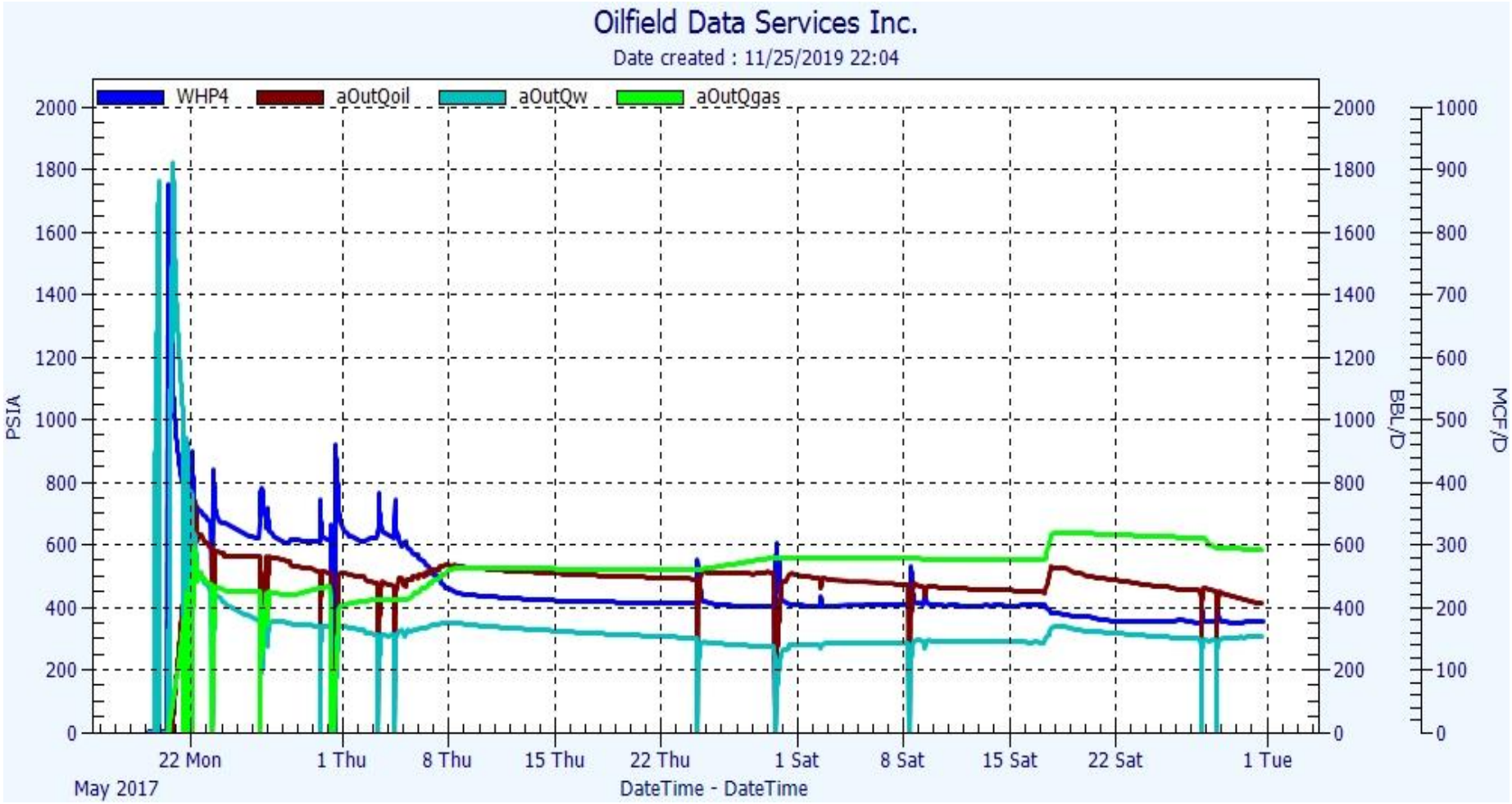


Frac'd Horizontal Example

BHP Conversion

Min & Max Oil Recovery

Frac'd Horizontal Example - Inputs



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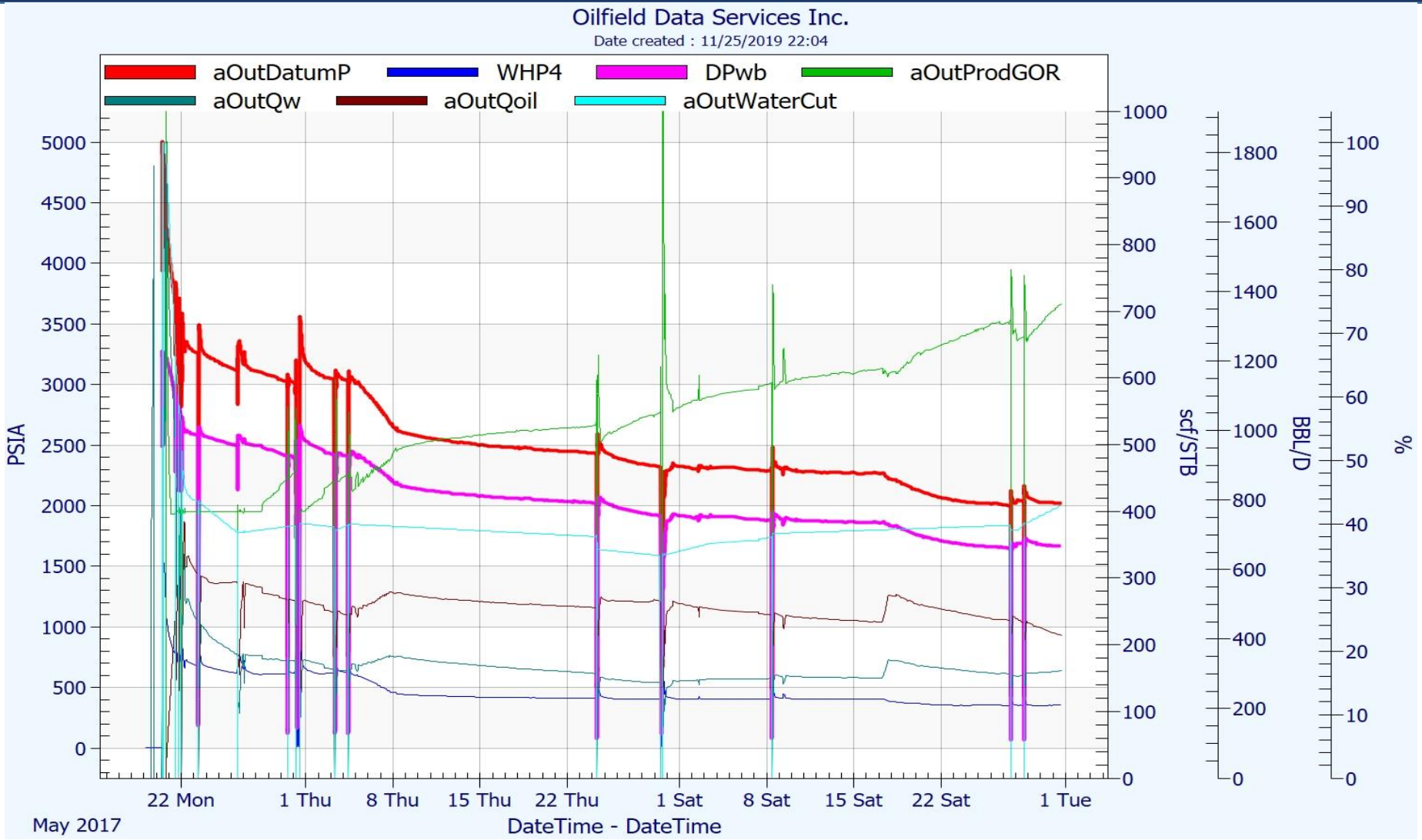
Frac'd Horizontal Example – Calc BHP



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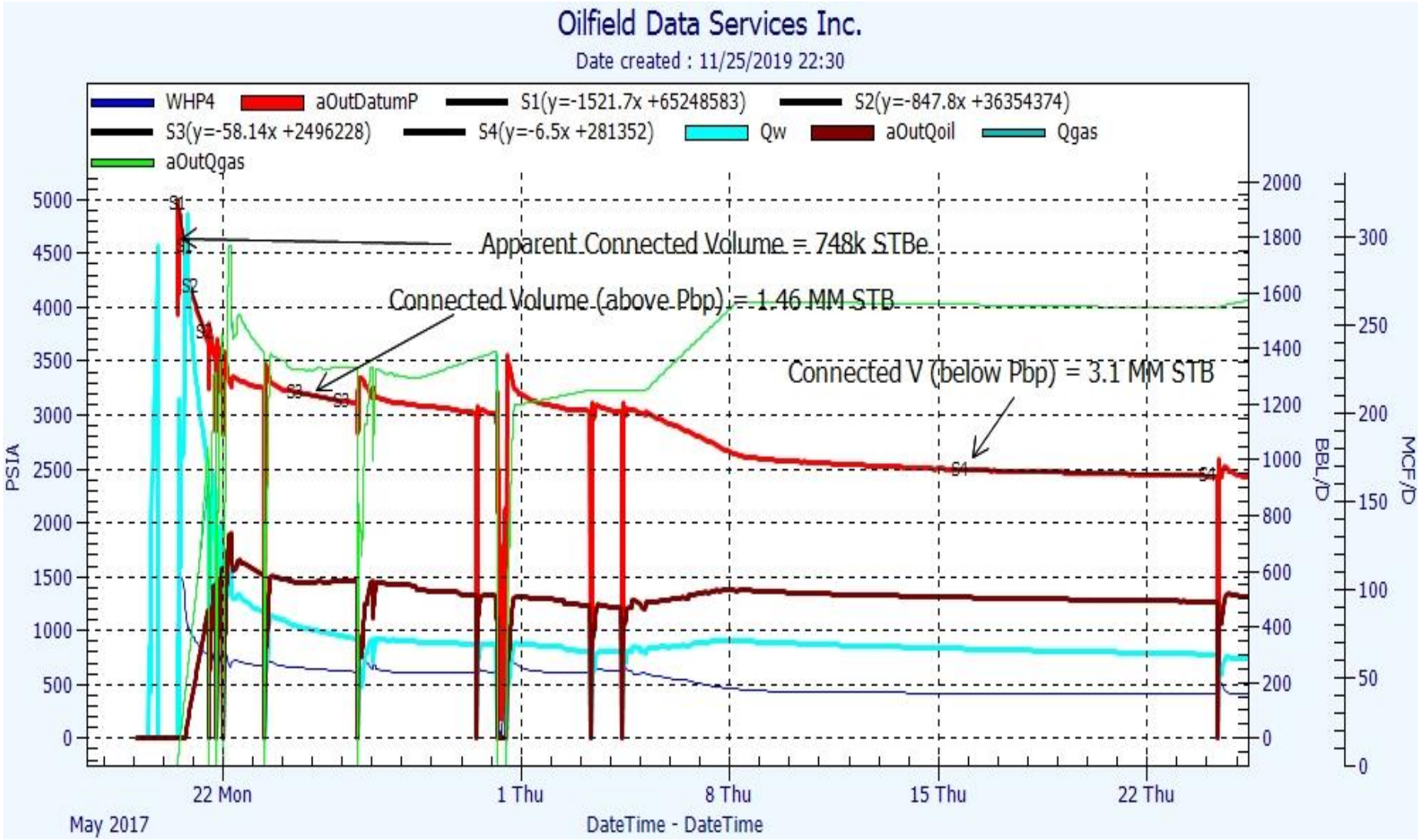
Decline Analysis - Definitions

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

The Four Flowing MBAL/EBAL Calculations

- **Conventional Decline Analysis**
  - **Conventional SLD**: Hydraulically Connected Potential Elastic Energy, assuming infinite water drive
  - **Conventional Vc**: Hydraulically Connected Potential Elastic Energy, assuming expansion drive
- **TTA Decline Analysis**
  - **TTA-SLD**: Mobile Connected Apparent HC Volume, assuming infinite water drive
  - **TTA-Vc**: Mobile Connected Apparent HC Volume, assuming expansion drive

Frac'd Horizontal Example – Connected Volumes (S1 = Water, S3 = Above Pbp; S4 = Below Pbp)



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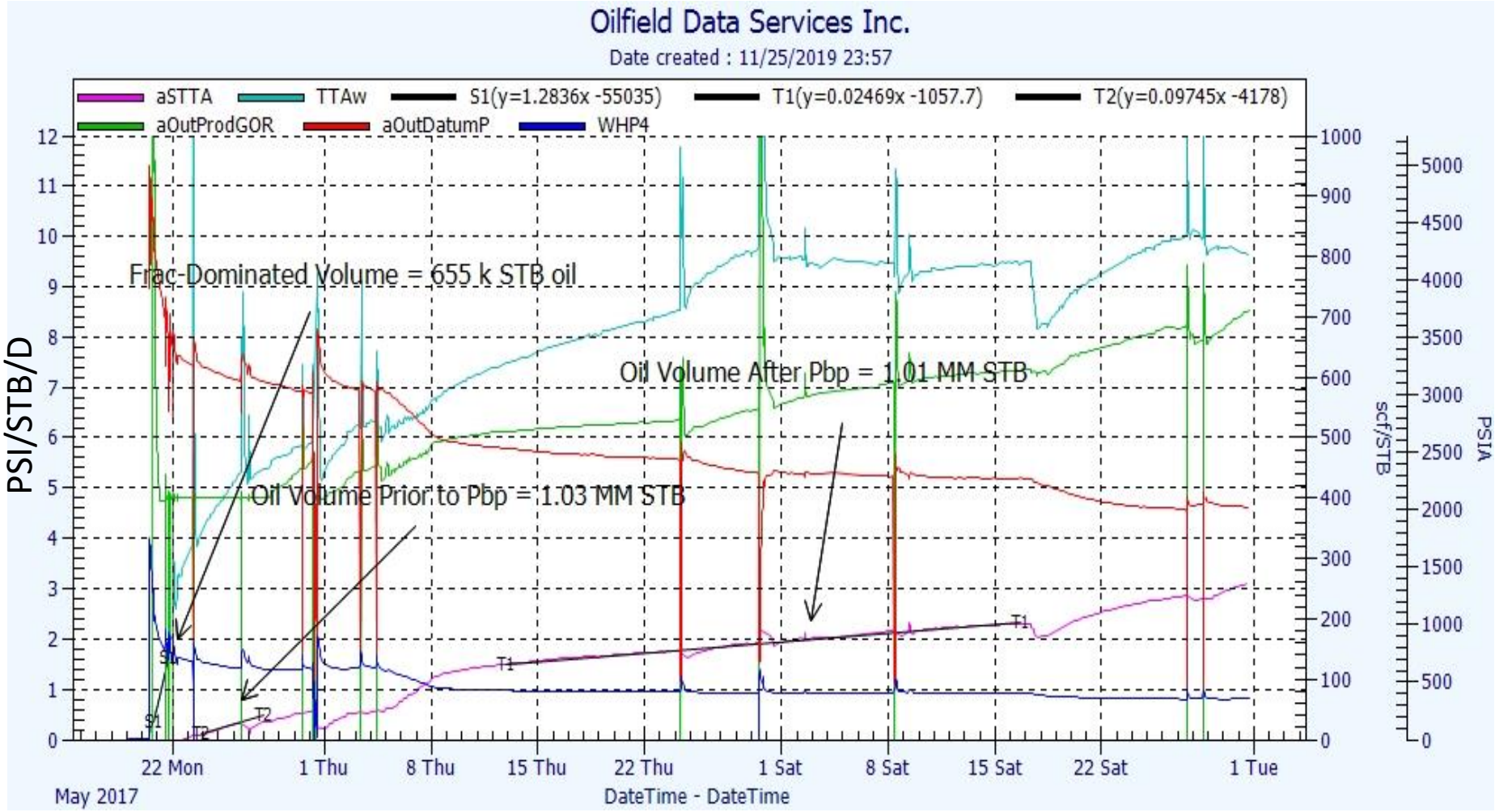
Frac'd Horizontal Ex – TTA Volumes



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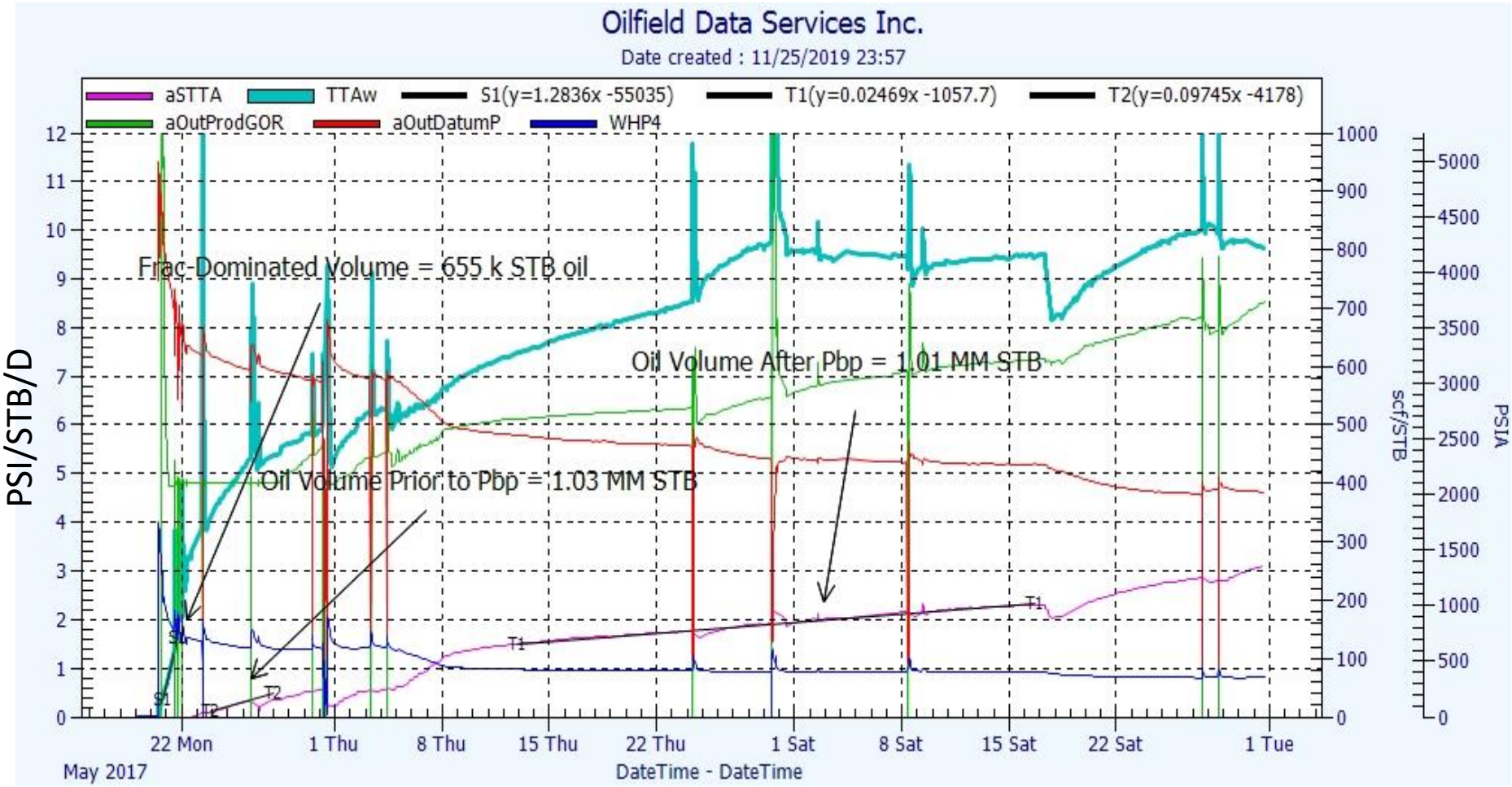
Frac'd Horizontal Ex – Mobile Frac Volume



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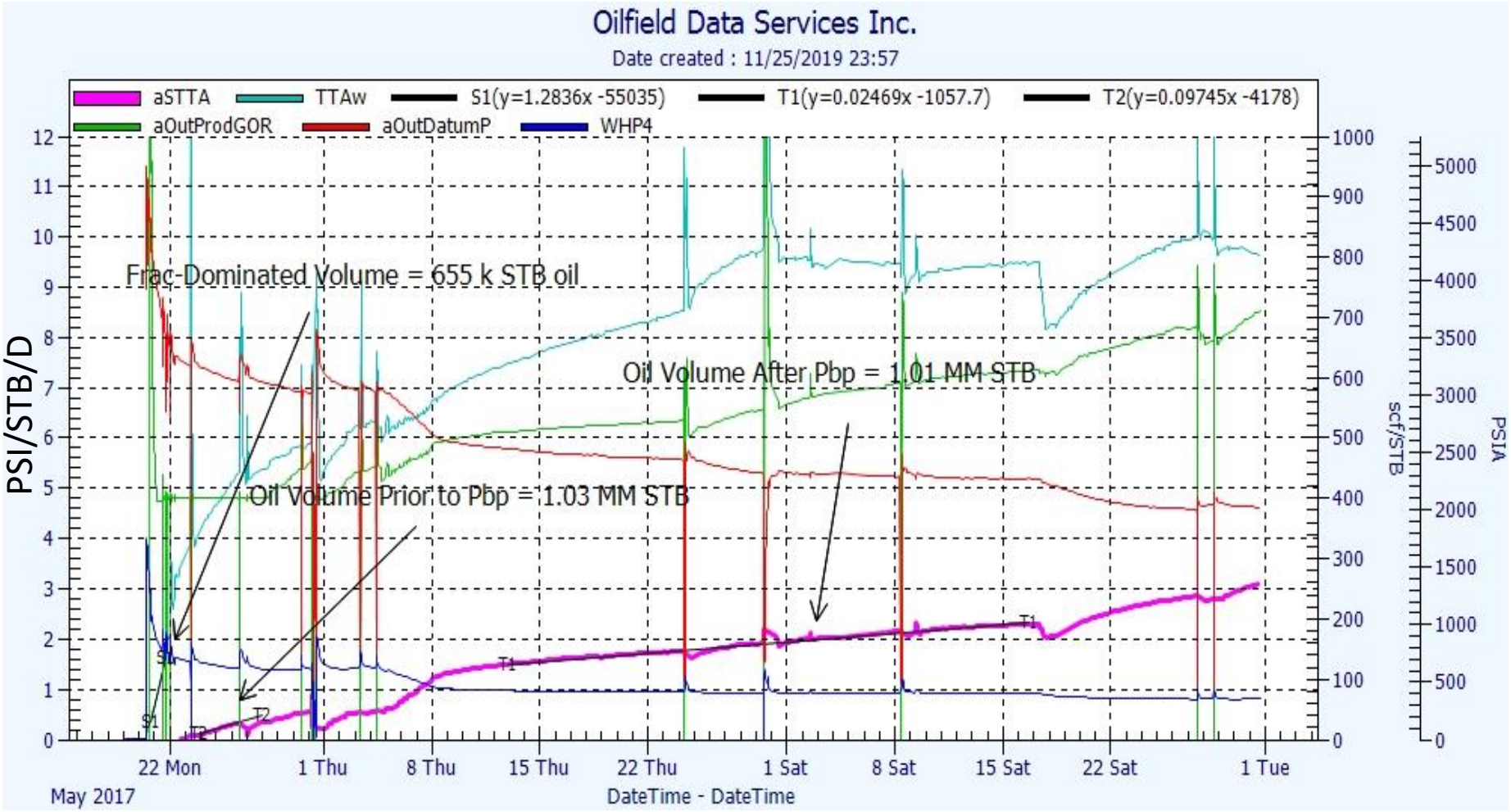
Frac'd Horizontal Ex – Mobile Oil Volumes Before and after the BHP drops below Pbp



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Frac'd Horiz. Ex. – Apparent Volumes

- Connected Volumes:
  - Frac-Dominated Volume = 748,000 STB Oil
  - Matrix + FDV (Above Pbp) = 1.46 MM STB Oil
  - Matrix + FDV (Below Pbp) = 3.10 MM STB Oil
    (solution gas drive effect)
- Mobile Volumes:
  - Frac-Dominated Volume = 655,000 STB Oil
  - Matrix + FDV (Above Pbp) = 1.03 MM STB Oil
  - Matrix + FDV (Below Pbp) = 1.01 MM STB Oil
- VConn (above Pbp) – Mobile FDV = 805,000 STB
- Mobile (above Pbp) – Mobile FDV = 380,000 STB

Frac'd Horiz. Ex. – Minimum Rec Volume

- Based on PVT: Recovery for Depletion = 18%
- Sol'n Gas Drive Boost = 3.1/1.46 = 2.12
- No Observed Mobile Volume Decrease after BHP drops below Pbp
- Adjusted RF = 38.2% (of Mobile FDR)

- Based on the FDV, the proximity of the above & below Pbp Additional Volume, the PVT of the fluid and the decay of oil rate due to gas bypass, the recovery of the well can be determined
- For this well: Minimum Recoverable = 249,000 STB oil

Frac'd Horiz. Ex. – Probable Rec Volume

FDR Min Recovery = 249,000 STB (add to Matrix Rec.)
Remaining Connected Volume (total) = 805,000 STB
Remaining Mobile Volume= 337,000 MM STB
Non-Mobile (yet) Connected Volume = 468,000 STB

- Based on PVT: Recovery for Depletion = 18%
- Sol'n Gas Drive Boost = 3.1/1.46 = 2.12
- Adjusted RF = 38.2% (of Remaining Mobile Volume)
- No adjustment in RF for Non-Mobile Connected Volume

Additional Recoverable Volumes:

- Mobile: 129,000 STB
- Non-Mobile (yet): 84,000 STB
- For this well: **Probable Recoverable = 462,000 STB oil**

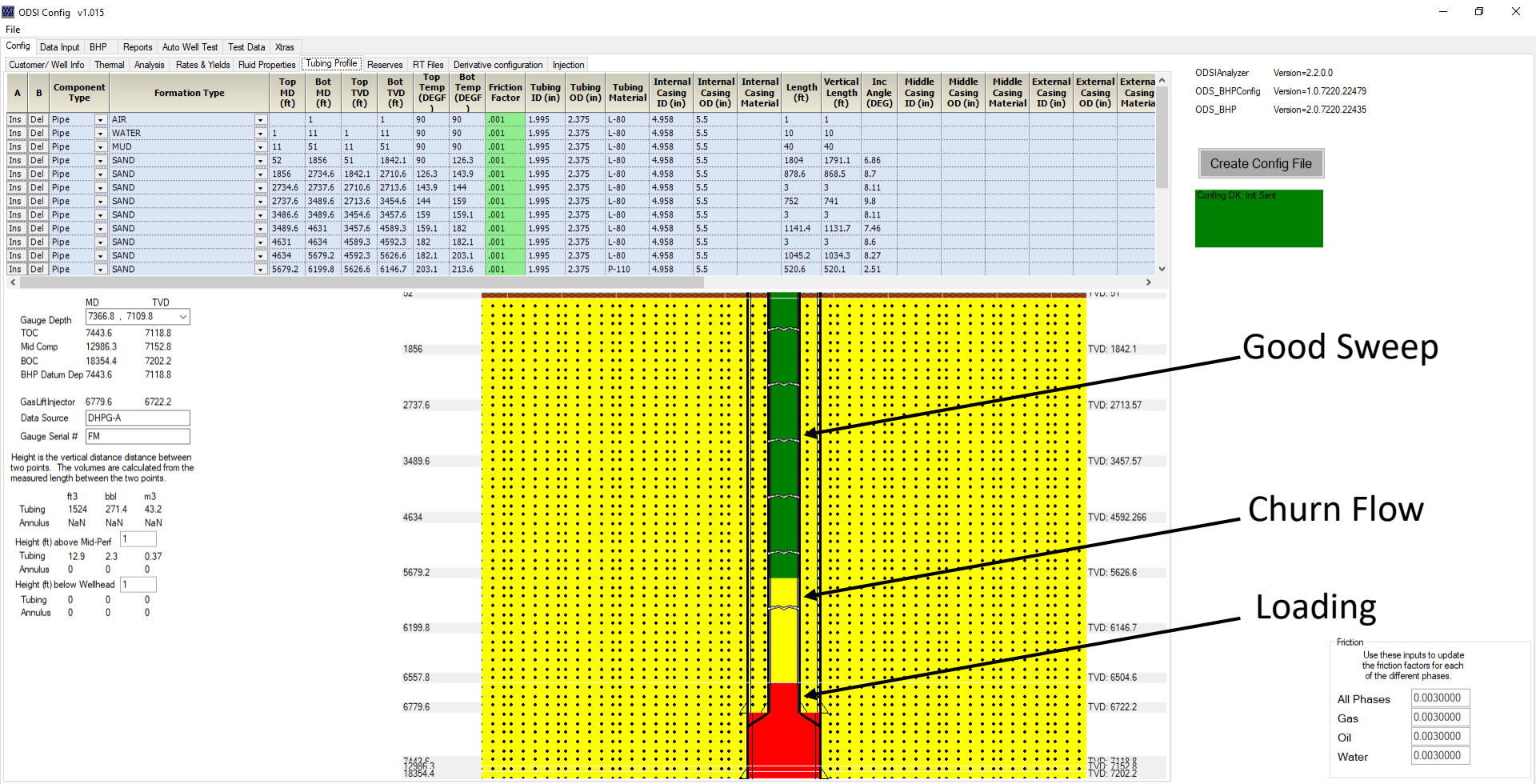
Gas Lifted Well Evaluation & Optimization

Major Wellbore Flow Regimes

- **Full Sweep Flow (Green – Efficient Lift)**
  - All Phases Mix and Effectively flow at the same velocity
- **Churn Flow (Yellow – Inefficient Lift)**
  - Not All Phases Mix and can have different velocities, but all velocities are positive (out of the well bore)
- **Slug Flow (Orange – Poor Lift)**
  - Little Phase Mixing, different velocities and some velocities (especially water) can be negative (dropping down the well bore)
- **Loaded/Intermittent Flow (Red – Egad!)**
  - Dying or dead well – spurts of fluid (mostly gas)

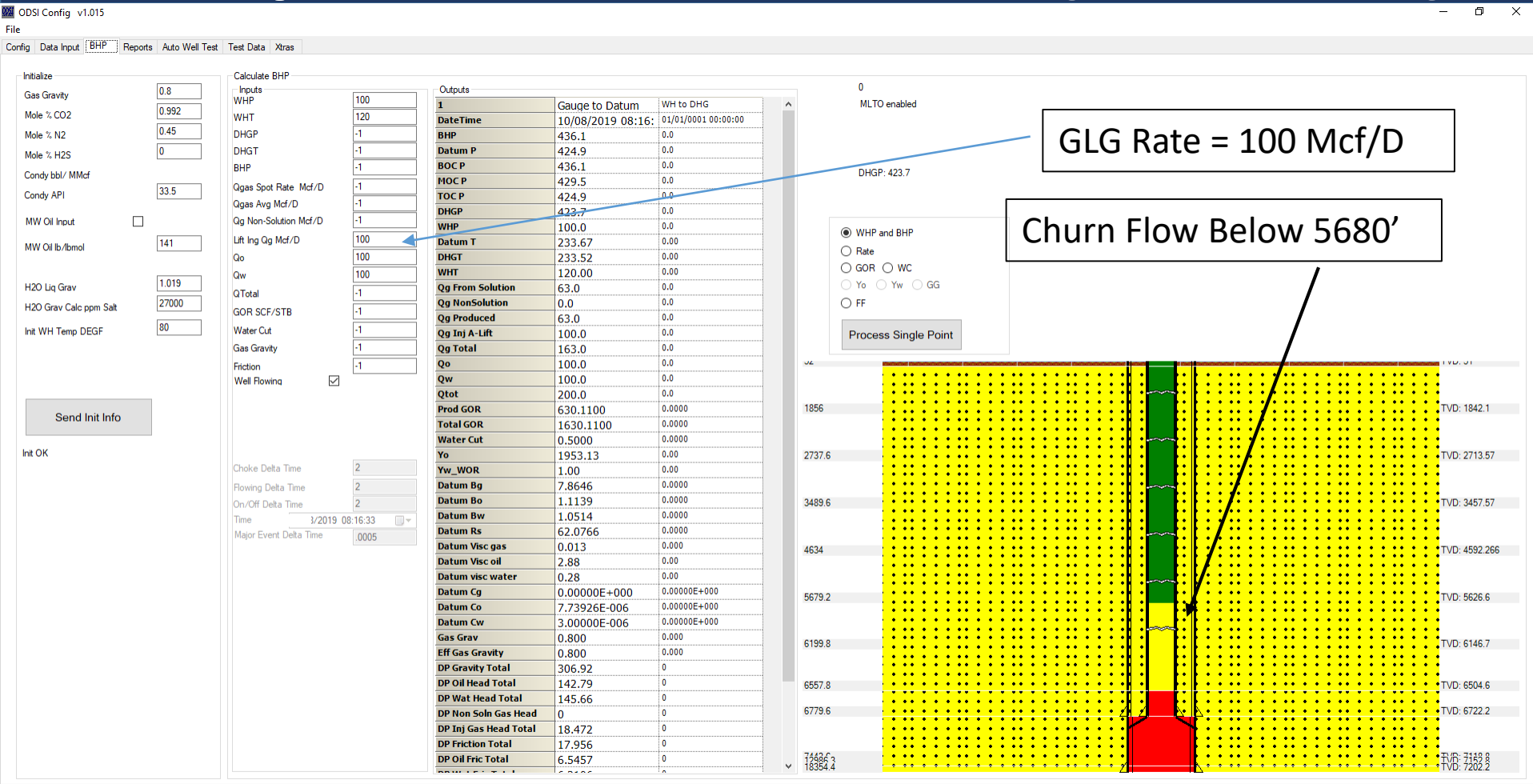
ODSI Lift Performance Evaluation

Recognize Inefficient Lift and Where it's Occurring: 100 BBL/D Oil Well w/50% WC



A	B	Component Type	Formation Type	Top MD (ft)	Bot MD (ft)	Top TVD (ft)	Bot TVD (ft)	Top Temp (DEGF)	Bot Temp (DEGF)	Friction Factor	Tubing ID (in)	Tubing OD (in)	Tubing Material	Internal Casing ID (in)	Internal Casing OD (in)	Internal Casing Material	Length (ft)	Vertical Length (ft)	Inc Angle (DEG)	Middle Casing ID (in)	Middle Casing OD (in)	Middle Casing Material	External Casing ID (in)	External Casing OD (in)	External Casing Materia
Ins	Del	Pipe	AIR		1		1	90	90	.001	1.995	2.375	L-80	4.958	5.5		1	1							
Ins	Del	Pipe	WATER	1	11	1	11	90	90	.001	1.995	2.375	L-80	4.958	5.5		10	10							
Ins	Del	Pipe	MUD	11	51	11	51	90	90	.001	1.995	2.375	L-80	4.958	5.5		40	40							
Ins	Del	Pipe	SAND	52	1856	51	1842.1	90	126.3	.001	1.995	2.375	L-80	4.958	5.5		1804	1791.1	6.86						
Ins	Del	Pipe	SAND	1856	2734.6	1842.1	2710.6	126.3	143.9	.001	1.995	2.375	L-80	4.958	5.5		878.6	868.5	8.7						
Ins	Del	Pipe	SAND	2734.6	2737.6	2710.6	2713.6	143.9	144	.001	1.995	2.375	L-80	4.958	5.5		3	3	8.11						
Ins	Del	Pipe	SAND	2737.6	3489.6	2713.6	3454.6	144	159	.001	1.995	2.375	L-80	4.958	5.5		752	741	9.8						
Ins	Del	Pipe	SAND	3486.6	3489.6	3454.6	3457.6	159	159.1	.001	1.995	2.375	L-80	4.958	5.5		3	3	8.11						
Ins	Del	Pipe	SAND	3489.6	4631	3457.6	4589.3	159.1	182	.001	1.995	2.375	L-80	4.958	5.5		1141.4	1131.7	7.46						
Ins	Del	Pipe	SAND	4631	4634	4589.3	4592.3	182	182.1	.001	1.995	2.375	L-80	4.958	5.5		3	3	8.6						
Ins	Del	Pipe	SAND	4634	5679.2	4592.3	5626.6	182.1	203.1	.001	1.995	2.375	L-80	4.958	5.5		1045.2	1034.3	8.27						
Ins	Del	Pipe	SAND	5679.2	6199.8	5626.6	6146.7	203.1	213.6	.001	1.995	2.375	P-110	4.958	5.5		520.6	520.1	2.51						

What-if Example: Required GLG for full sweep above GLG Mandrel (6780’ MD)



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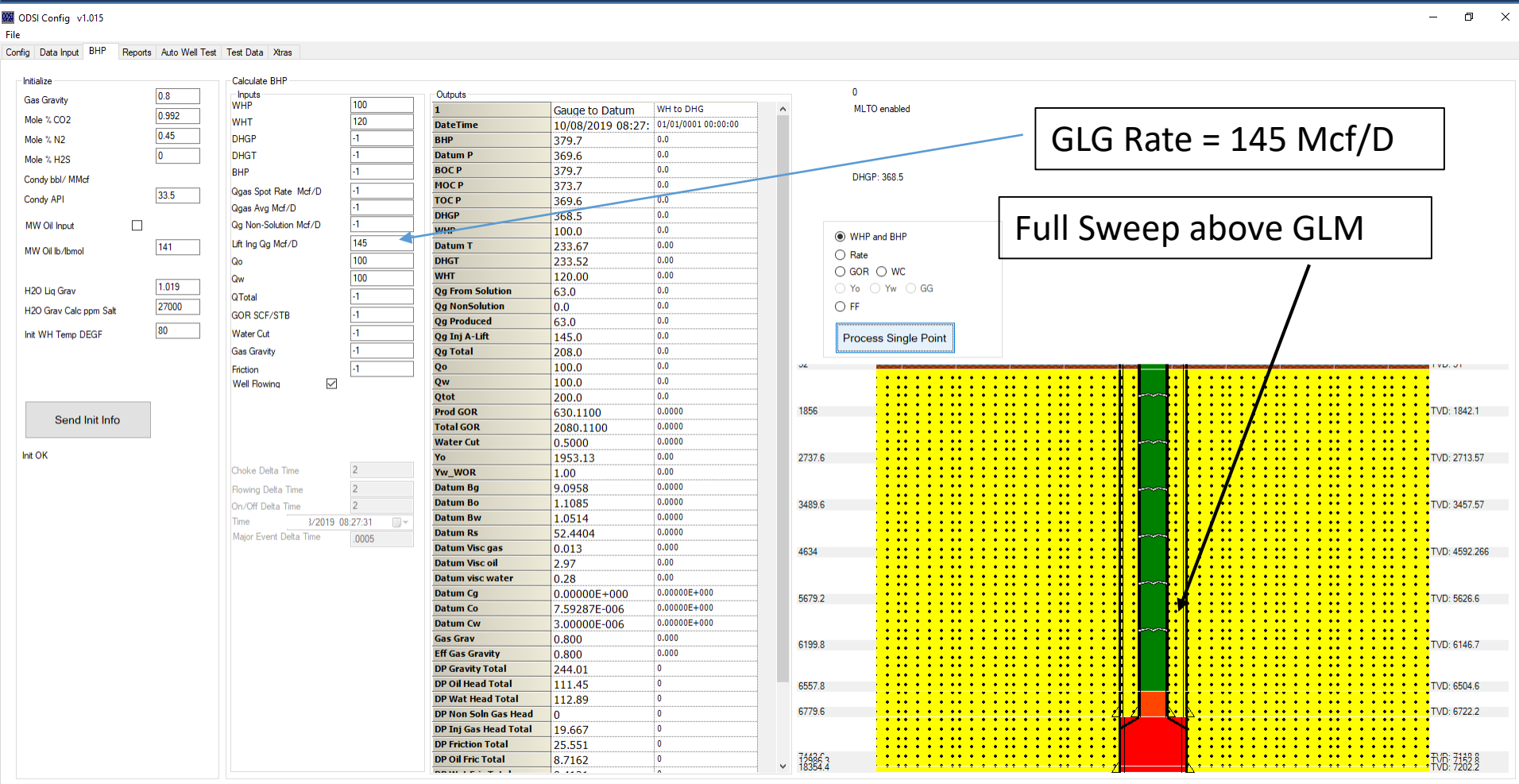
What-if Example: Required GLG for full sweep above GLG Mandrel (6780’ MD)



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Optimum GLG Rate: Maximize the Density Reduction w/o Excessive Friction

ODSI Config v1.015

File

Config | Data Input | BHP | Reports | Auto Well Test | Test Data | Xtras

Initialize

Gas Gravity	0.8
Mole % CO2	0.992
Mole % N2	0.45
Mole % H2S	0
Condy bbl/ MMcf	
Condy API	33.5
MW Oil Input	☐
MW Oil lb/lbmol	141
H2O Liq Grav	1.019
H2O Grav Calc ppm Salt	27000
Init WH Temp DEGF	80

Send Init Info

Init OK

Calculate BHP

Inputs: Load | Save

WHP	100	PSIA
WHT	120	DEGF
DHGP	-1	PSIA
DHGT	-1	DEGF
BHP	-1	PSIA
Qgas Spot	-1	MCF/D
Qgas Avg	-1	MCF/D
Qg Non-Sol	-1	MCF/D
Lift Inj Qg	145	MCF/D
Qo	216.1	BBL/D
Qw	-1	BBL/D
QTotal	-1	BBL/D
GOR	-1	SCF/STB
Water Cut	0.5	0 - 1
Gas Gravity	-1	
Friction	-1	
Well Flowing	☑	
Line Pressure	-1	PSIA
Choke setting	-1	
Productivity	0.11	MCF/(PSI D)
Presleff	2500	PSIA
Choke Delta Time	2	HOURS
Flowing Delta	2	HOURS
On/Off Delta Time	2	HOURS
Time	7/2020 04:26:57	
Major Event DT	.0005	HOURS

Outputs

1	Gauge to Datum
DateTime	02/27/2020 16:26:57
BHP	1747.9
Datum P	1722.1
BOC P	1747.9
MOC P	1732.6
TOC P	1722.1
DHGP	1719.3
WHP	100.0
DP Gravity Total	421.74
DP Oil Head Total	130.38
DP Wat Head Total	132.25
DP Non Soln Gas Head	0
DP Inj Gas Head Total	159.11
DP Friction Total	1200.3
DP Oil Fric Total	98.477
DP Wat Fric Total	90.28
DP Prod Gas Fric Total	22.539
DP Inj Gas Fric Total	989.01
Datum T	233.67
DHGT	233.52
WHT	120.00
Qg From Solution	136.2
Qg NonSolution	0.0
Qg Produced	136.2
Qg Inj A-Lift	5000.0
Qg Total	5136.2
Qg From Solution Datum	71.9
Qg Total Free Datum	71.9
Qo	216.1
Qw	216.1
Qtot	432.2
Prod GOR	630.1100
Total GOR	23767.5464
Water Cut	0.5000
Yo	1953.13
Yw_WOR	1.00
Datum Bg	1.7573
Datum Bo	1.2382
Datum Bw	1.0495
Datum Rs	297.4970
Datum Visc gas	0.013
Datum Visc oil	1.36
Datum visc water	0.30

◉ WHP and BHP
○ Rate
○ GOR ○ WC
○ Yo ○ Yw ○ GG
○ FF

Process Single Point

0
MLTO enabled

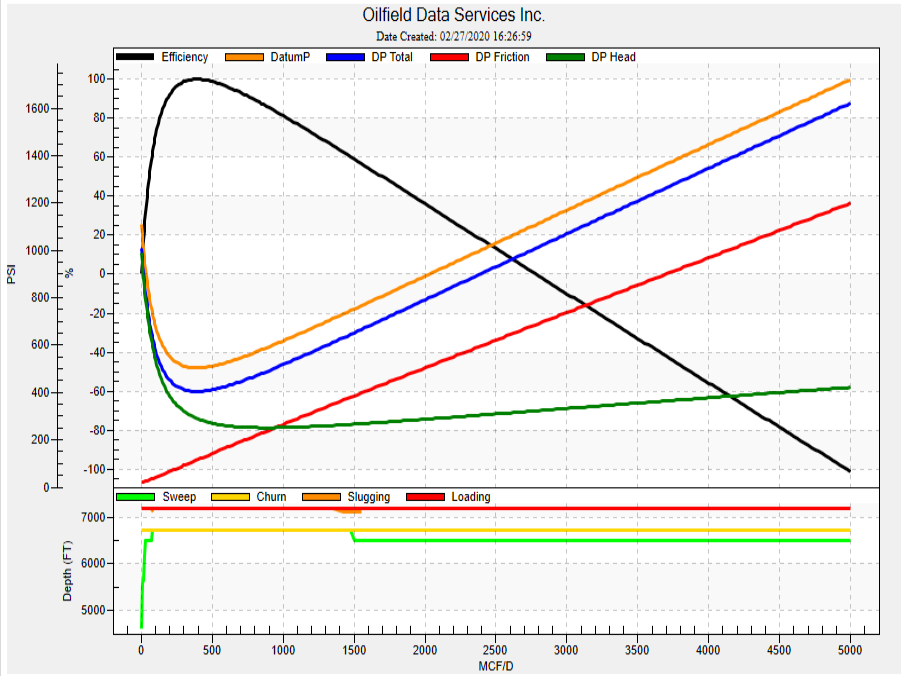
DHGP: 368.2

Optimum GLG Rate = 230 Mcf/D
Expected Oil Rate = 216 STB/D

Wellbore | Gas Lift DP | GL - Fixed PI

Process GL Batch | Min GL 0 | Max GL 5000 | Iterate | eff% 95 | Clear

Qo = 216.1 BBL/D : Qinjeff = 230 MCF/D



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GLG Optimization:

- Just Having Full Sweep (Green) Doesn't Mean that the GLG has been Optimized
- Adding More Gas Lift Gas also Reduces the Density of the Mixed Fluids
- But…adding more GLG Increases the Frictional Losses
- Need to balance the cost of additional GLG with the benefits, without getting negative effects of friction
- By the way…the WHP, the P.I., the Water Cut and the Formation GOR can all change once the GLG rates are changed, so this process needs to be repeated once the well stabilizes

‘WHP Only’ Issues:

- Flow Rates are not very reliable
  - GLG rates usually OK
  - Production rates are infrequent and often inaccurate
- Usually need to run a DHG survey prior to the optimization work to figure out where the GLG is coming in to the tubing - which mandrel(s) are taking gas
- No way of tracking GOR or WC without well tests or MPFMs…and even those ‘measurements’ can be dodgy

What Else can be done with WHP & DHPG

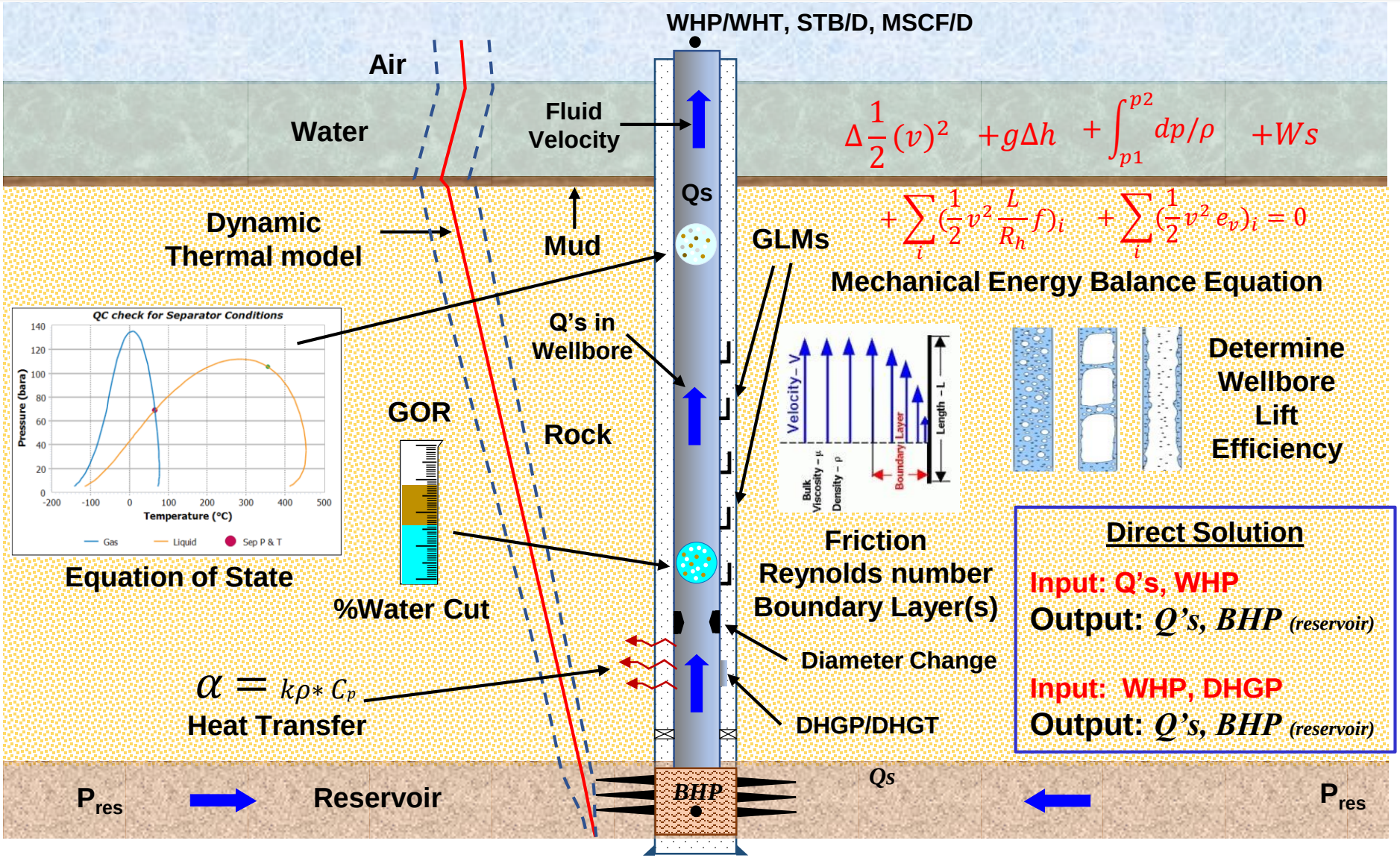
If GLG Rates are reliable and frequent:

- Spot Production Rate Calculations (If the well has efficient lift)
- Water Cut Tracking
- GOR Tracking
- Datum BHP Calcs
- Automatic Lift Efficiency Calcs
  - Multi-Pointing Diagnostics

What can be done with Surface & Downhole Tubing and Annulus Gauges

- Calculated GLG Rates
  - PVT Recalibration during shut-ins
- Spot Production Rate Calculations (If the well has efficient lift)
- Water Cut Tracking
- GOR Tracking
- Datum BHP Calcs
- Automatic Lift Efficiency Calcs
  - Multi-Pointing Diagnostics
- Automatic PTA & Decline Analysis

ODSI's Wellbore Solution, 1, 2, & 3-Phase



Multi-Pointing & GLG Injection Point Diagnostics with Full Kit-up

- Where's the gas coming in? How do you tell?
  - Gas/Water Head Intersection to match Annular DHGP
  - Tubing Performance Bifurcation
- Where it the lift efficient? Where is it loading?
  - WHP-down wellbore pressure calcs (w/ color coding)
  - BHP-up " " "
  - Locate Discontinuities
- System Gas Balance
  - Does QgINJ + Qoil * GOR match QgProd?
- Porting Pressure Checks (with Annular MEB)
- Chatter Check: Noise Level in WHP/T vs DHGP/T

Additional Benefits of DHPGs (Frac'd Horizontals)

- Need the observation well to be S/I and with a continuous phase fluid between the DHPG and the completion
- Frac Surge vs. Frac Hit
  - Pressure Surge Through Rock? No worries
  - Pressure Surge Through Formation Fluid? Comms
  - Pressure Surge and Spike? Pad Arrival
  - Pressure Surge, Spike and Discontinuity? Sand Arrival

Note: I haven't messed with this stuff in YEARS…in the past, nobody cared or paid any attention to it. I don't have any data to show these responses, but once you see it, it's hard to forget what it means. If you guys have some data showing these things, please send it my way and I'll add it in to the presso.

ODSI's Well Analyzer Benefits - Summary

- Reduce Planned Downtime (Test Passively)
- Analyze ALL of the data, not just the data you have time to look at
- Optimize Production at Every Opportunity
- Understand how much Money you have left in the ground
- Train Your Team in Proactive Surveillance
- Spend Your Time Thinking about What to Do to Make More Money!