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Production Optimisation of Conventional & Unconventional Wells with ESP Real Time Data

SPE DISTINGUISHED LECTURER

Lawrence CAMILLERI
Production Optimization Advisor
Artificial Lift Domain Head
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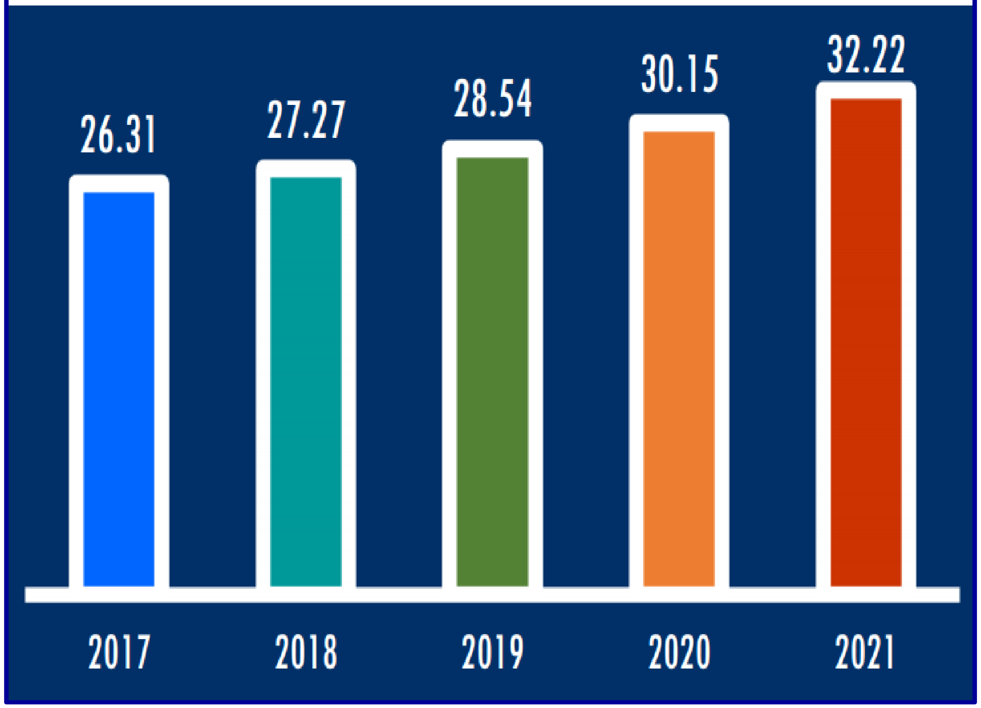
Schlumberger

The Digital Transformation Is Growing Fast

Global Digital Oilfield Market ($bn)



Global Digital Oilfield Market 2017-2021
Technavio.com

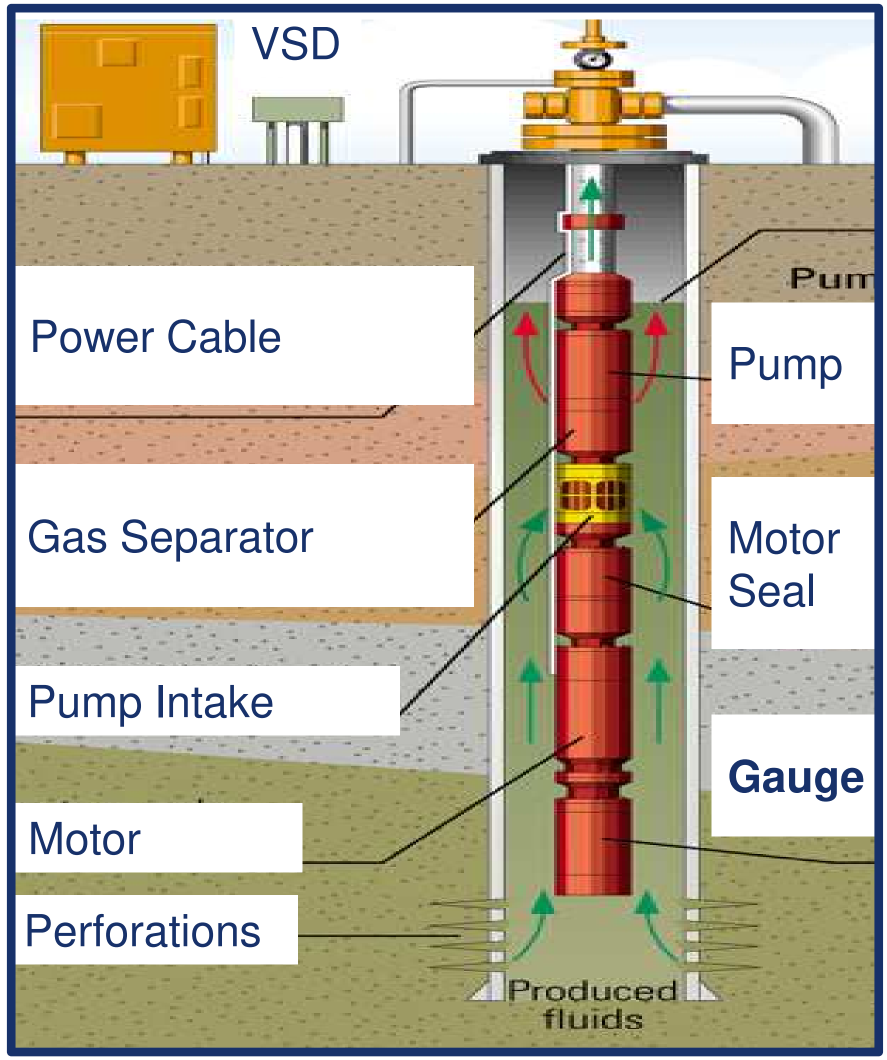
Enablers:

- Declining costs of sensors and data storage
- Rapid progress in advanced analytics (e.g. machine learning)
- Greater connectivity of people and devices
- Faster & cheaper data transmission

Why ESP Production Optimisation?

- 940,000 producing wells worldwide
- 125,000 (13%) of these wells lifted by ESP
- More than 54% of artificial lift global spend is on ESP (4.8 B$ out of 8.8B$ in 2017) with all other types representing less than 23% each.
- More than 30% of production lifted by ESP as it is the lift type with the highest rate

➔ ESP optimization has the biggest impact on both production and AL expenditure



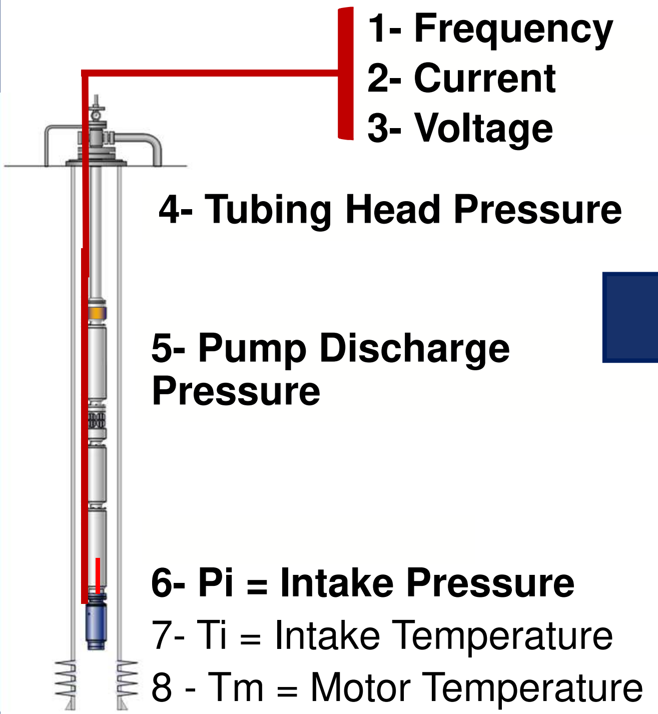
Operator's View

BP **Technology Outlook: 2015**	**Rossneft** **SPE 112238, Real Time Optimisation Approach for 15,000 ESP Wells**

BP Believes that digital technologies can deliver
• 4% Production Enhancement
• 13% Cost Savings
	▪ "***Calculations showed economical efficiency of system implementation on 7451 wells out of over 11,000 working ESP wells, with possible annual oil production increase of <u>11 million bbls</u>.***"
	▪ This justified the investment of 6400 US$ per well in automation hardware i.e. Variable Speed Drive, Gauges and real time data transmission
	▪ ***Compare potential to actual***
	  ▪ What is the actual IPR curve? Pr and PI?
	  ▪ What could be the PI after possible stimulation?

Agenda

Commonly Available ESP Real Time Data



VALUE OBJECTIVES

1. **Uptime**
2. **Run Life**
3. **Power Consumption**
4. **Production Enhancement**

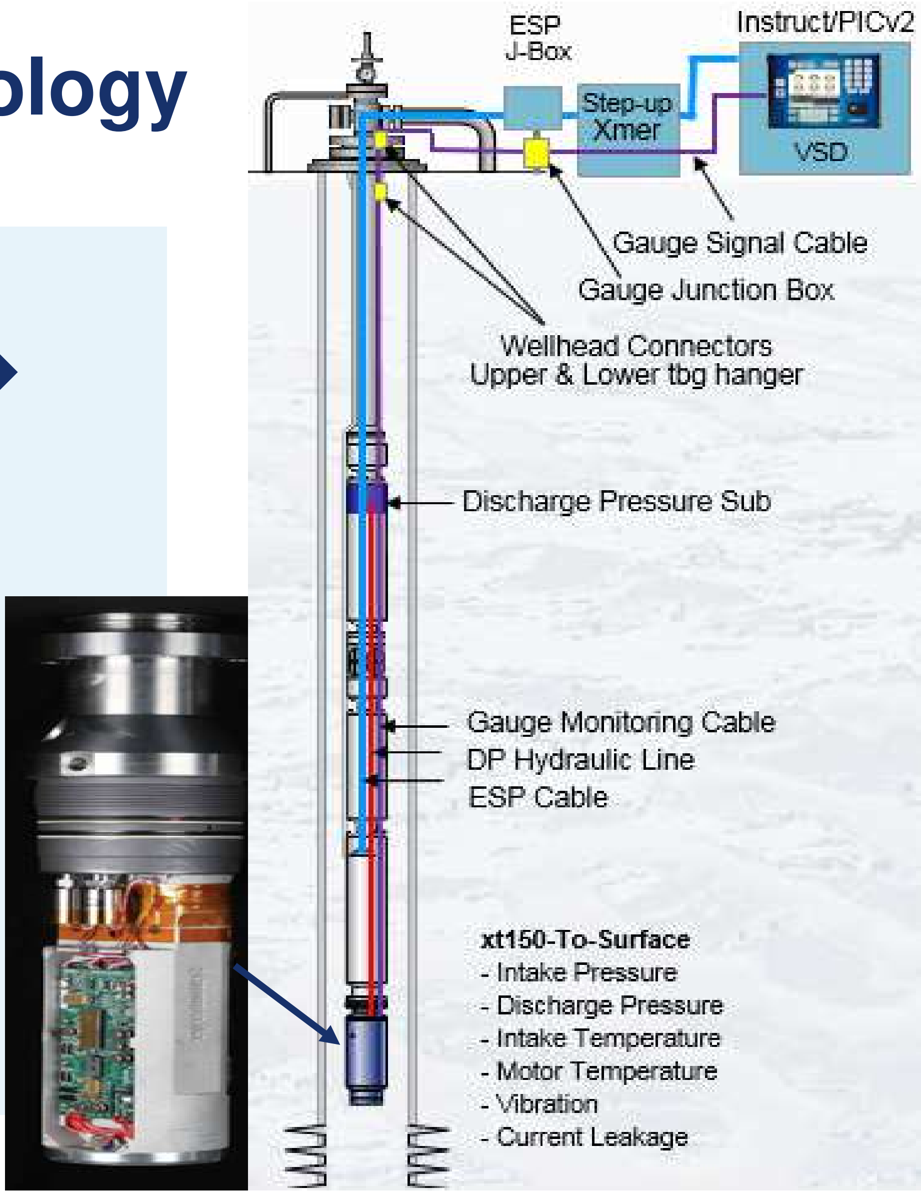
Generic Concepts:

- Gauge metrology
- Data visualization
- Slow & Fast Loop
- Data to Value Chain
- The importance of high frequency flowrate in addition to pressure data
- ***Compare potential & actual***

ESP Gauges…mature technology

1. **Reliability – MTBF >10 years**
2. **No need for instrument line ➔ low cost**
3. **Metrology of ESP gauges**
   - Accuracy +/- 5 psi
   - Resolution **<u>0.1 psi</u>**
   - Drift 5 psi / year

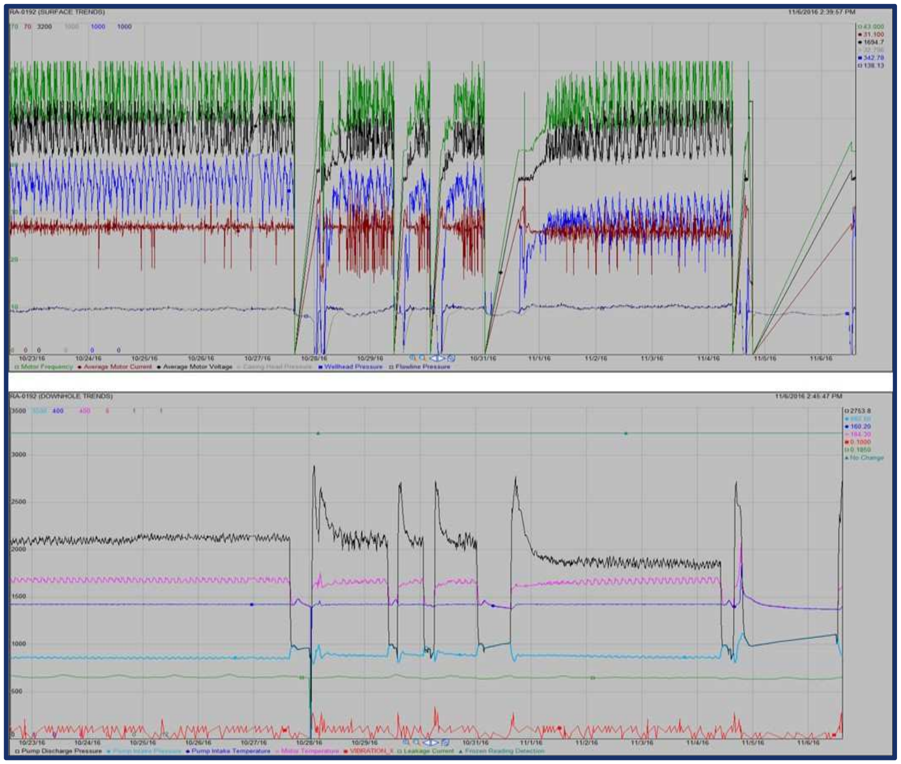
➔INFLOW ANALYSIS IS POSSIBLE

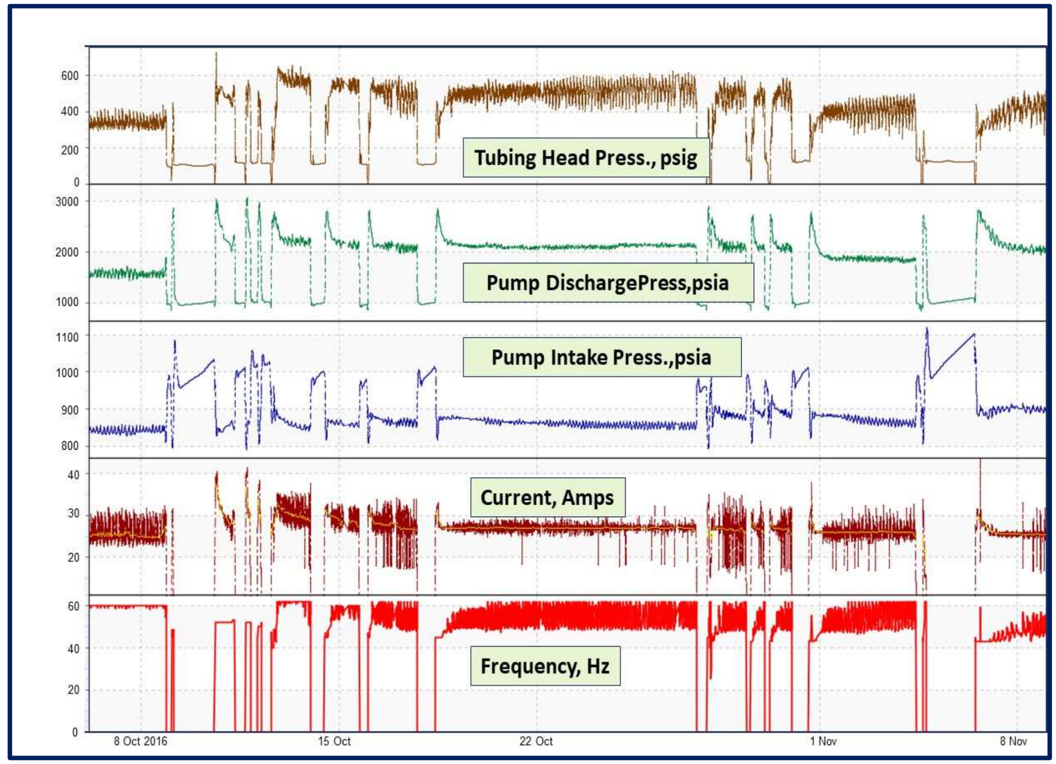


Data Visualisation ➔ Solution = Multiple Tracks

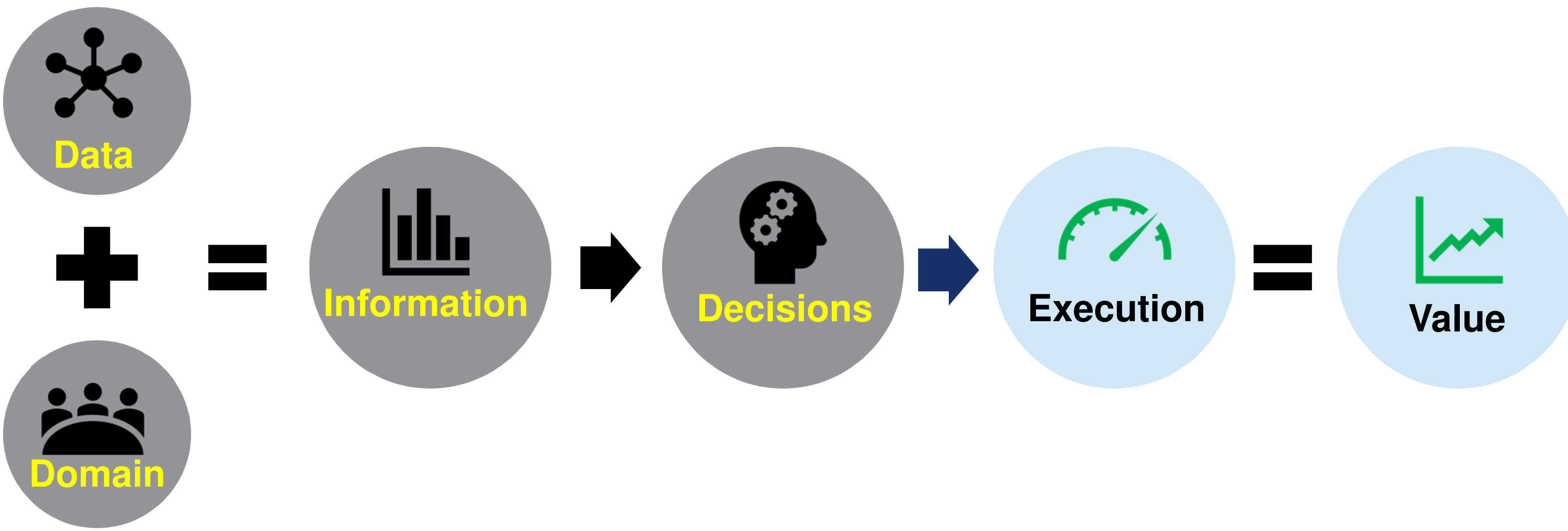
Challenge = Large Production Sets
- 6 to 15 analogue signals per well
- 1 million points / year /signal

Solution
- Separate tracks for signal groups
- User defined filtering

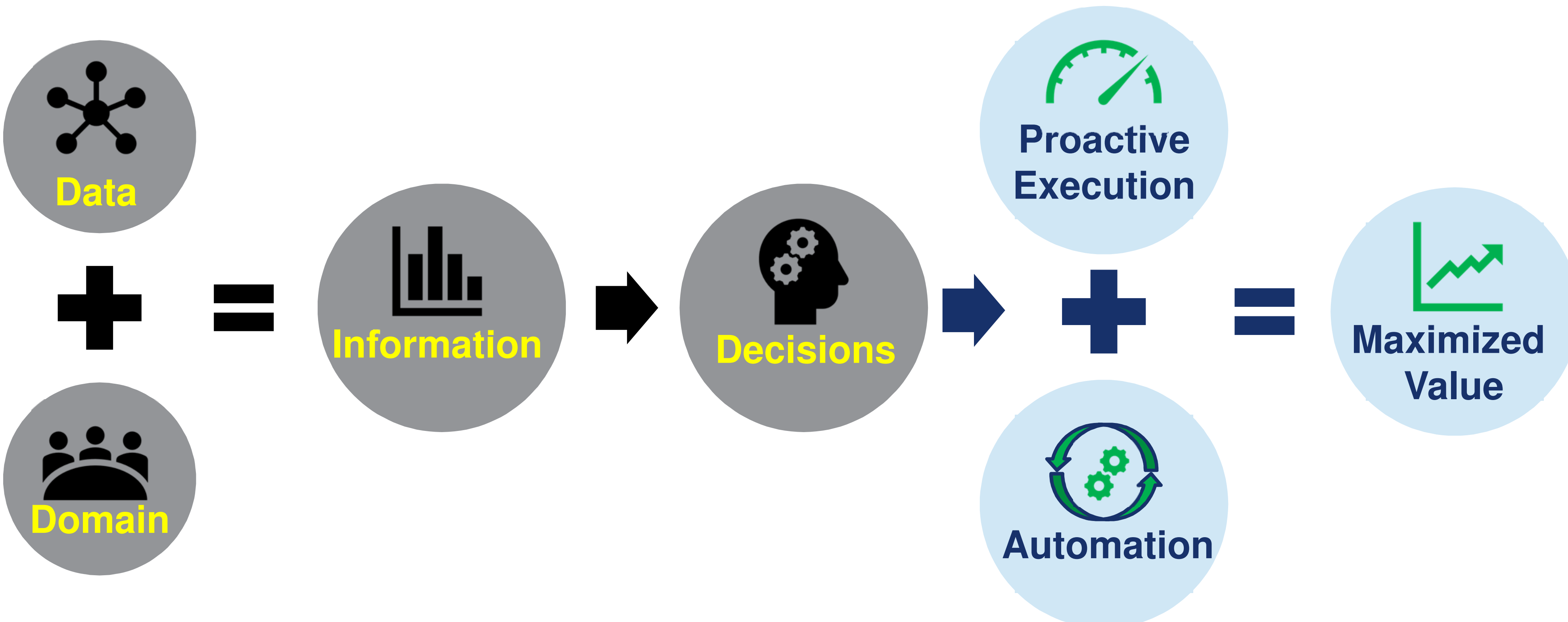




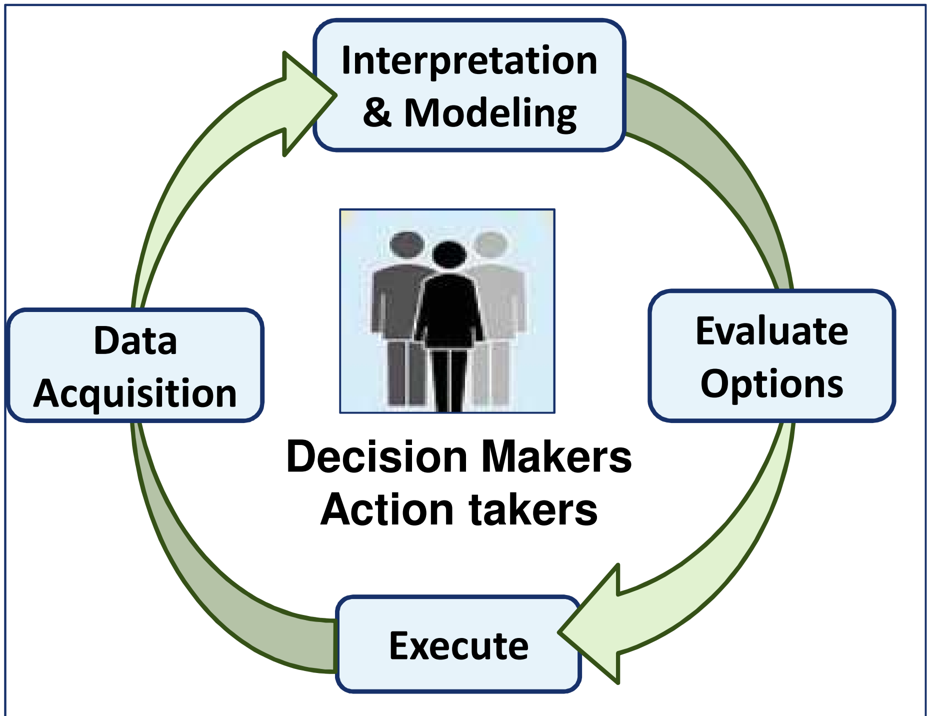
Data to Value Chain



How Real Time Data & Automation



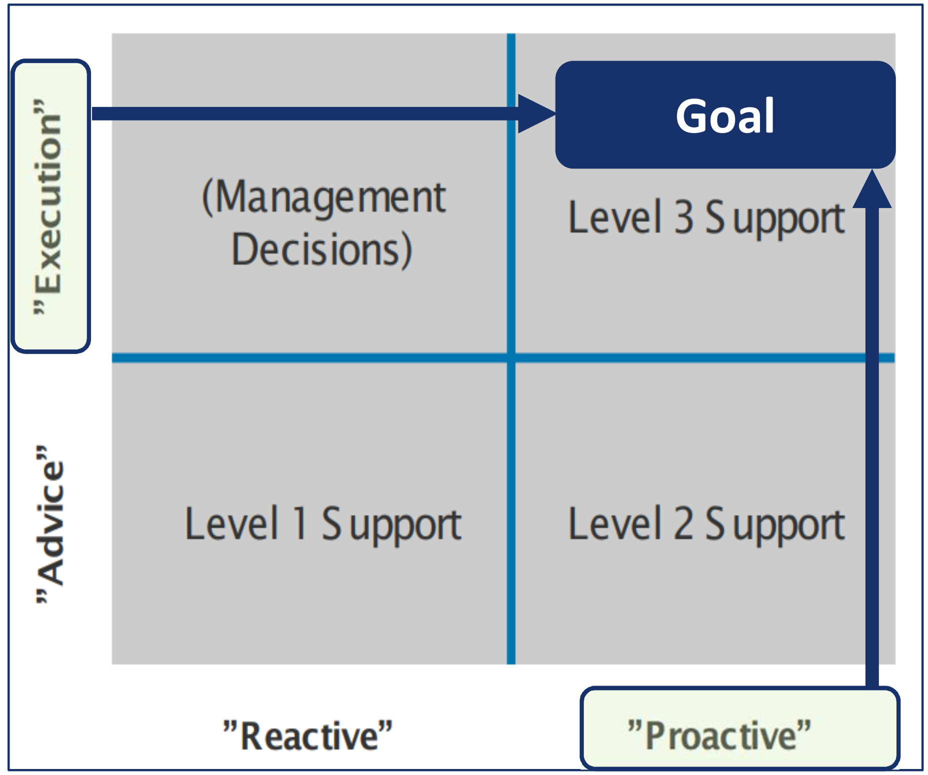
The Value of Data…



Shell's Smart Fields Value Loop

SPE 127858

Perdido: The First Smart Field® in the Western Hemisphere
Robert K. Perrons, SPE, Shell International Exploration & Production



SPE 127730

Multi-asset Production Support Centre—Generating Values
Kjell Lejon and Karl Johnny Hersvik, Statoil ASA, and Arild Bøe, Epsis AS

VALUE OBJECTIVES

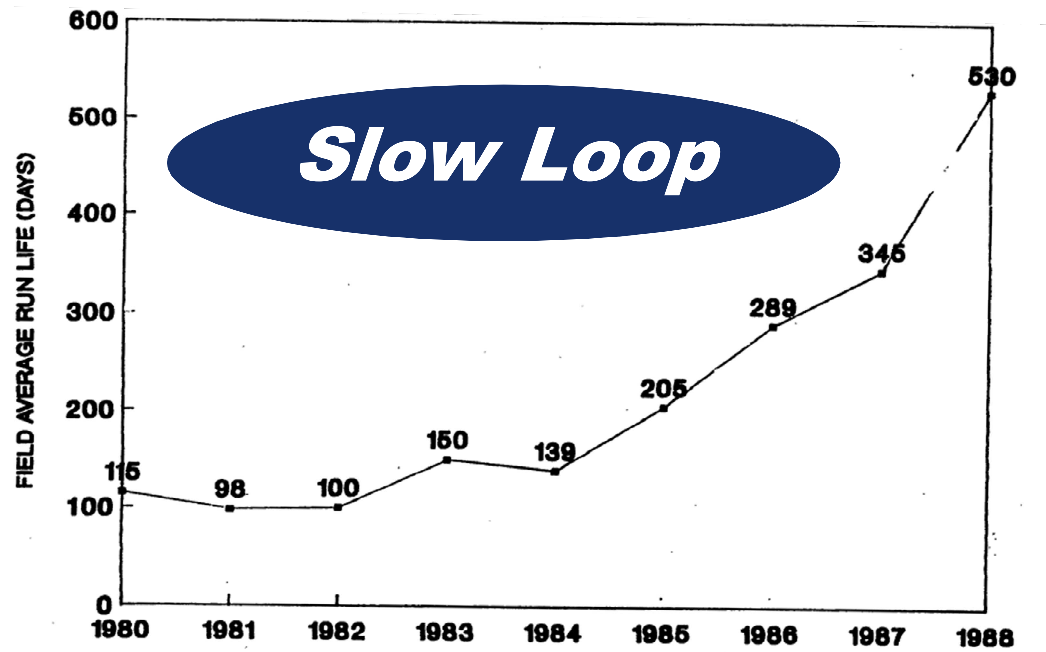
1. **Run Life**
2. Power Consumption
3. Uptime
4. Production Enhancement

Measure, Classify and Record….➔ *Slow Loop*

- **Run life improvement requires continuous monitoring and failure analysis in the *slow loop* i.e. years as opposed to minutes**

- **"Classification"** is a key enabler

- **This principle can also be applied to:**
  - Uptime Improvement
  - Power Optimisation
  - Production Enhancement



"Implementation of a comprehensive monitoring and failure investigation system was essential in the optimization of North Kaybob ESP Performance" SPE 19379 – ESP Improving Run Lives in the North Kaybob BHL Unit No 1, by C.G. Bowen and R.J Kennedy, Chevron Canada Resources. **(1989)**

Example of Importance of Classification

Database of stress creating events

Recording & *Classification*

Quest Number	Date (of SQ Creation)	Well	First Symptoms seen	Classification Code new	Classification Group	Most Probable Cause (Calculation conditions)
20080303182656	Mar 03, 2008	LV 07	High Motor Temperature	PE3	Procedure Error	Site Hardware not correctly set-up (PAC/UniConn/ISP etc)
20080725165629	July 25, 2008	LV 07	Pressure Data	GF4	Gauge Fault	Values different from normal operations
20080801231434	Aug 01, 2008	LV 07	High Motor Temperature	LF1	Low Flow	ESP running below minimum speed
20080918160320	Sept 18, 2008	Sinoe 311	Average amps	PE3	Procedure Error	Site Hardware not correctly set-up (PAC/UniConn/ISP etc)
20081009081552	Oct 09, 2008	Sinoe 318	Intake Pressure	IN5	Information	ESP Running above normal production
20081013170236	Oct 13, 2008	Sinoe 318	Intake Pressure	LF1	Low Flow	ESP running below minimum speed
20081014123107	Oct 14, 2008	Sinoe 318	Pressure Data	GF4	Gauge Fault	Values different from normal operations
20081024191752	May 11, 2008	LV 07	Frozen Data	GF3	Gauge Fault	Short circuit in MDT
20081027162048	Oct 27, 2008	Sinoe 318	Intake Pressure	DH3	Deadhead	Partial Restriction above the ESP
20081101181305	Oct 31, 2008	Sinoe 311	Intake Pressure	PO1	Pump Off	Isolation valve closed below ESP
20081103025329	Nov 03, 2008	Sinoe 311	Intake Pressure	DH3	Deadhead	Partial Restriction above the ESP
20081110174651	Nov 10, 2008	T 1763	Review - Missing Data	IN3	Information	11 point documentation (or part of) not sent
20081115172949	Nov 15, 2008	T 1763	Review - Missing Data	IN3	Information	11 point documentation (or part of) not sent
20081117143505	Nov 17, 2008	Sinoe 318	Average amps	PE3	Procedure Error	Site Hardware not correctly set-up (PAC/UniConn/ISP etc)
20081117152928	Nov 17, 2008	T 1763	Temperature data	GF5	Gauge Fault	Failure/issue to Motor Temperature thermocouple
20081125162829	Nov 25, 2008	LV 01	Temperature data	IN5	Information	ESP Running above normal production
20081128101054	Nov 28, 2008	T 1763	Frozen Data	DT2	Data Transmission	No communication from Site - Frozen data
20081130211612	Nov 30, 2008	Sinoe 311	Temperature data	IN4	Information	ESP Running below normal production
20081130220033	Nov 30, 2008	Sinoe 316	Pressure Data			
20081221163235	Dec 15, 2008	Sinoe 318	Pressure Data			
20090105120308	Jan 05, 2009	Sinoe 318	Intake Pressure			
20090109003453	Jan 07, 2009	Sinoe 318	Intake Pressure			
20090116164551	Jan 16, 2009	Sinoe 318	Intake Pressure			
20090131092050	Jan 31, 2009	Sinoe 318	Average amps			
20090204121206	Feb 04, 2009	LV 01	High Motor Temp			
20090205030928	Feb 05, 2009	LV 07	Intake Pressure			
20090205111028	Feb 05, 2009	Sinoe 318	Pressure Data			
20090205173202	Feb 05, 2009	LV 01	VSD Input Voltag			
20090302192416	Mar 02, 2009	Sinoe 316	Pressure Data			
20090322211608	Mar 22, 2009	Sinoe 311	Frozen Data			
20090329111806	Mar 29, 2009	Sinoe 316	Pressure Data			
20090405052033	Apr 04, 2009	Sinoe 316	Pressure Data			
20090407114109	Apr 06, 2009	LV 01	Site Hardware no			
20090410090031	Apr 10, 2009	Sinoe 311	Intake Pressure			
20090417193122	Apr 17, 2009	Sinoe 311	Review - Missing			
20090419024008	Apr 19, 2009	Sinoe 318	Frozen Data			
20090421142017	Apr 21, 2009	LV 07	VSD Input Voltag			
20090504081449	May 03, 2009	All Sinoe	Frozen Data			
20090527024149	May 27, 2009	All Sinoe	Review - Missing			
20090615022012	Jun 15, 2009	Sinoe 311	Pressure Data			
20090620005912	Jun 19, 2009	LV 01	High Motor Temperature	DH3	Deadhead	Partial Restriction above the ESP
20090620014623	Jun 20, 2009	LV 07	High Motor Temperature	DH3	Deadhead	Partial Restriction above the ESP
20090713114554	Jul 04, 2009	Sinoe 311	Pressure Data	IN5	Information	ESP Running above normal production
20090711191010	Jul 11, 2009	Sinoe 318	Frozen Data	GF7	Gauge Fault	ISP/PIC card errors
20090719150440	Jul 17, 2009	OR-7	Frozen Data	DT2	Data Transmission	No communication from Site - Frozen data
20090728005730	Jul 24, 2009	Sinoe 311	Frozen Data	GF7	Gauge Fault	ISP/PIC card errors
20090728013600	Jul 26, 2009	OR-7	Frozen Data	DT2	Data Transmission	No communication from Site - Frozen data
20090730093053	Jul 30, 2009	Sinoe 316	Pressure Data	GF4	Gauge Fault	Values different from normal operations
20090815015118	Aug 14, 2009	Sinoe 318	Pressure Data	DH3	Deadhead	Partial Restriction above the ESP
20090923221827	Jul 01, 2009	OR-7	Pressure Data	DH3	Deadhead	Partial Restriction above the ESP
20090923223018	Jul 01, 2009	OR-7	VSD Input Voltage	SE1	Surface Electrical	High/Low Voltage supply power issue
20090923220645	Jul 09, 2009	OR-7	High Motor Temperature	DH3	Deadhead	Partial Restriction above the ESP
20090923213758	Jun 30, 2009	OR-7	Average amps	PE3	Procedure Error	Site Hardware not correctly set-up (PAC/UniConn/ISP etc)
20090906035749	Sep 06, 2009	Sinoe 318	Frozen Data	GF3	Gauge Fault	Short circuit in MDT
20090909015257	Sep 09, 2009	Sinoe 316	Pressure Data	GF4	Gauge Fault	Values different from normal operations
20090916190314	Sep 16, 2009	OR-7	Review - Missing Data	IN3	Information	11 point documentation (or part of) not sent
20090926103105	Sep 19, 2009	LV 01	Pressure Data	DH3	Deadhead	Partial Restriction above the ESP
20090921222148	Sep 20, 2009	OR-7	Frozen Data	DT2	Data Transmission	No communication from Site - Frozen data
20091010133142	Oct 10, 2009	Sinoe 318	Pressure Data	DH3	Deadhead	Partial Restriction above the ESP
20091015095916	Oct 15, 2009	Sinoe 316	Pressure Data	DH3	Deadhead	Partial Restriction above the ESP
20091018120627	Oct 18, 2009	Sinoe 316	Average amps	IN4	Information	ESP Running below normal production
20091024105843	Oct 24, 2009	OR-7	Pressure Data	DH3	Deadhead	Partial Restriction above the ESP
20091027232646	Oct 27, 2009	OR-7	Intake Pressure	DH3	Deadhead	Partial Restriction above the ESP
20091102042146	Nov 02, 2009	Sinoe 318	Pressure Data	IN6	Information	Temporary step change in Pi and Pd with both parameters folo
20091108173929	Nov 07, 2009	OR-7	Pressure Data	DH3	Deadhead	Partial Restriction above the ESP
20091112092134	Nov 11, 2009	OR-7	Pressure Data	DH3	Deadhead	Partial Restriction above the ESP
20091118131435	Nov 11, 2009	OR-7	VSD Input Voltage	SE3	Surface Electrical	Loss of input power/voltage
20091114023402	Nov 12, 2009	Sinoe 316	Pressure Data	GF4	Gauge Fault	Values different from normal operations
20091113103810	Nov 13, 2009	Sinoe 318	Pressure Data	IN5	Information	ESP Running above normal production
20091124035736	Nov 24, 2009	Sinoe 318	Pressure Data	DH1	Deadhead	Restriction above the ESP (Up-stream of flowline pressure indi

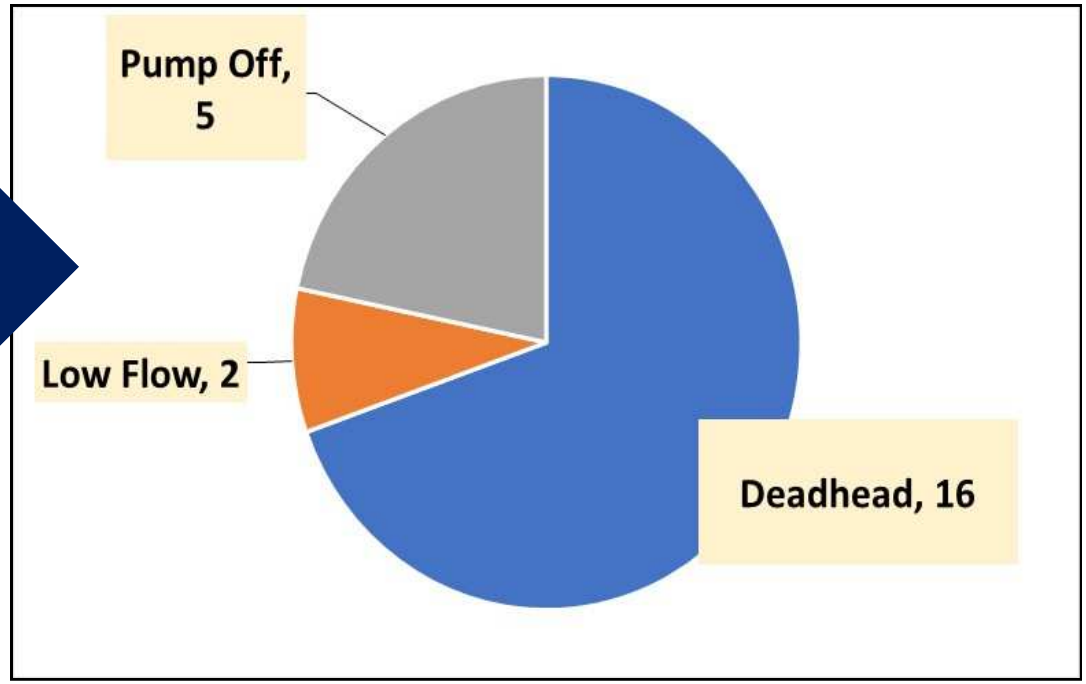
enabled by

CLASSIFICATION

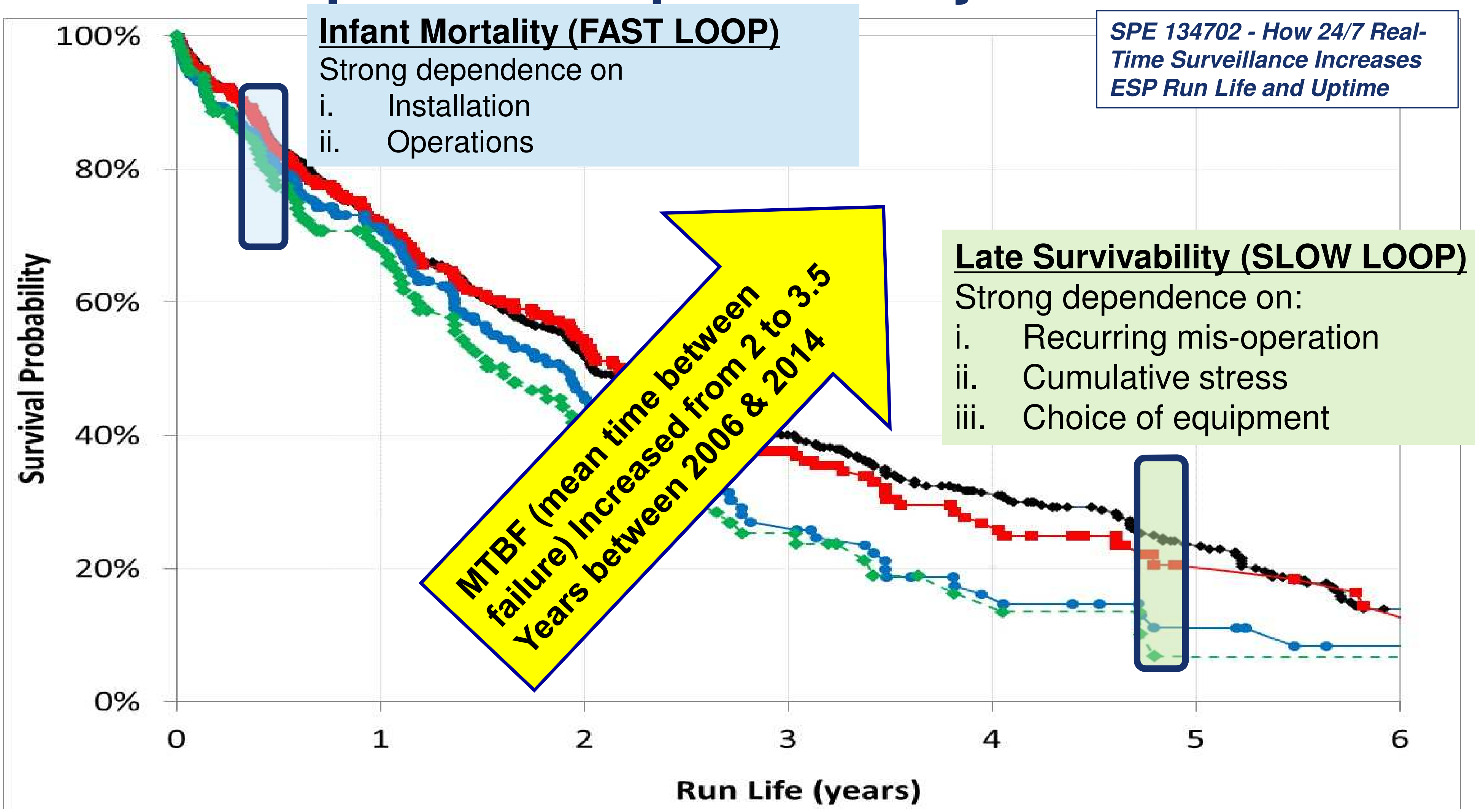
Identify Deadheads as <u>recurring</u> event

Investigate root cause

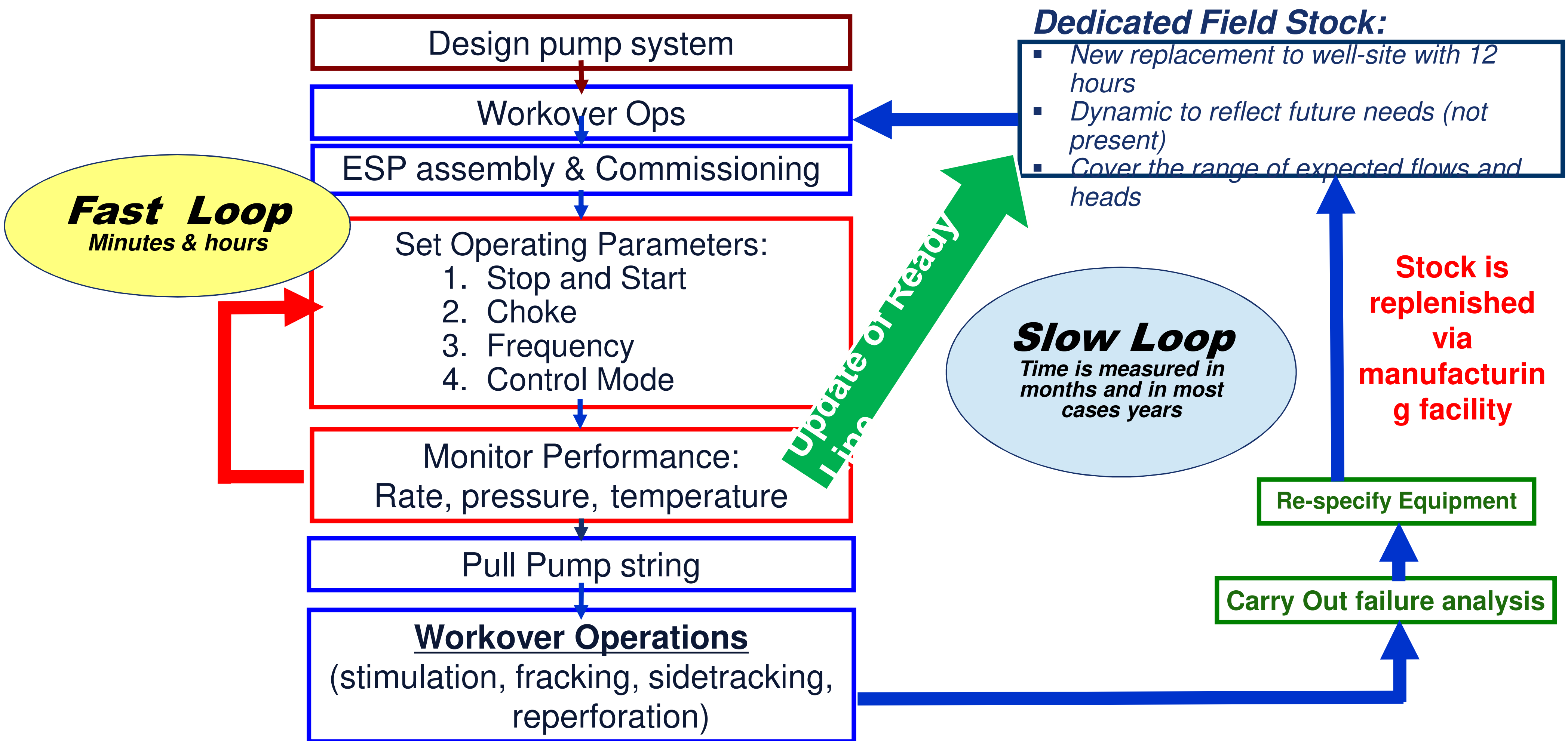
& implement remedial action



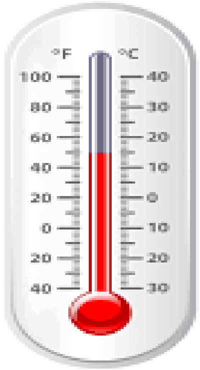
Run-Life Improvement powered by data



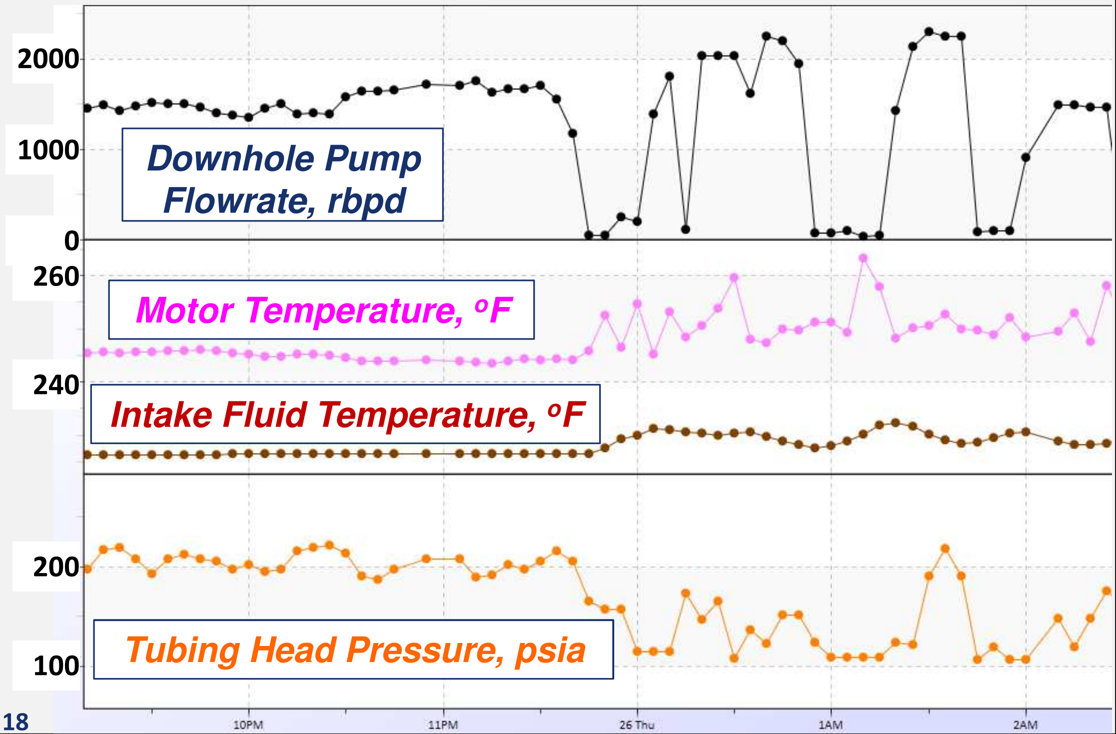
Slow & Fast Feedback Loops

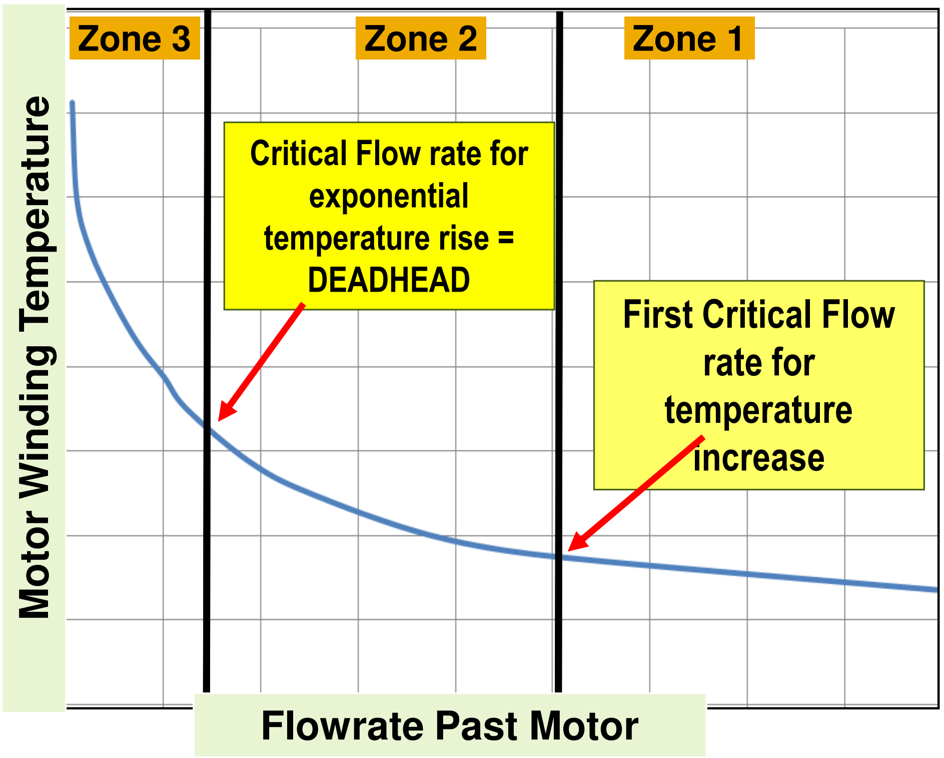


Low FLOWRATE → Motor Heat Rise

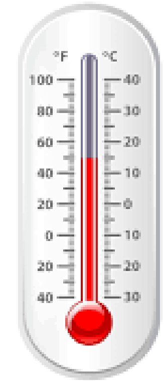


Heat rise happens fast, within minutes in this example, data sampling is every 5 minutes. Cause here is no flow due to gas degradation in unconventional well.





Low FLOWRATE ➔ Pump Heat Rise



$$\delta T_{pump} = \frac{Power_{pump}(1 - \eta_{pump})}{C_p \times \rho \times Q}$$

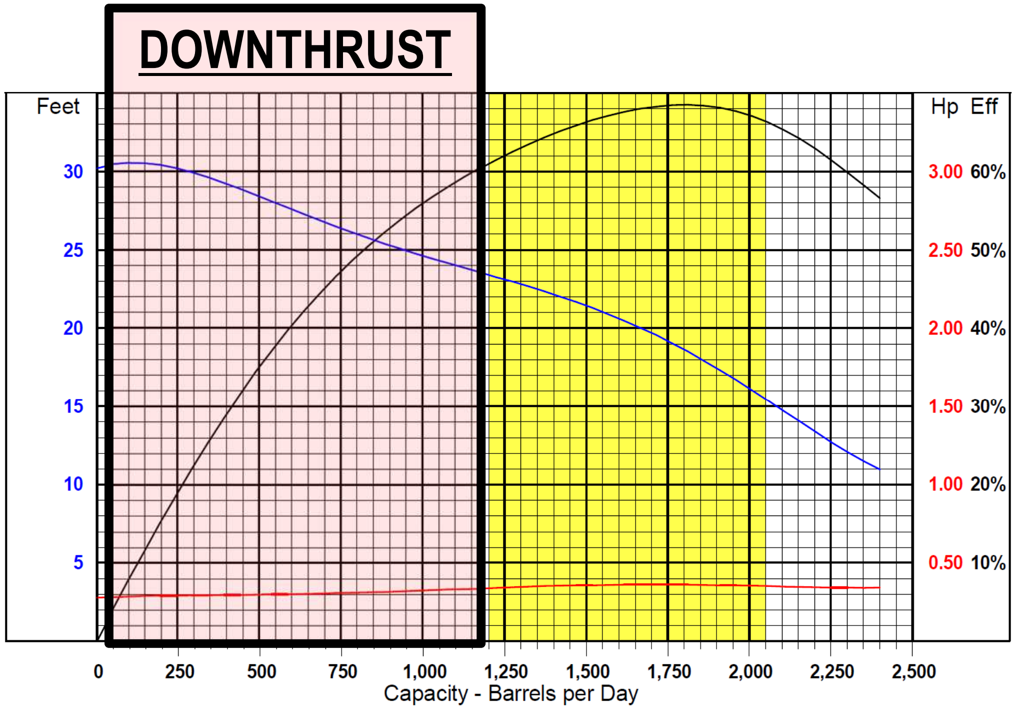
Note that the localized shaft & radial bearing heat rise is fast due to friction and can happen in minutes …Analogy: Drill bit tip gets much hotter than the motor…

1. **Galled stage running surfaces**
2. **Galled or cracked bearings**
3. **Shaft failure**

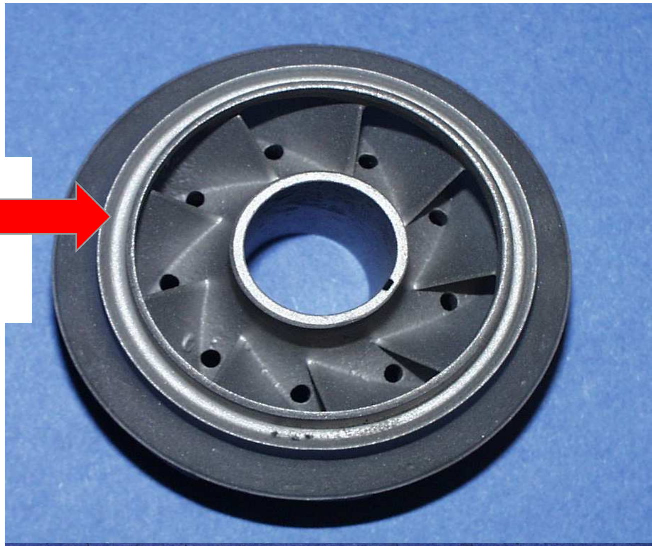
Pump heat rise can be very high, especially on high HP motors where in extreme cases the lead in the cable can melt, Temp > 327 °C

Low FLOWRATE ➔ Downthrust Mechanical Wear

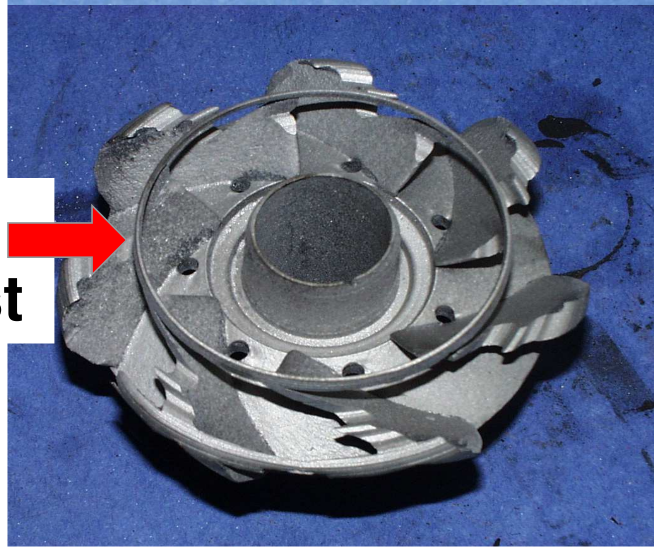
Loss of balance chamber function further increases downthrust load ➔Can fail thrust bearing, thrust washers, and stages ➔ Snowball!



Moderate Downthrust



Extreme Downthrust



Pump Flowrate = Real Time Indicator

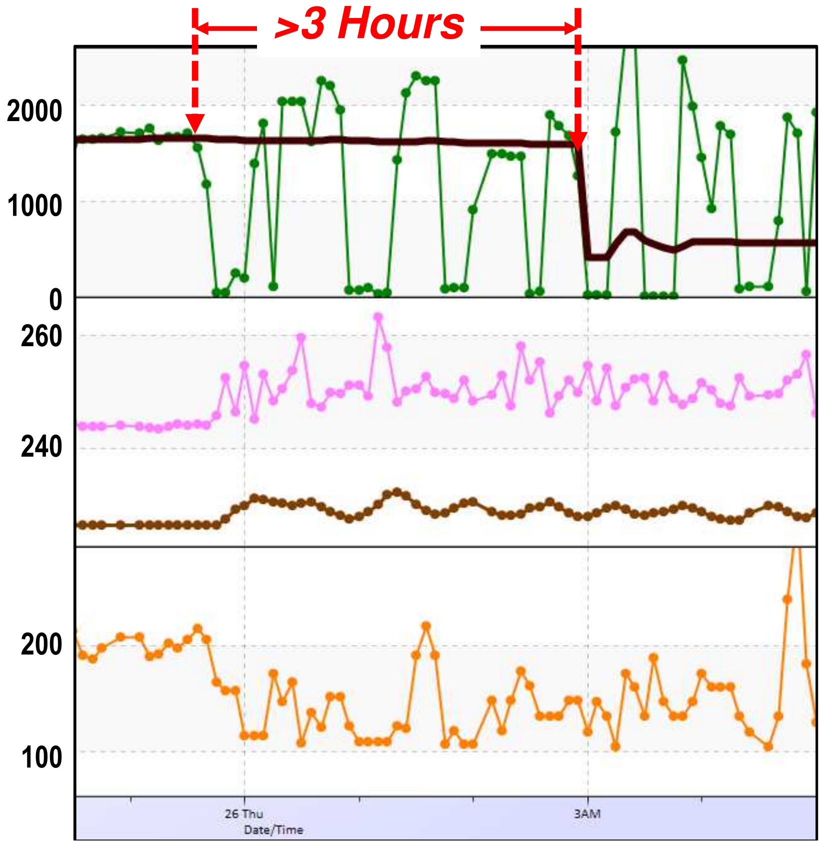
Test Separator lags by > 3 hours

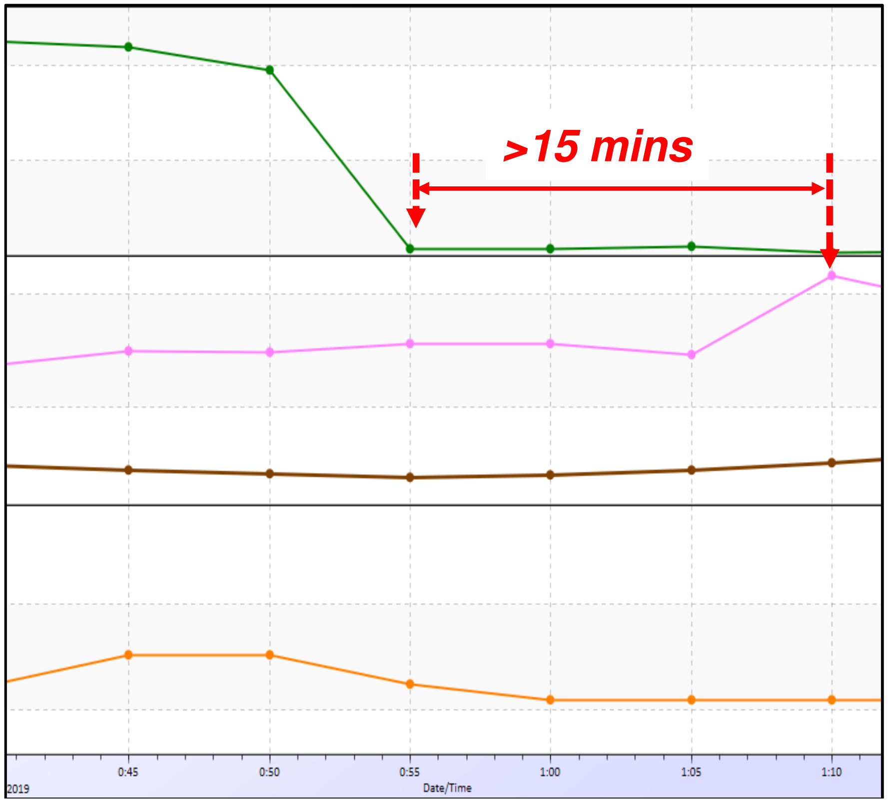
Motor Temperature Sensor lags by ~15 mins…

Downhole Pump & Surface Flowrate, rbpd

Motor Temp., °F Intake Fluid Temp. °F

Tubing Head Pressure, psia





Managing pump flowrate is key to minimizing ESP stress, but also…

Flowrate is a leading indicator whereas Surface Test Separator & Motor Temperature Sensors are lagging indicators

VALUE OBJECTIVES

1. Run Life
2. **Power Consumption**
3. Uptime
4. Production Enhancement

Power Optimisation ➔ Maximise PF x EFF

$$\text{Power} = \frac{V \times I \times PF \times EFF \times \sqrt{3}}{746}$$

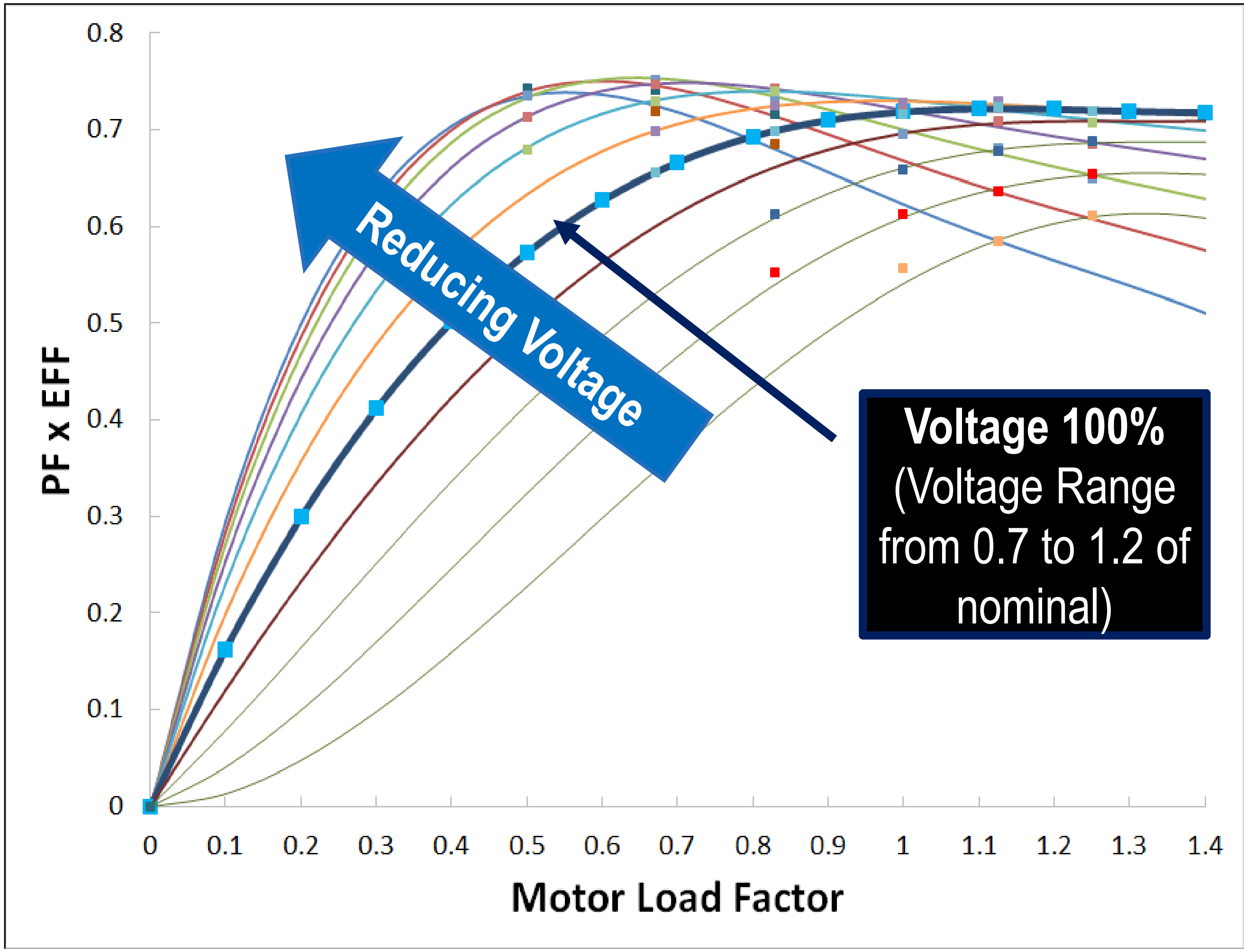
V	Voltage
I	Current
PF	Power Factor
EFF	Efficiency

The power equation shows that for a given pump load, when the (PFxEFF) is maximized, the current is minimized.

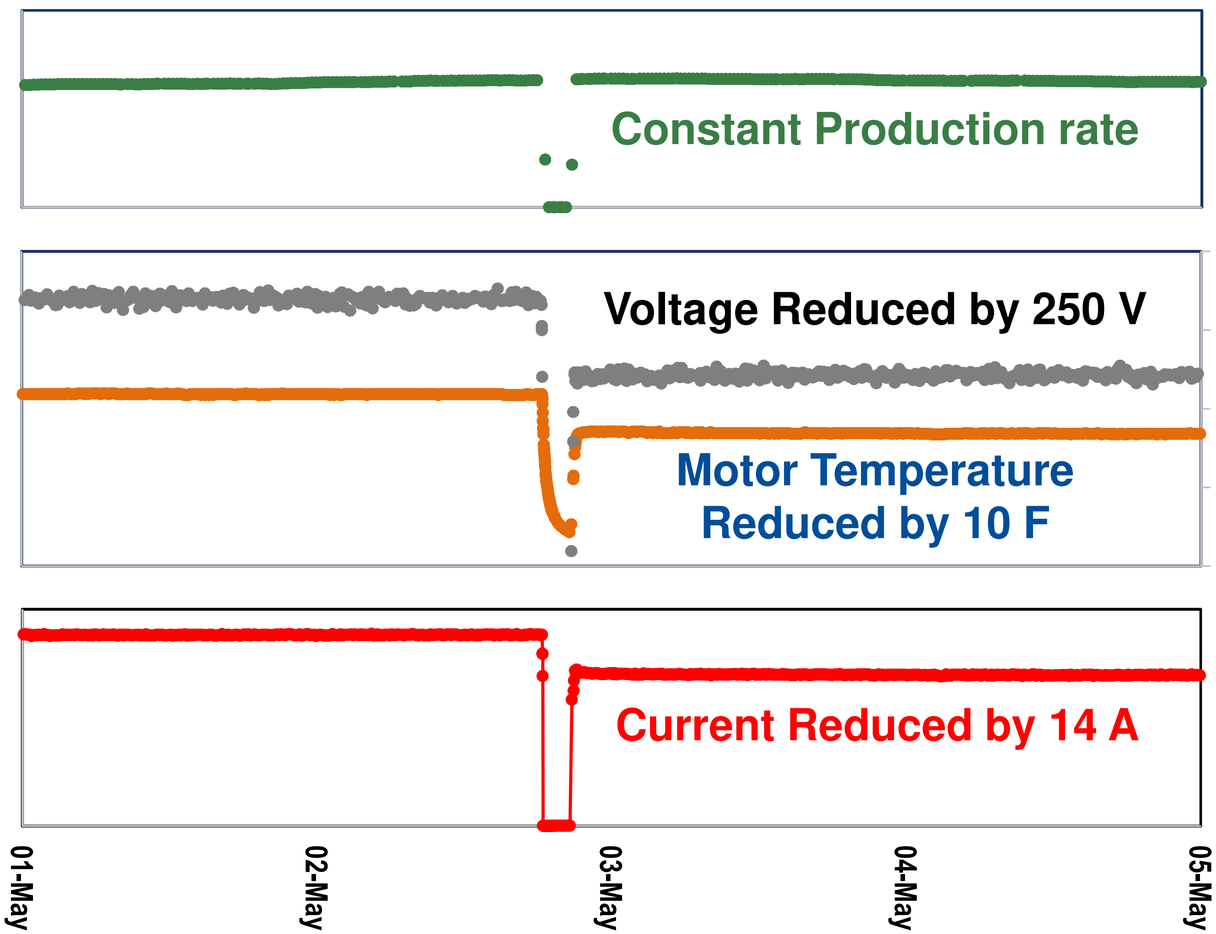
➔ Minimise Power consumption

➔ Minimise Motor Temperature, which maximises run life

This is achieved by controlling voltage



ESP Power Optimisation → Double Benefit



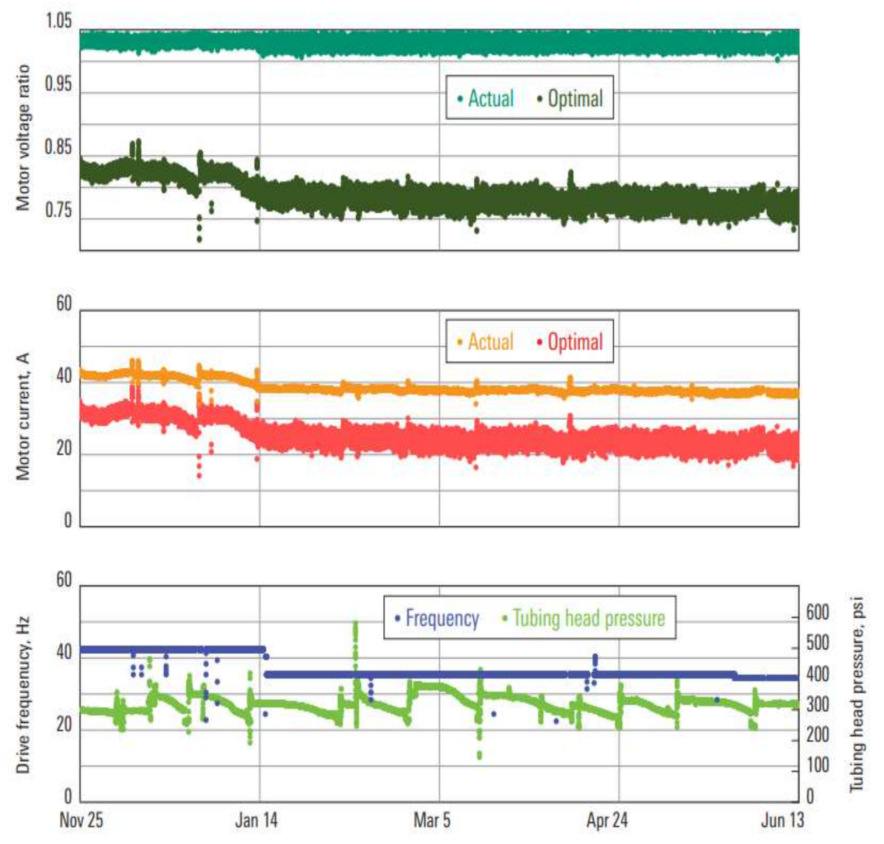
Reduction in voltage:

- **38% power saving** (156 KVA vs 248 KVA)
- Run Life Increase
  - Motor Temperature reduction
  - Motor Voltage reduction

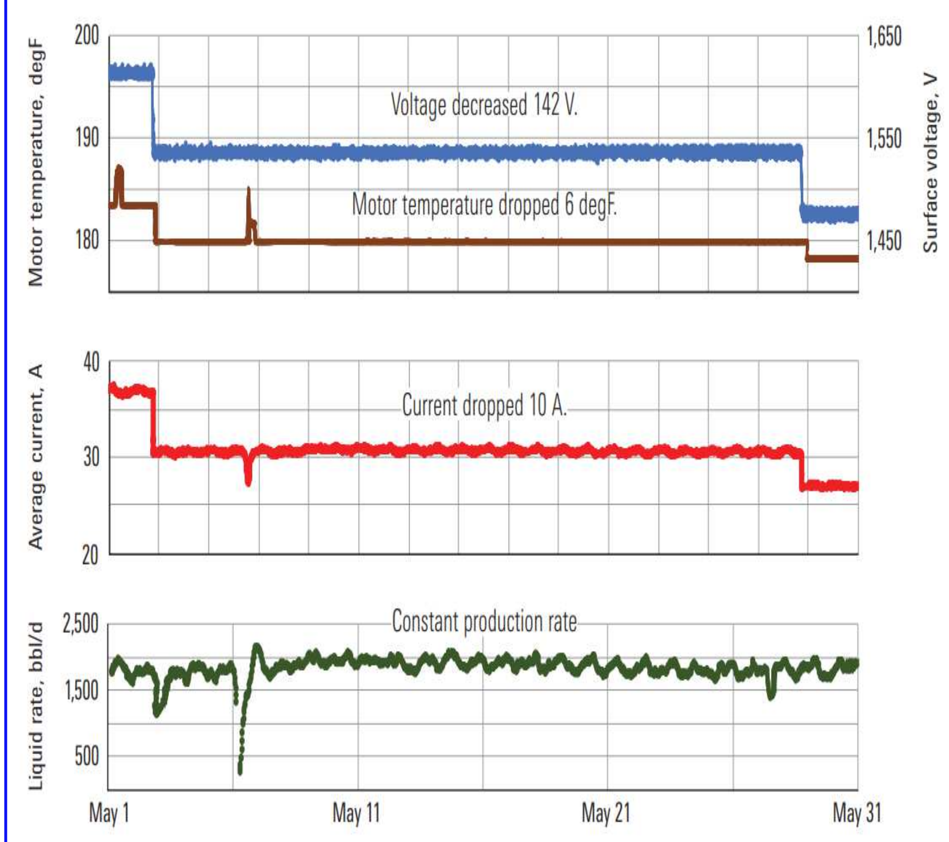
Achieved without any loss in production

Automation & 2 Way Control

Compare Potential to Actual



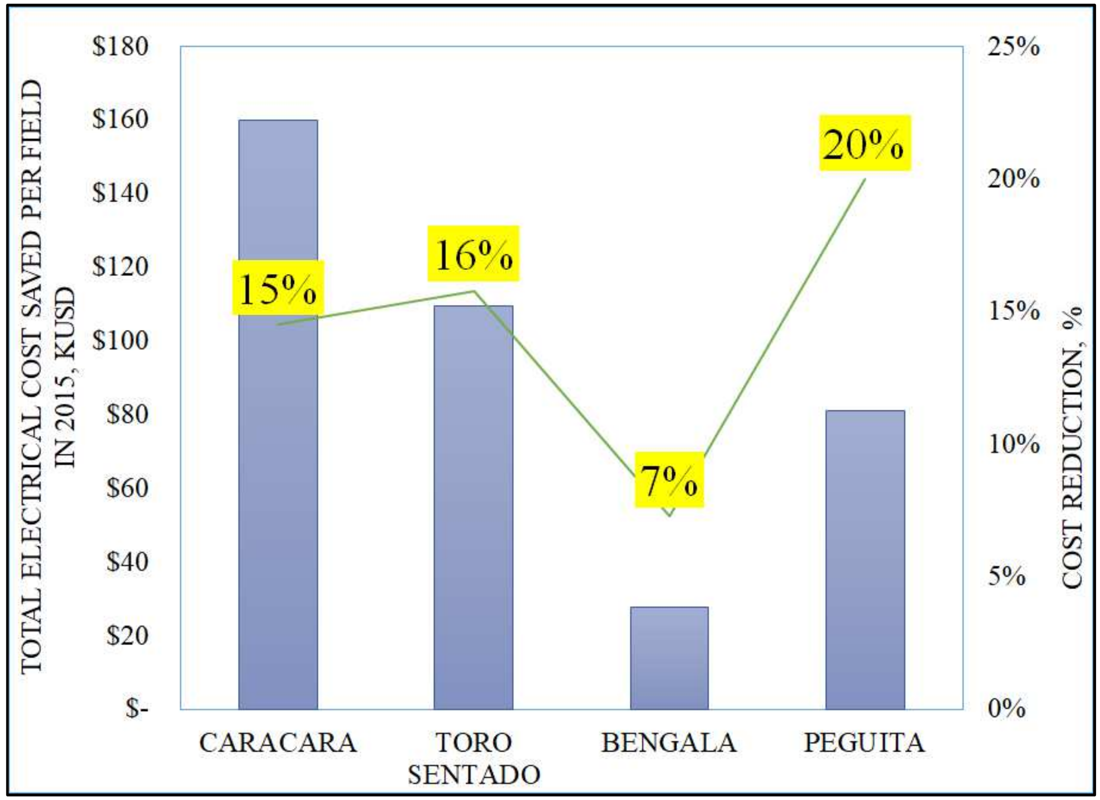
2-way control enables "baby steps"



Cost Reduction – Field Wide Energy Saving

- 24 wells
- Total Power Cost = 2.4M$ / month
- Saving= 380k$/month = 14%

- Industry pay-back period on energy savings is between 0.8 & 1.2 years with savings of 30 M$ in 2010 (source IAC 2017)
- For ESP wells, the pay-back period is zero as real time data is available anyway



SPE-184006-MS

Electrical Cost Optimization for Electric Submersible Pumps: Systematic Integration of Current Conditions and Future Expectations
A. Nieto, D. Brinez, J.E. Lopez, P. Marin, S. Cabrera, D. Paya, R. Arismendi, Cepsa Colombia. L. Fernandez, J. Villalobos, E. Cifuentes. Artificial Lift, Schlumberger.

VALUE OBJECTIVES

1. Run Life
2. Power Consumption
3. **Uptime**
4. Production Enhancement

SPE DISTINGUISHED LECTURER

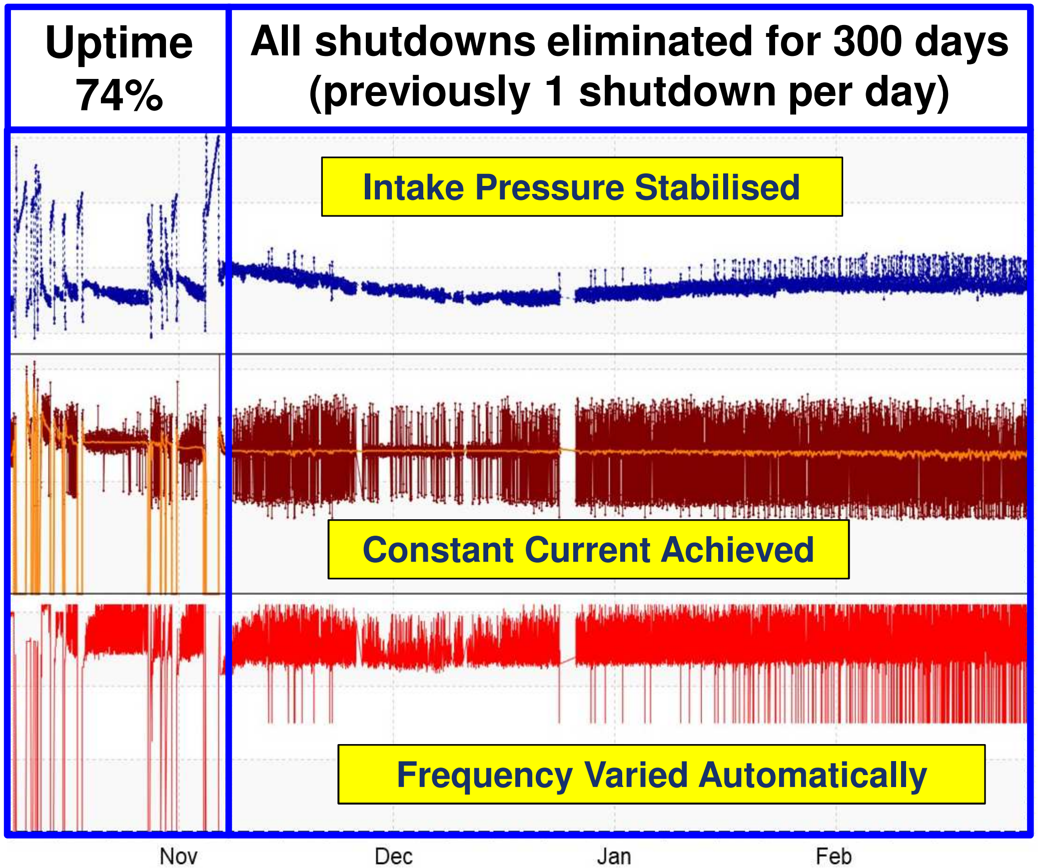
The Main Causes of ESP Downtime

1. Facility shut-downs e.g. electrical power interruption.
2. ESP stops automatically triggered by the motor controller to protect the ESP from low flowrate / Overheating.

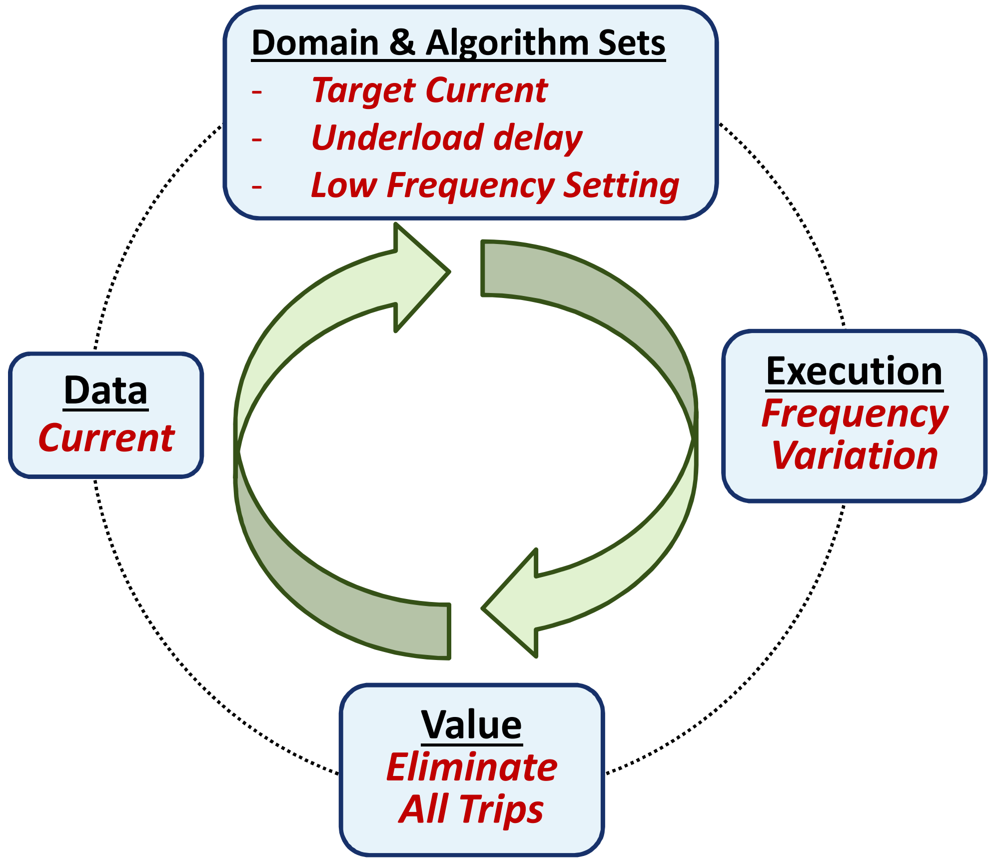
Deadheading:	Usually caused by inadvertent valve closure
Pump-off	Loss of submergence caused by pump rate greater than inflow
Gas Lock:	Gas degradation ➔ low flow ➔ stalling / no flow to surface

3. Pump performance degradation due to:
    - Mechanical Wear
    - Free gas
    - Viscosity

Improving Uptime with ***FAST LOOP*** – Gas Lock



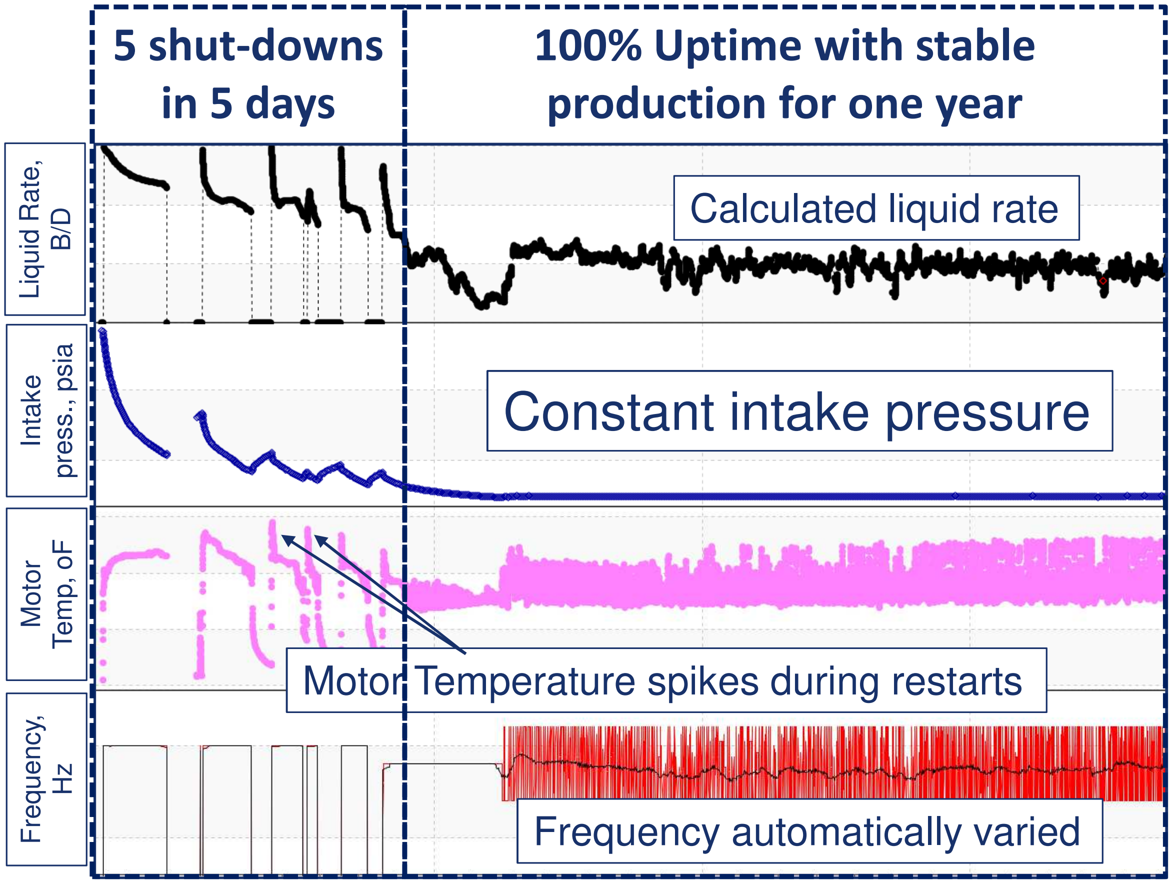
Courtesy of SPE-190940-MS; Tuning VSDs in ESP Wells to Optimize Oil Production—Case Studies



Improving Uptime with ***FAST LOOP*** – Pump Off

Challenge:
Low PI well with some gas tripping on underload causing downtime.

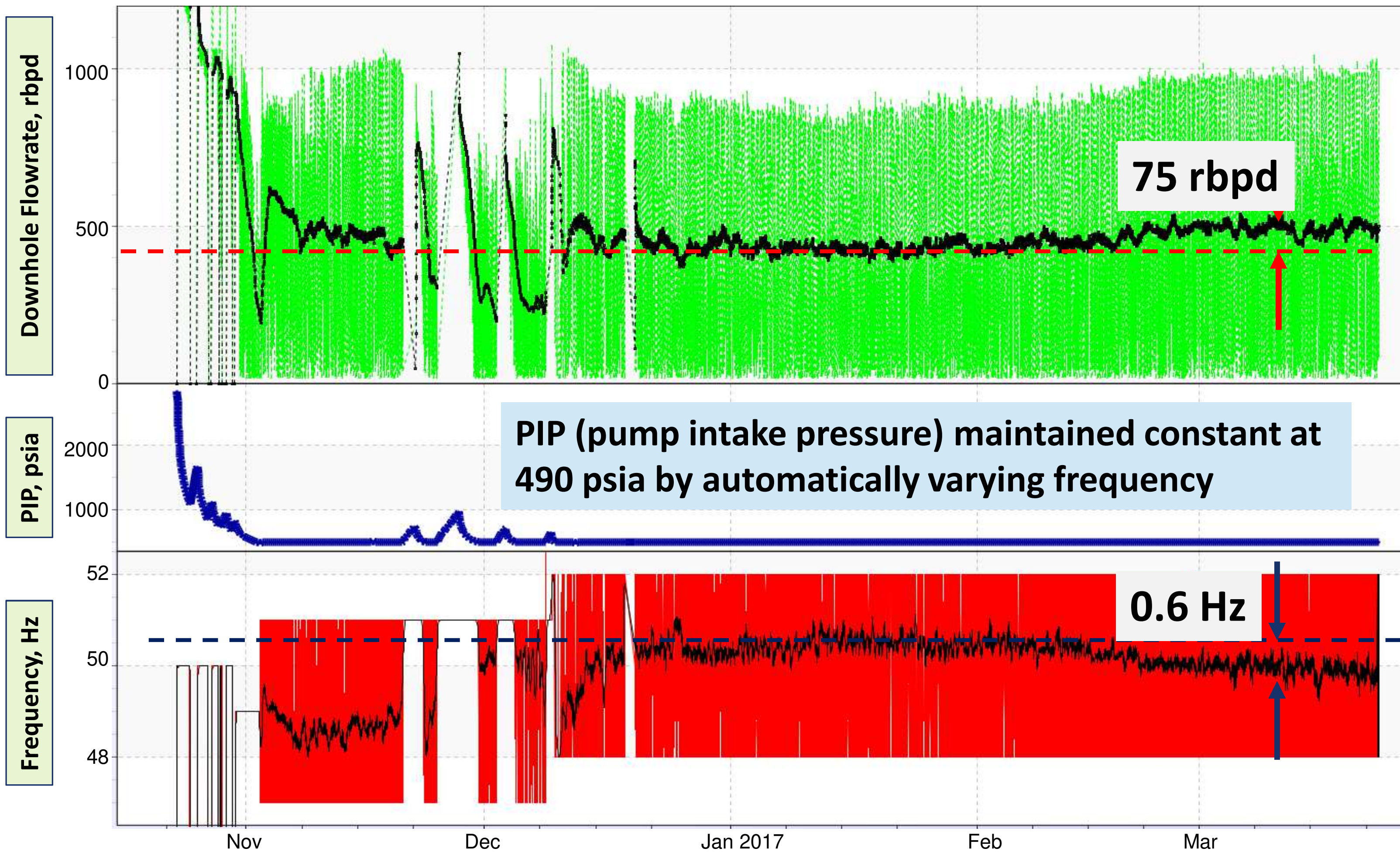
Solution
Constant intake pressure feedback mode➔ maintains drawdown and avoids tripping.



Courtesy of SPE-190940-MS; Tuning VSDs in ESP Wells to Optimize Oil Production—Case Studies

Inflow Surveillance with Constant PIP Mode

High frequency & high resolution rate measurement enables detection of increase in rate of 75 rbpd despite large variations in rate due to frequency oscillations & production tubing slugging due to liquid loading



Measuring Pump Degradation
PHI - Pump Health Indicator*

Identify degradation :

- **Without flowrate or well test**
- **Use commonly available real-time data**

$$\mathbf{PHI} = \frac{\left(\frac{DP}{Power}\right)_{actual}}{\left(\frac{DP}{Power}\right)_{reference}} = \frac{C_\eta}{C_q}$$

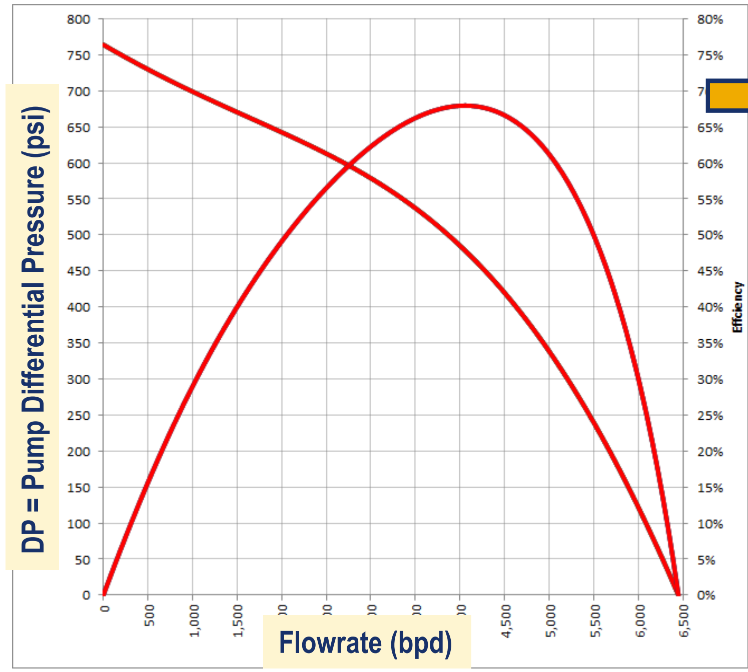
$C_\eta = \eta_a / \eta_r$	Efficiency Degradation
$C_q = Q_a / Q_r$	Flow Degradation
DP = Pd-Pi	Pump Differential Pressure
Power	Pump Absorbed Power = Power generated by motor

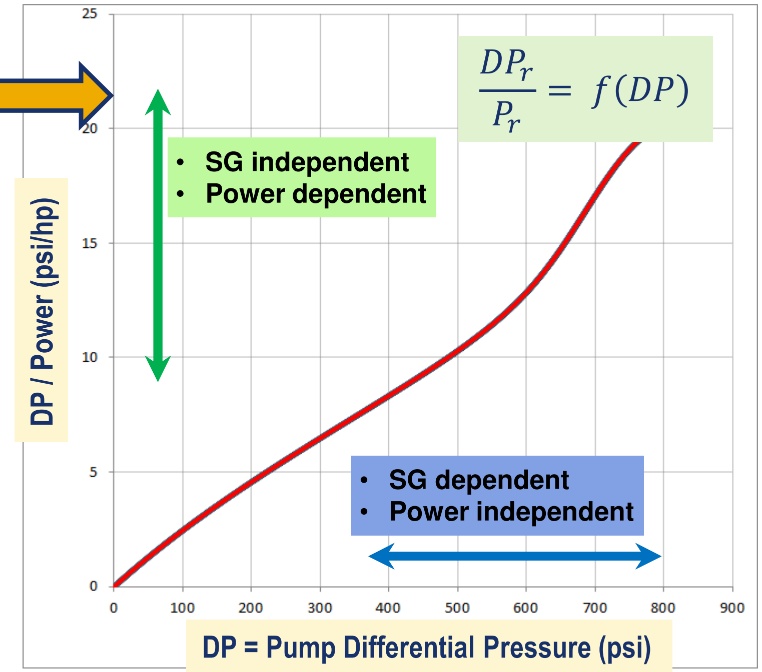
Enables:

- **Monitori Pump Health in Real Time - Downtime can be caused by degradation**
- **Calibrate Flowrate Models where well tests are not available for calibration**

The Alternative Reference Curve

Remove dependency on Flowrate & Specific Gravity



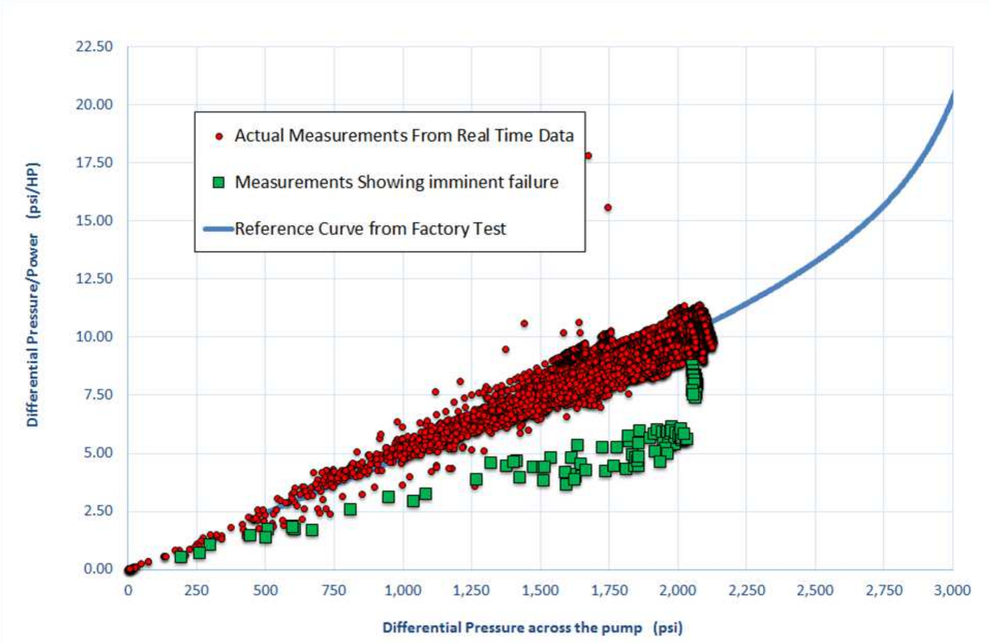


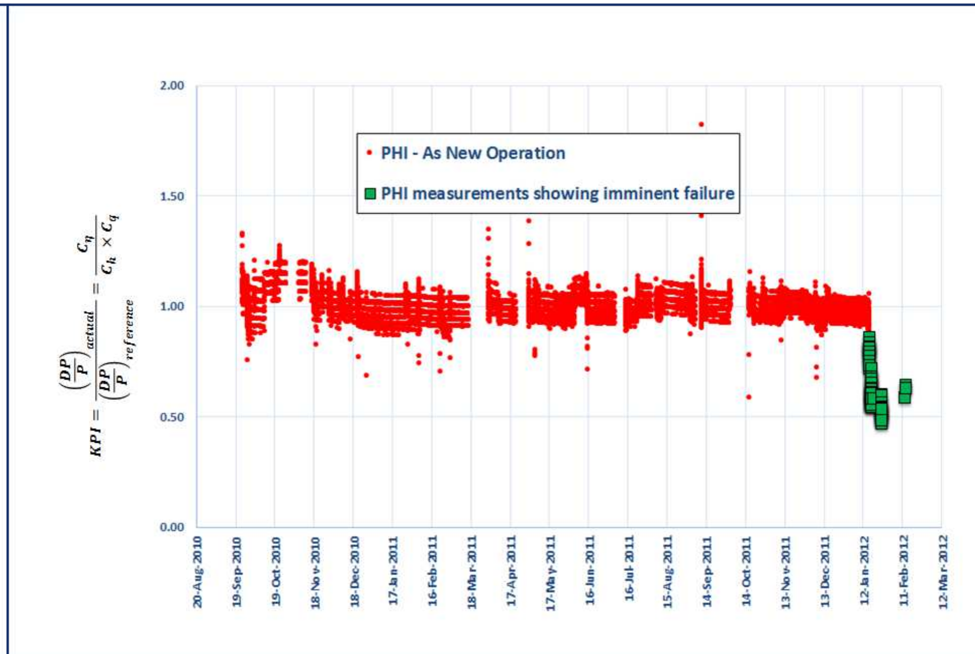
Conventional **WITH** Flowrate

NEW **WITHOUT** Flowrate

Pump Health Indicator (PHI)
…independent of flowrate

No Degradation for 16 months identified without well test i.e. knowledge of flowrate and SG.

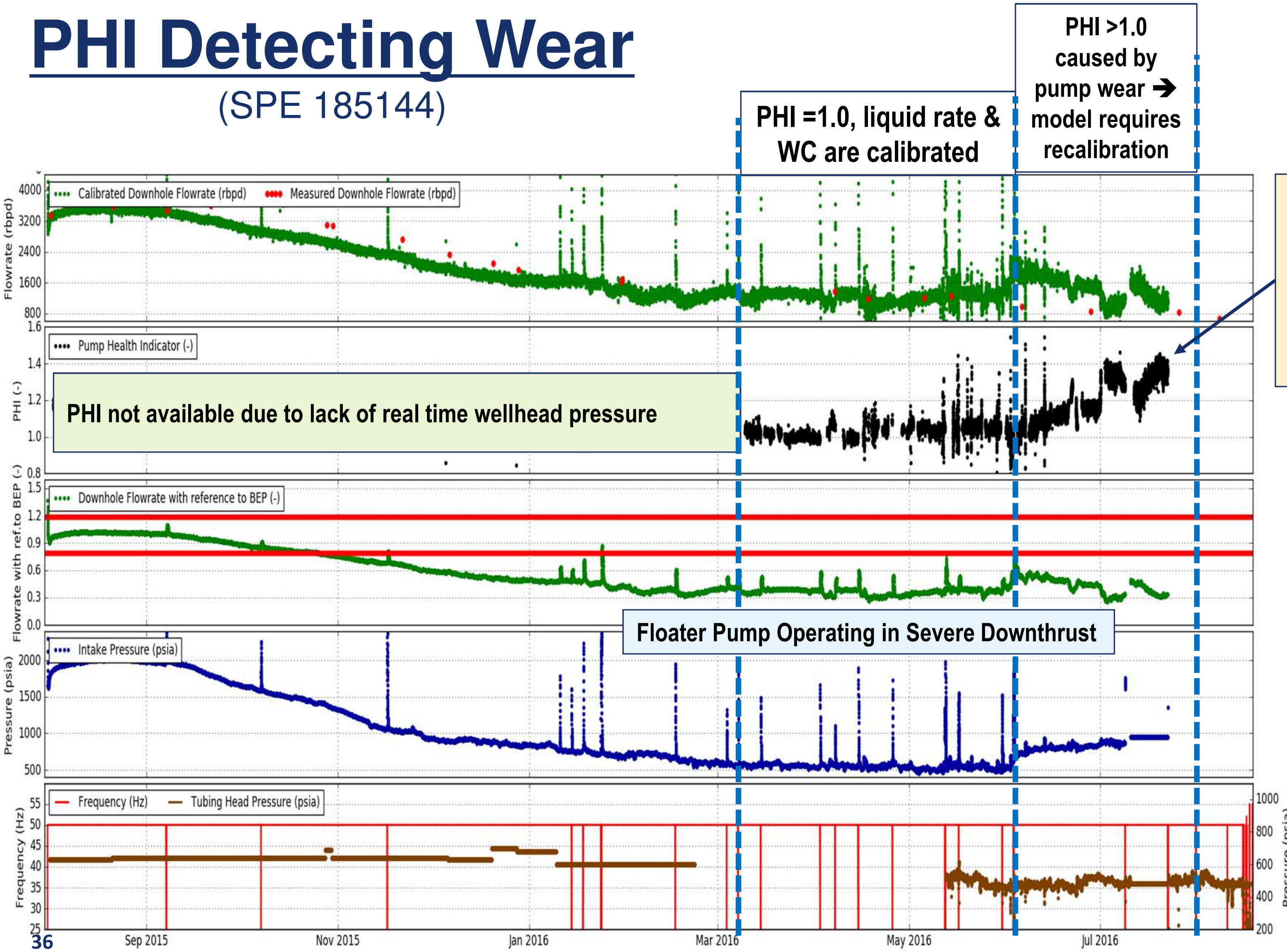




SPE paper 176780

PHI Detecting Wear

(SPE 185144)

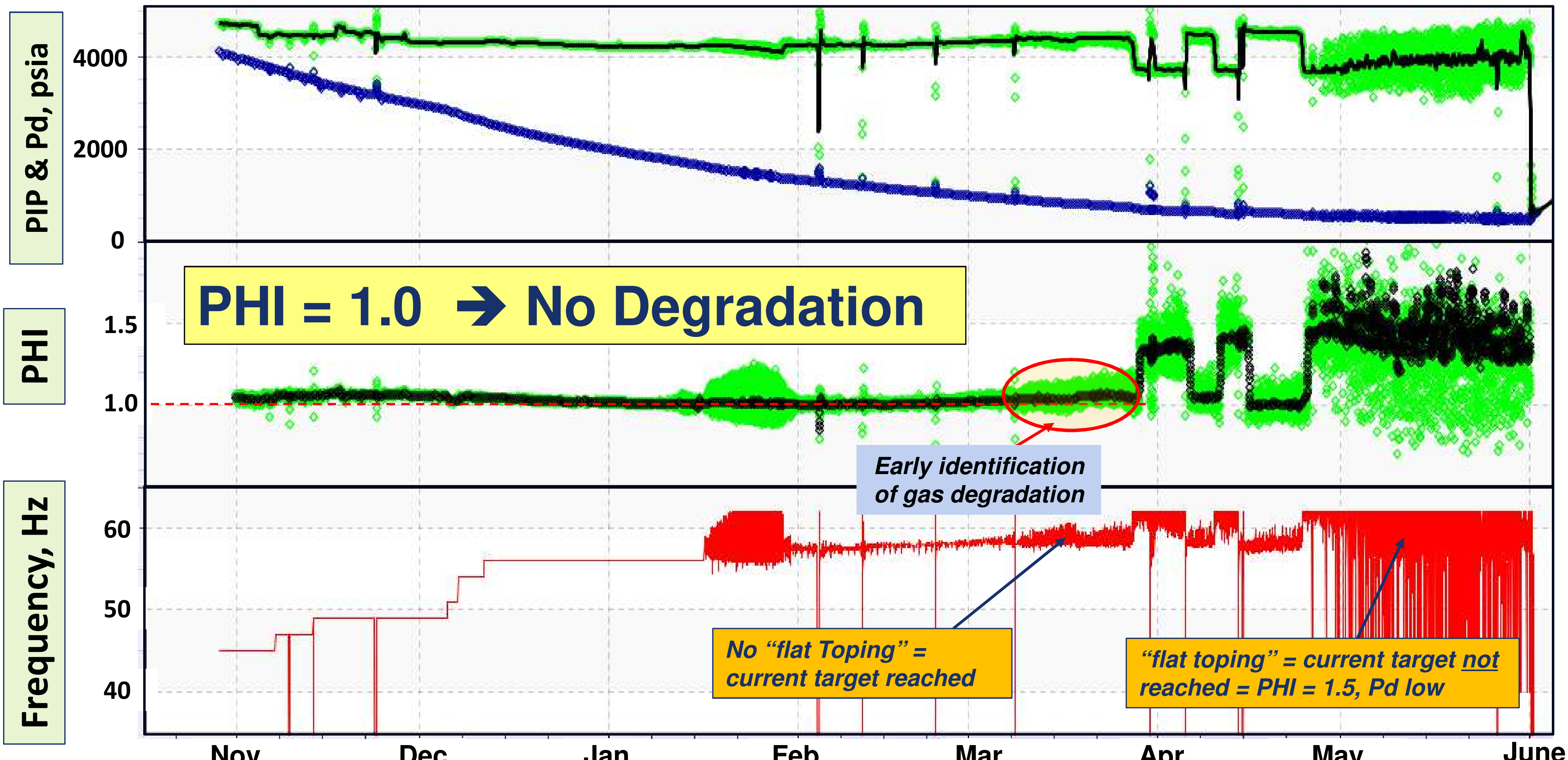


Rise in PHI detects pump mechanical wear after prolonged operation in downthrust in sandy environment

Pump Operating in downthrust in sandy environment cause of wear

Intake pressure rising with drop in production

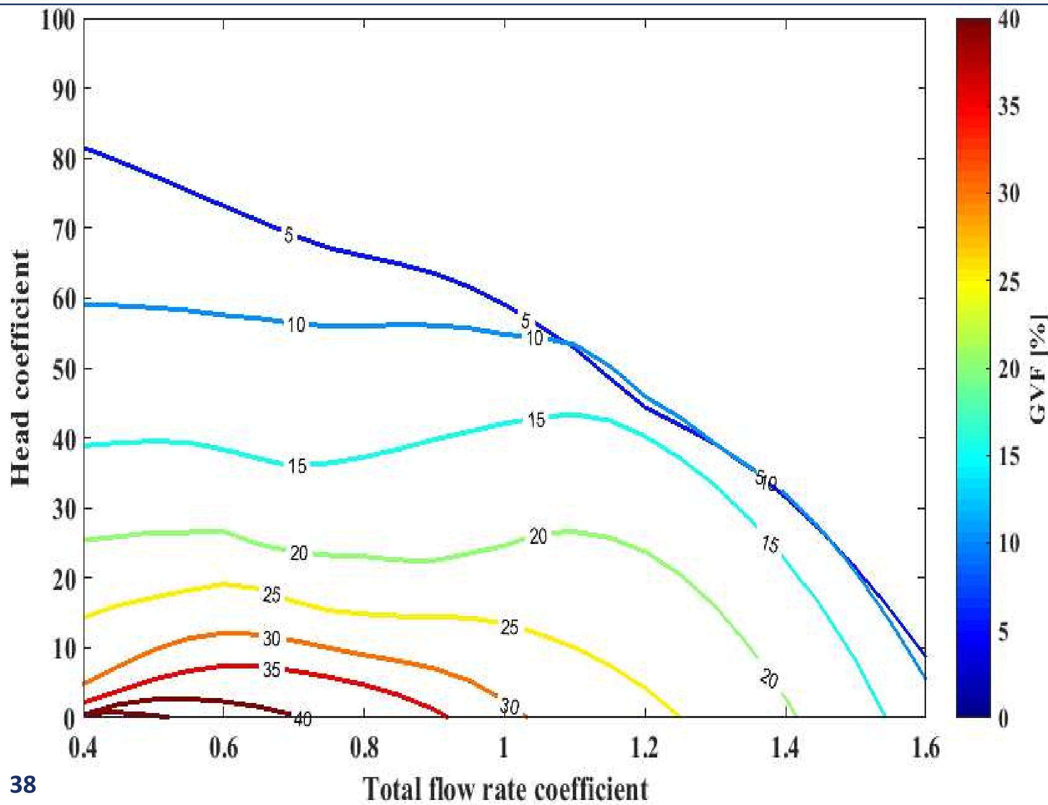
PHI = Pump health Indicator ➔ Detect Gas Degradation



Increased Gas Degradation at Operating Point < BEP

Multiple Stages – Schlumberger Test

Less severe as the GVF is lower closer to discharge of pump as gas is compressed



Single Stage – Tulsa University

Courtesy of Gamboa, J. and Prado, M., 2012, Experimental Study of Two-Phase Performance of an Electric-Submersible-Pump Stage, SPE-163048-PA.

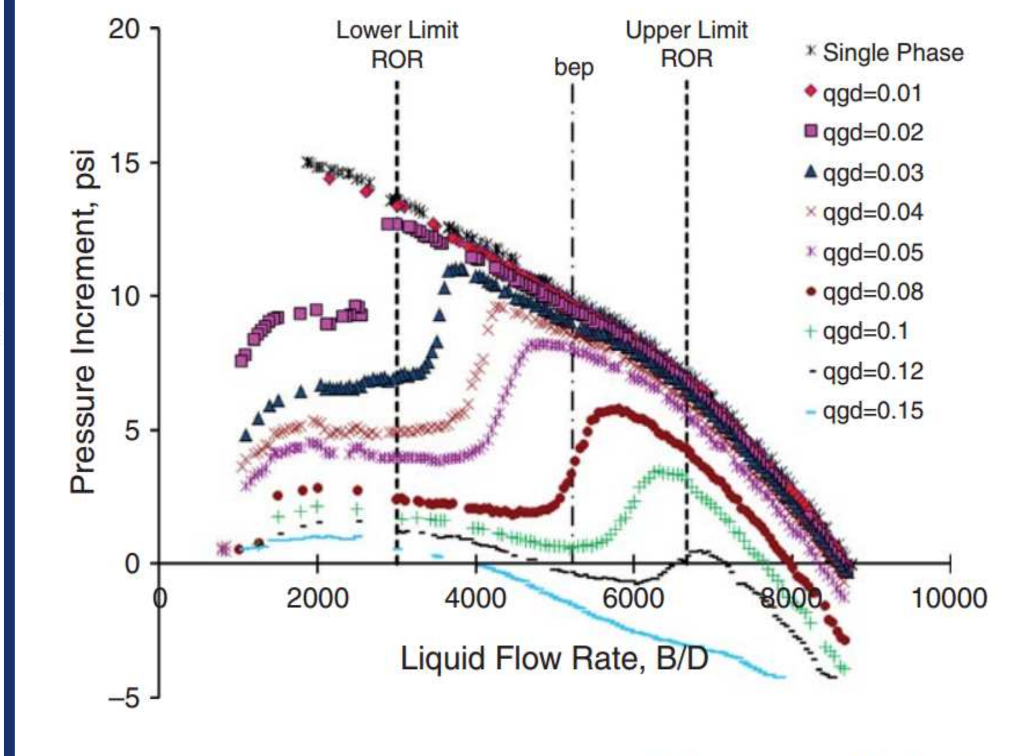
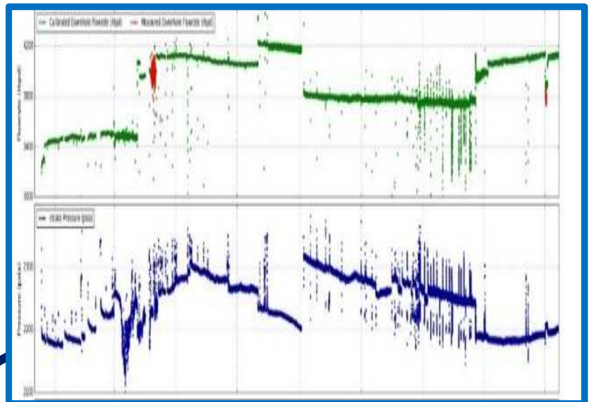


Fig. 1—Mapping performance curves at 3,000 rpm and 150 psig.

VALUE OBJECTIVES

1. Run Life
2. Power Consumption
3. Uptime
4. **Production Enhancement**

The Value of High Frequency Flowrate & Pressure

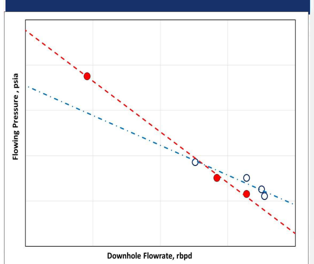


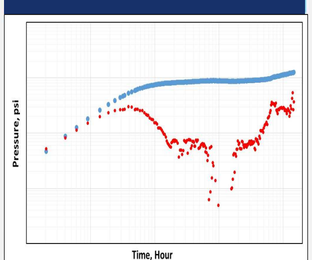
Liquid Rate

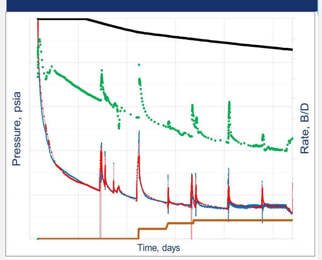
Pressure

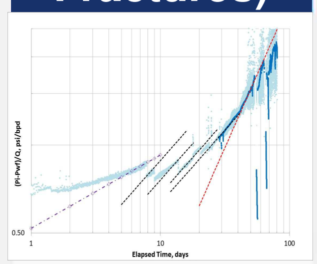
Downhole Measurement with:
- High Frequency
- High Resolution
- High Repeatability

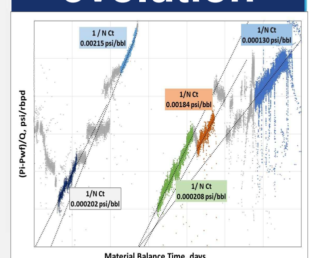
IPR on the fly	PTA in drawdown	Skin and depletion evolution	Reservoir Flow regime (e.g. Fractures)	Reserves & Drainage area evolution











Fast Loop | **Slow Loop**

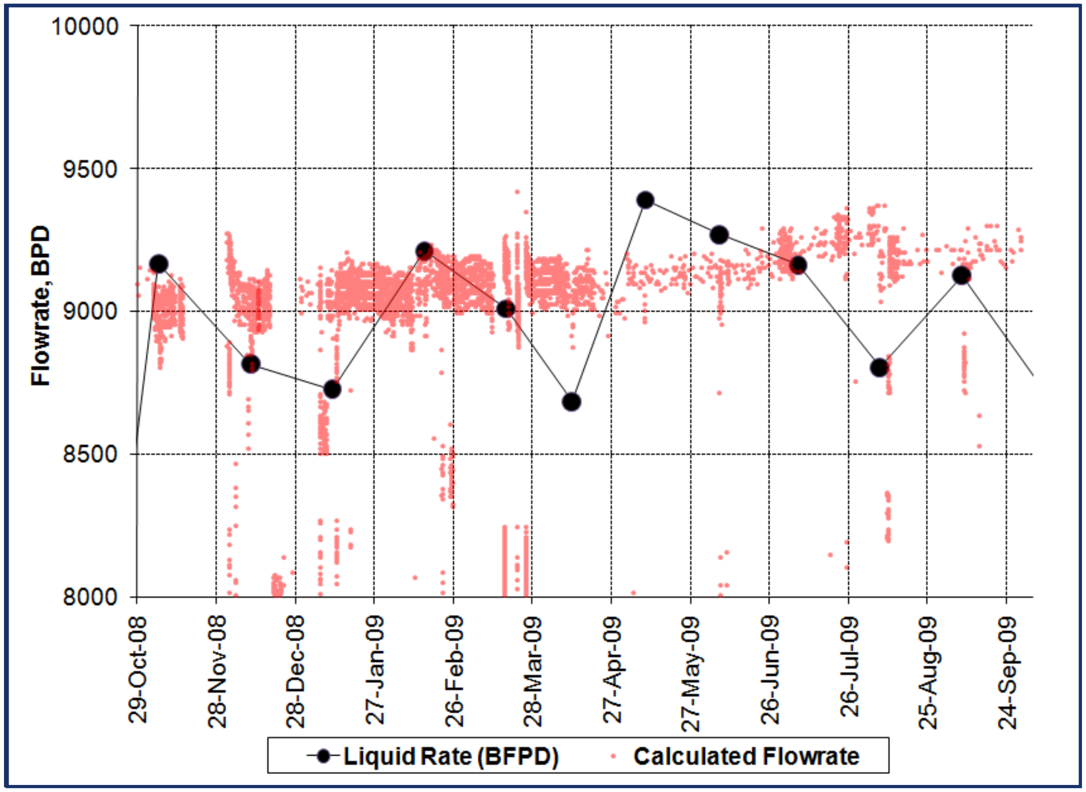
Without Build-ups

Flowrate trends….

- High frequency
- High resolution
- High repeatability

Discernible Trend

Accuracy not required for a trend



	Liquid rate from test separator	Calculated using real time data
Frequency	1/month	1/min
Accuracy	±5%	same
Resolution	?	<100 bbl/d
Repeatability	Poor	HIGH
Discernible Trend	NO	YES

One Possible Method of real time rate estimation…

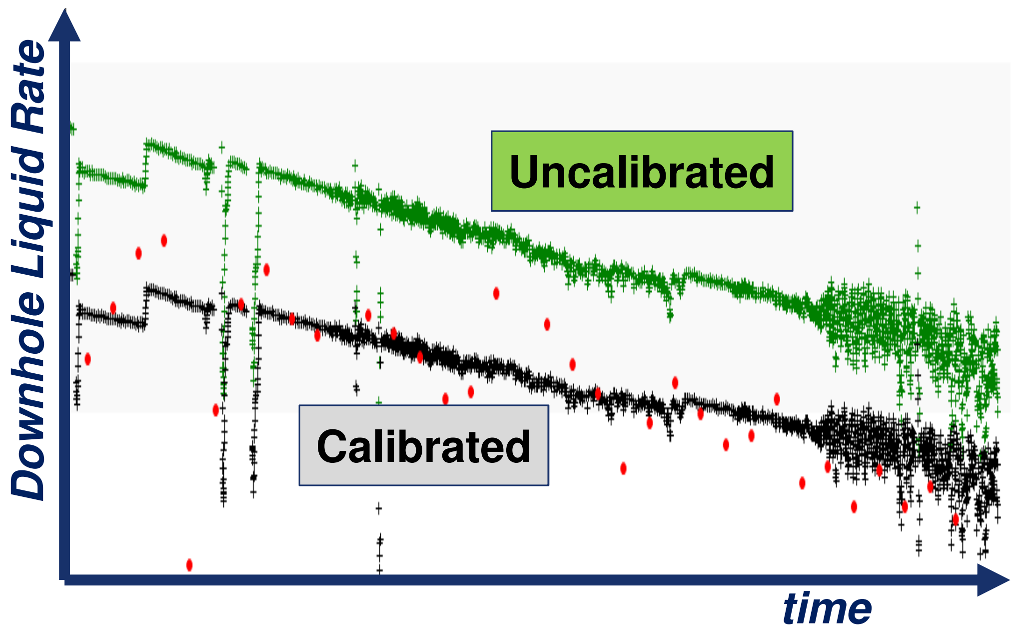
- **High frequency**
- **High resolution**
- **High repeatability**

Pump-absorbed Power = Motor-generated Power

$$\frac{(P_d - P_i) \times Q_p}{58847 \times \eta_p} = \frac{V \times I \times PF \times EFF \times \sqrt{3}}{746}$$

No need for additional hardware

1. Proven from first principles ➔ Always true
2. Equation is density independent:
   - Valid with changing WC
   - Can handle phase segregation
3. Analytical equation ➔ derivative provides resolution
4. Type Curve ➔ Shape does not change with calibration.
5. Valid across the full range of the pump curve irrespective of pump type.
6. Flow rate measurement at the exact same time as pressure
7. Independent of formation volume factor.



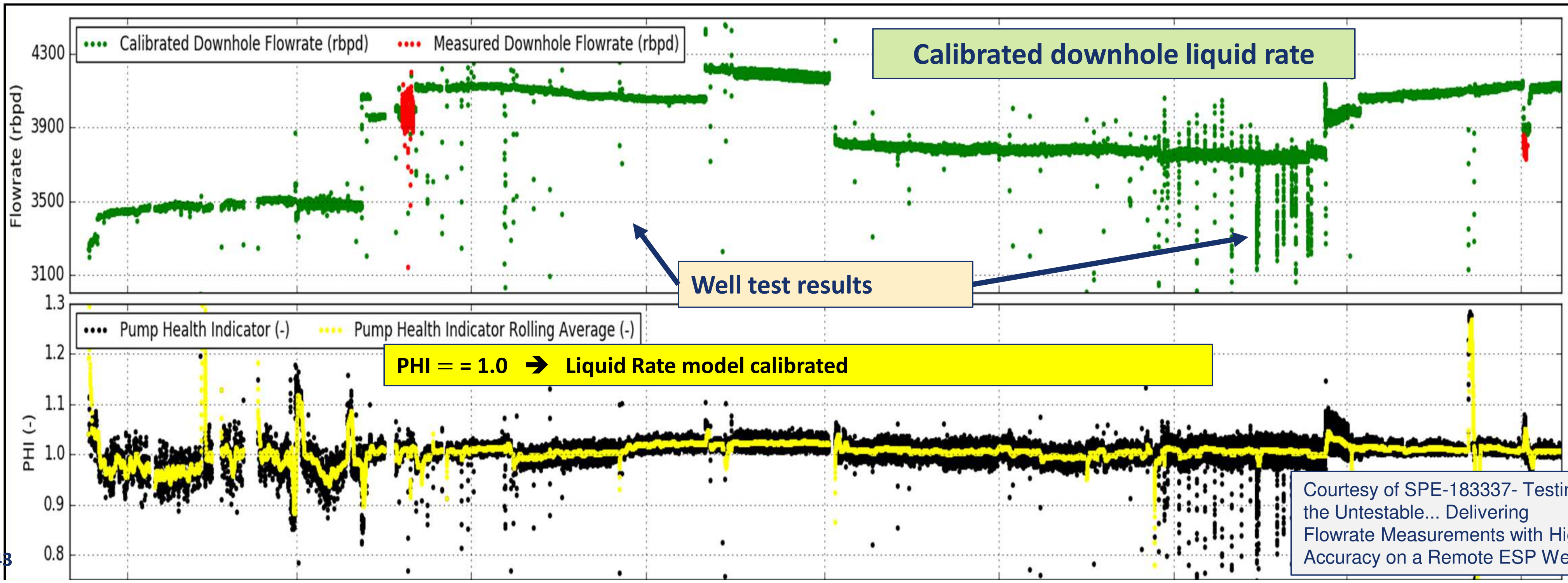
URTEC 2475126 - ESP Real-Time Data Enables Well Testing With High Frequency, High Resolution, and High Repeatability in an Unconventional Well

PHI Calibration Achieves Rate Accuracy < 2.5%

- Following ESP start-up initial calibration based on PHI (Pump Health Indicator) =1.0 as
  - Pump is new ➔ no wear
  - Based on PVT ➔ No Viscosity or gas degradation
- If PHI remains constant at 1.0 ➔calibration is maintained

Accuracy achieved

- **SPE 183337: Accuracy <2.5%**
- **SPE 2471526: Accuracy < 1%**



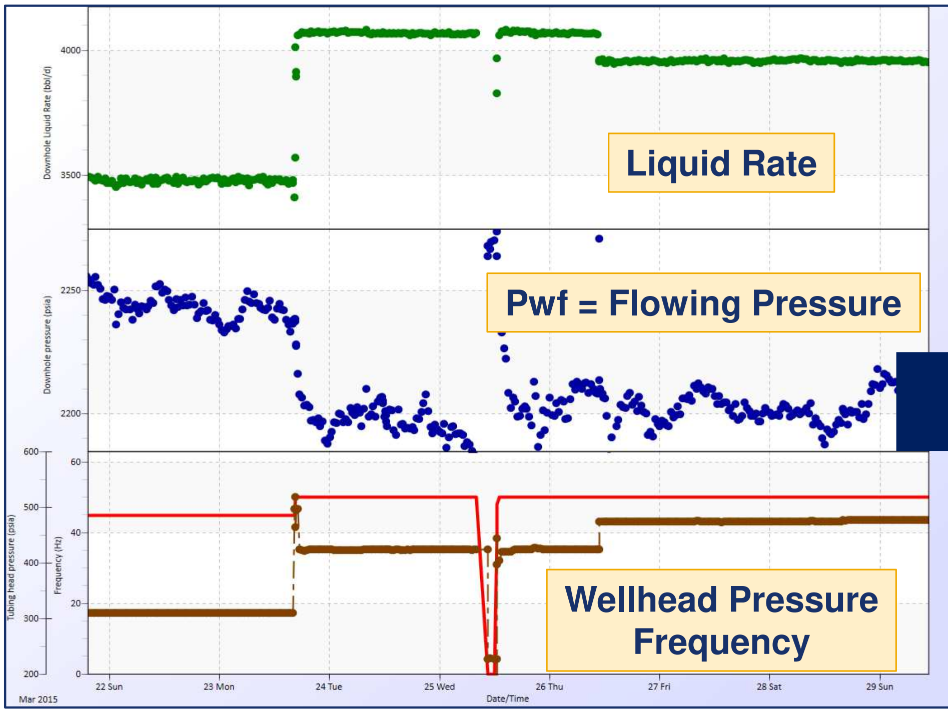
Courtesy of SPE-183337- Testing the Untestable... Delivering Flowrate Measurements with High Accuracy on a Remote ESP Well

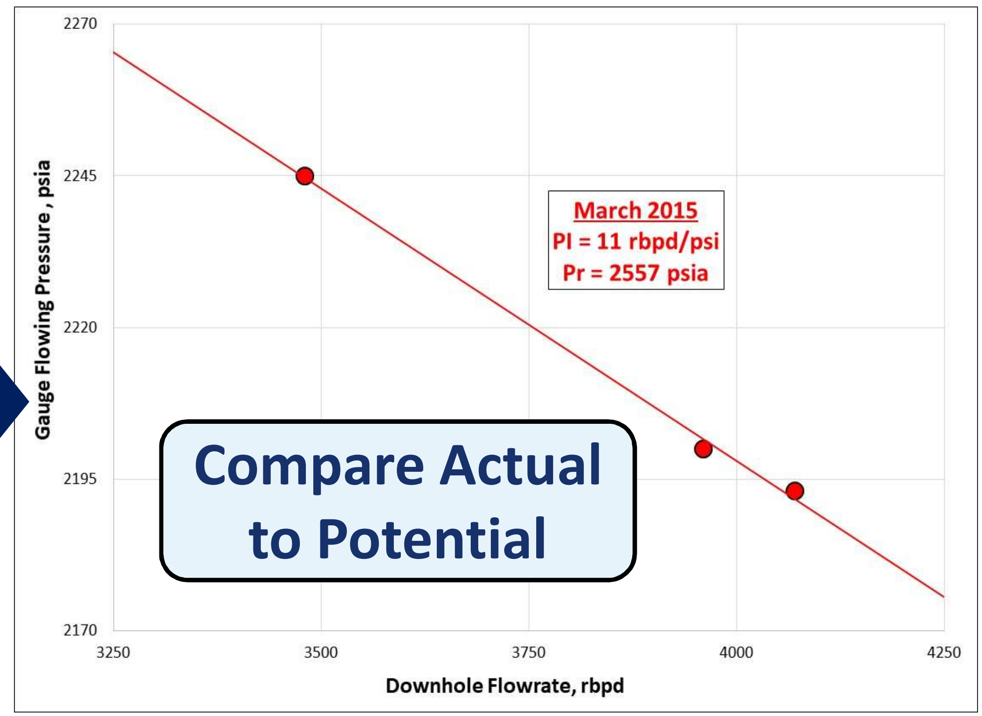
IPR on the fly without build-ups

Small changes in frequency and wellhead pressure provide multi-rate test opportunities

Enabled by flowrate and pressure with:

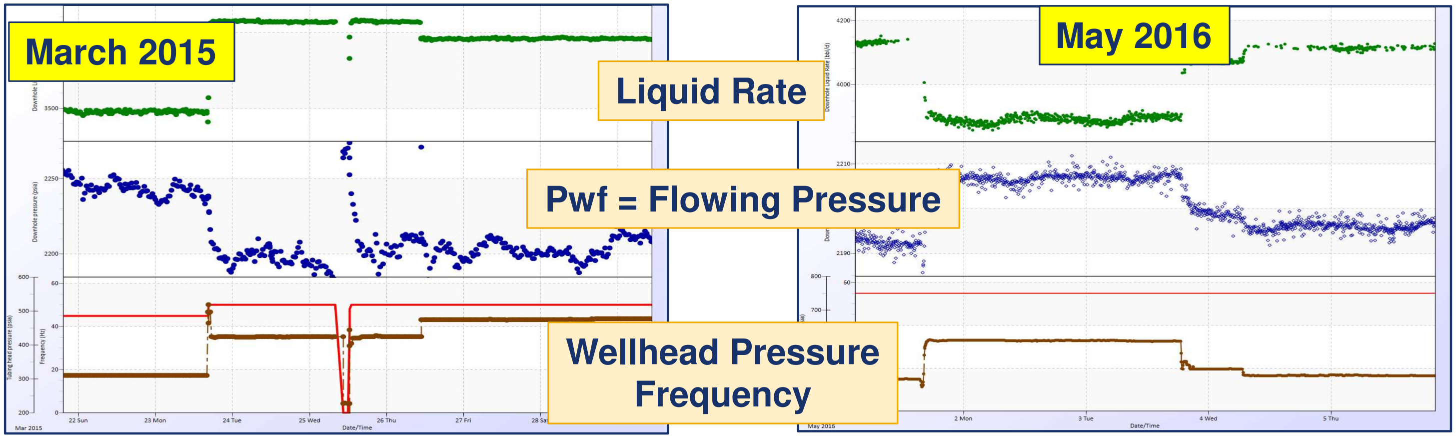
- High frequency = 1/min
- High resolution = <20 rbpd
- High repeatability

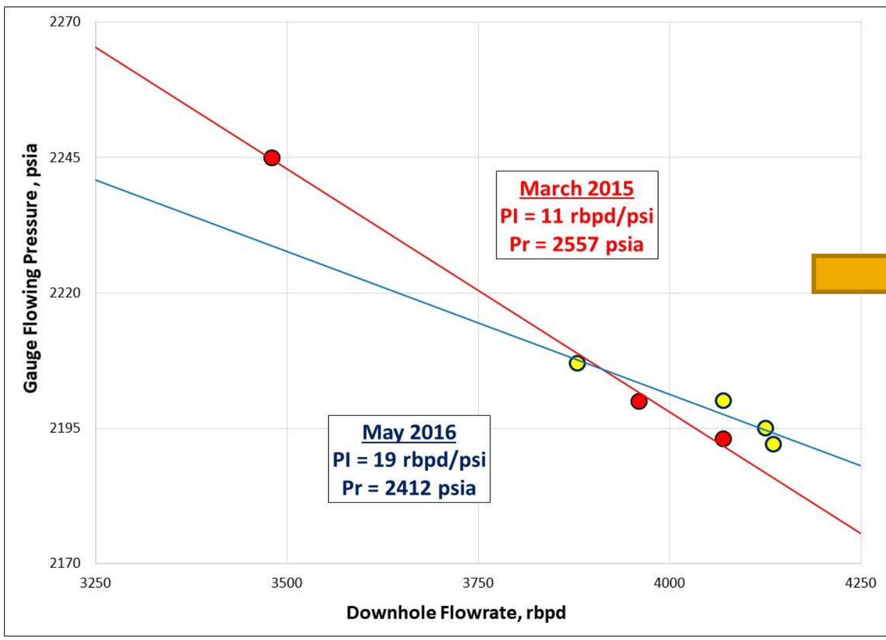




SPE paper 183337

IPR Measurement on the fly





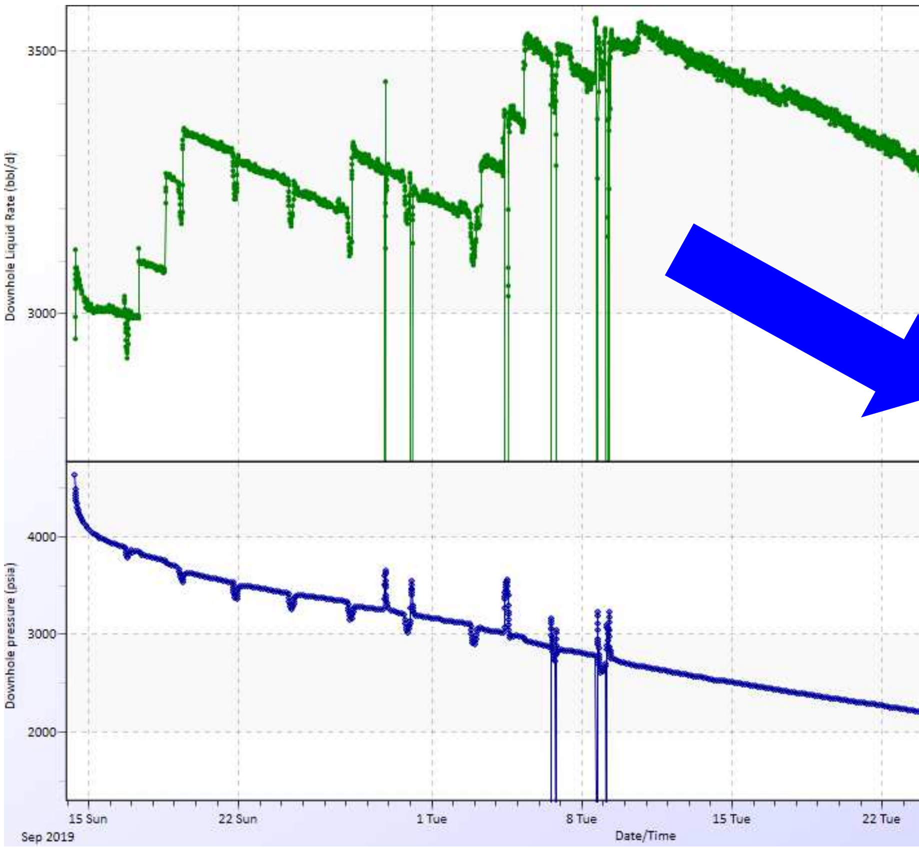
TIME LAPSED ANALYSIS

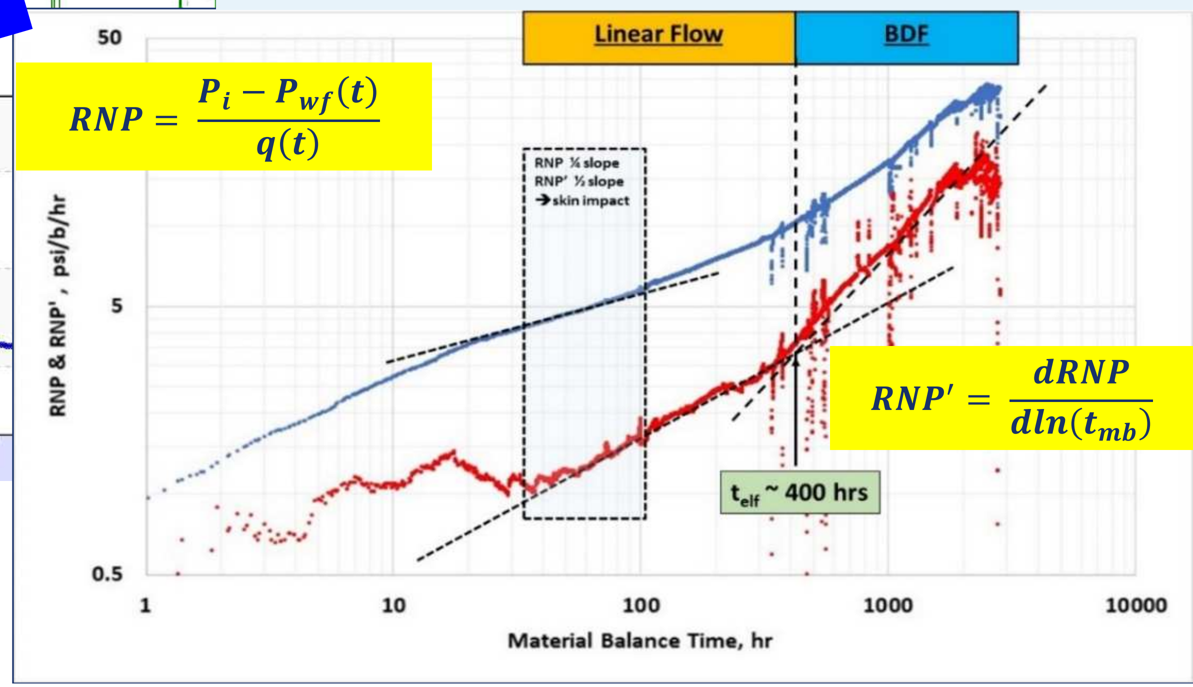
1. PI increase → no skin increase
2. Depletion is circa 145 psi over this 14 month period using SIP technique

SPE paper 183337

Rate Normalisation…even with multiple discreet rate steps

Rate normalization is essential to generating a pressure response similar to that resulting from a constant flowrate and removing discreet changes in pressure (common to most commercial PTA and RTA software packages)





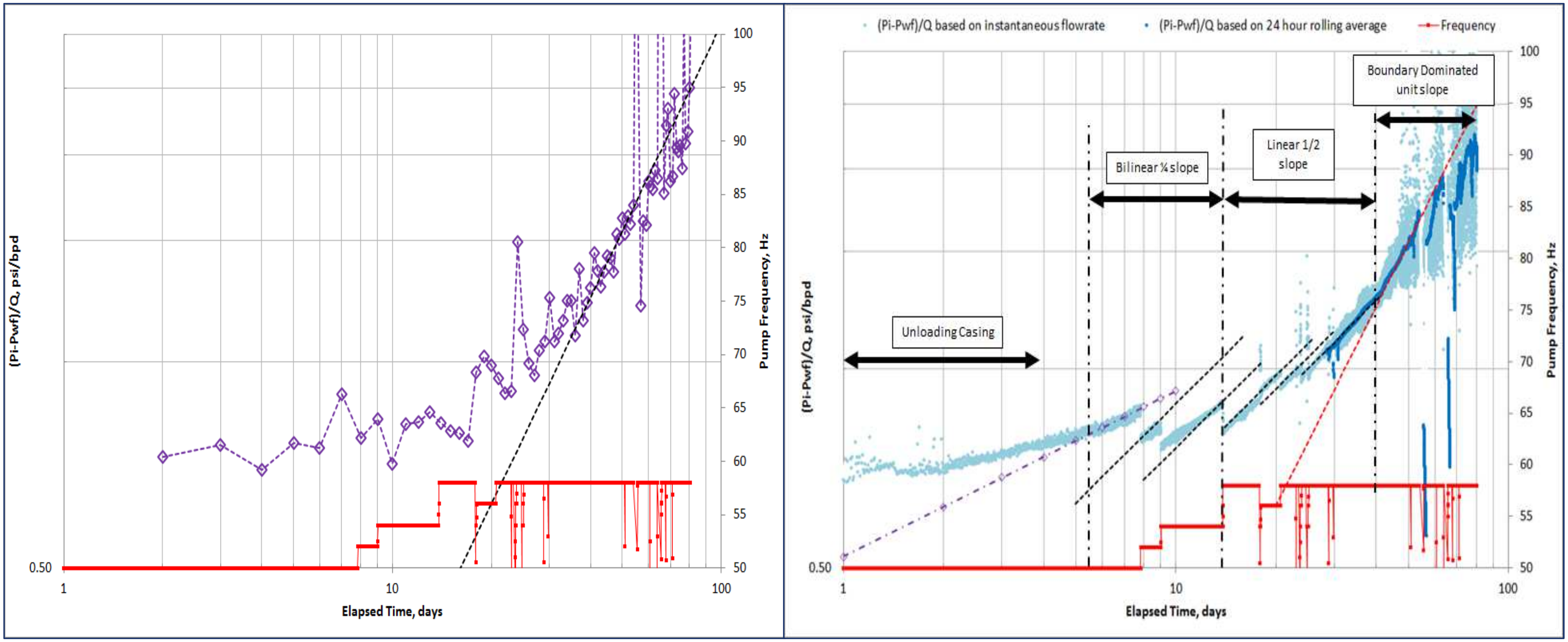
$$RNP = \frac{P_i - P_{wf}(t)}{q(t)}$$

$$RNP' = \frac{dRNP}{dln(t_{mb})}$$

High Frequency vs. Test Separator Flowrate

One cannot see transient fracture flow regimes with low frequency & low repeatability test separator data, even daily data is insufficient….

Example of a MFHW (Multiple Fractured Fracked Horizontal Well courtesy of Paper URTEC #2471526



PTA (Pressure Transient Analysis) in drawdown

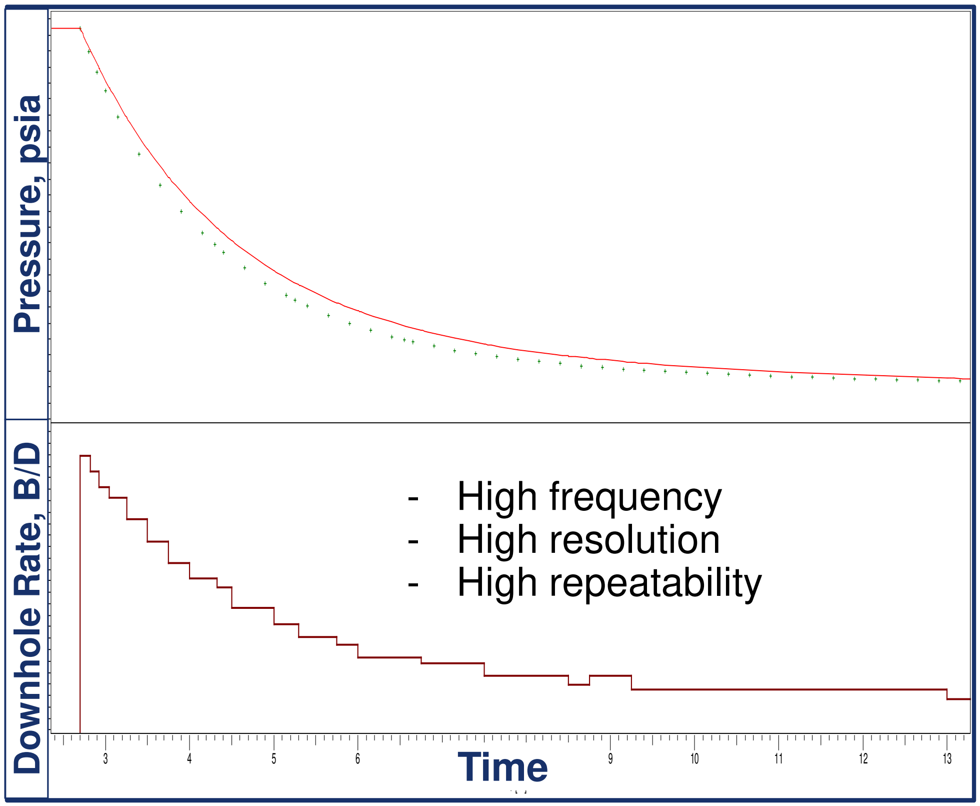
- **<u>Problem Statement:</u>**
  - PTA has a huge value for skin and boundary characterization, however traditionally requires build-ups due to lack of downhole transient rate.
  - However build-ups are associated with production deferment.
  - Also build-ups are rarely long enough to see boundaries.

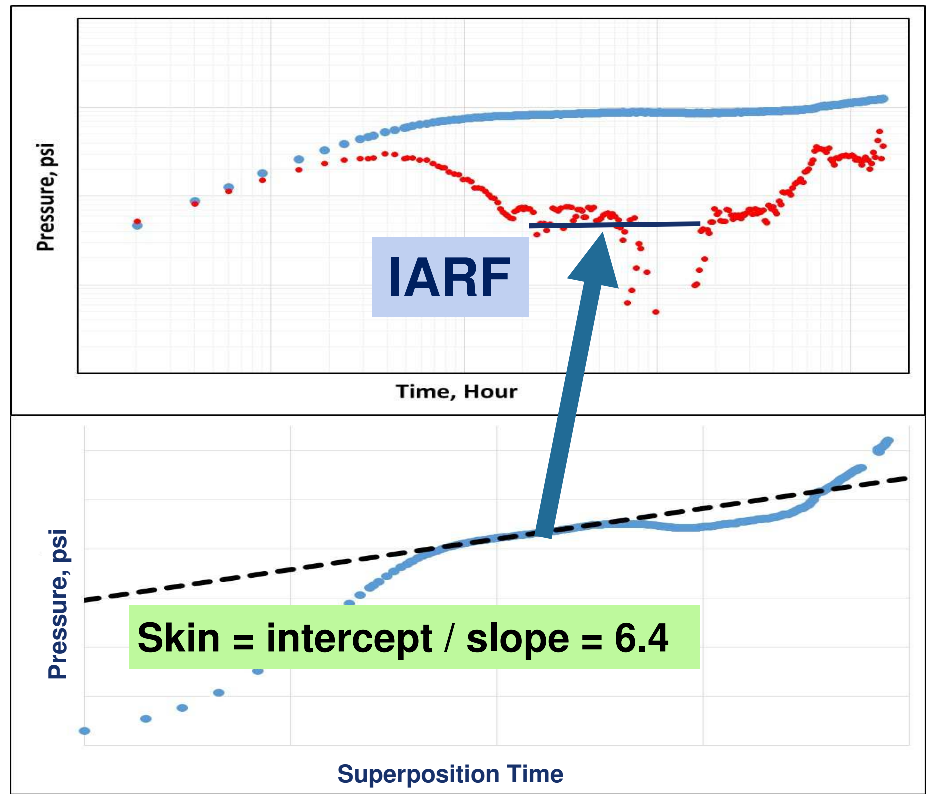
- **<u>The challenge:</u>** Drawdown PTA is mathematically equivalent to build-ups, however presents the following challenges:
  - Requires transient flowrate
  - High resolution ESP gauges ➔ Noisy derivative
  - Slugging wells

- **<u>The Solution:</u>**
  - Virtual flowmetering can provide downhole flowrate with high frequency and resolution
  - As flowrate is measured at the same point as pressure, there is no time lag between flow and pressure measurements.
  - Superposition time is enabled and provides smoothing
  - Drawdown means that one can wait to see boundary conditions.

Measuring Skin with Drawdown

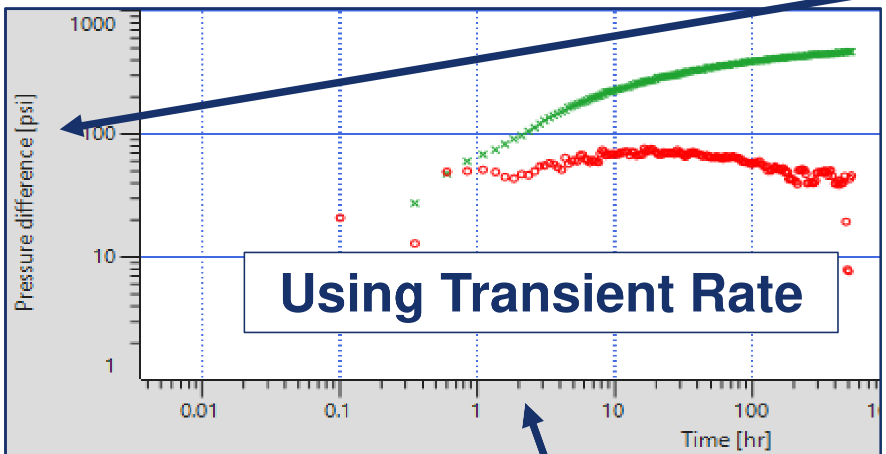
Example from SPE paper 185144 shows how rate data enables use of semi-log. This enables correct identification of IARF (Infinite Acting Radial Flow) and therefore skin measurement.

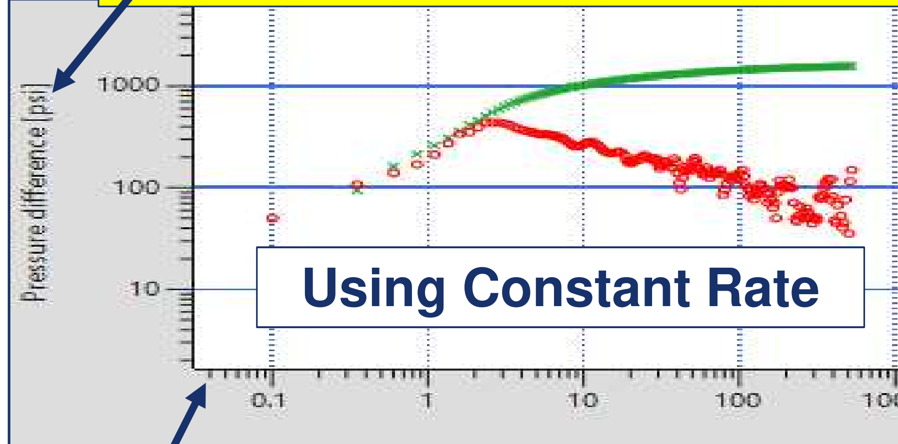


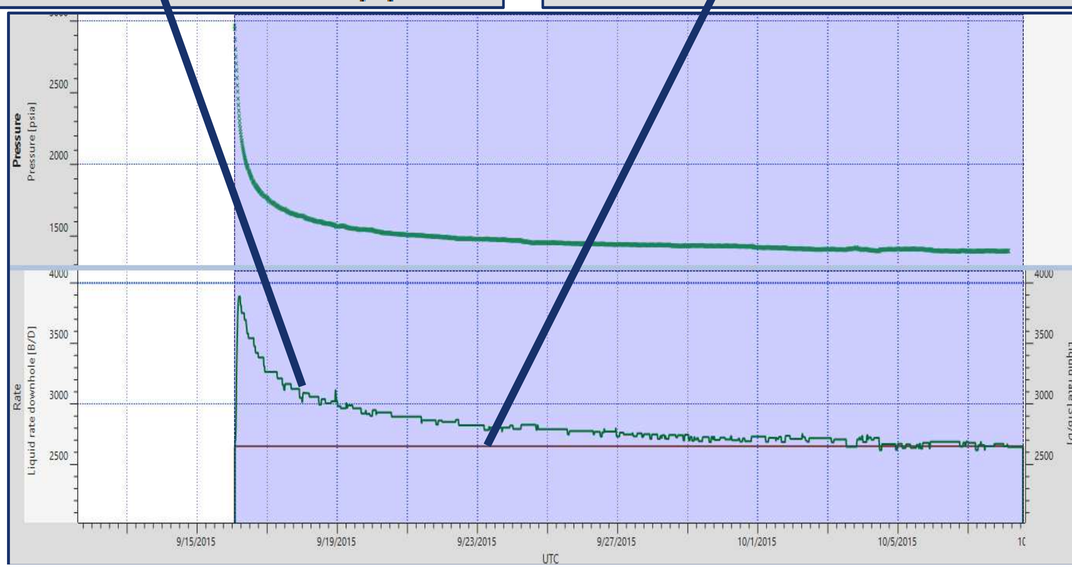


Why Transient Rate is so Important…

$$\text{Pressure} = \frac{\left(P_i - P_{wf}(t)\right)}{Q(t)} \times Q_n$$







The value of stimulation

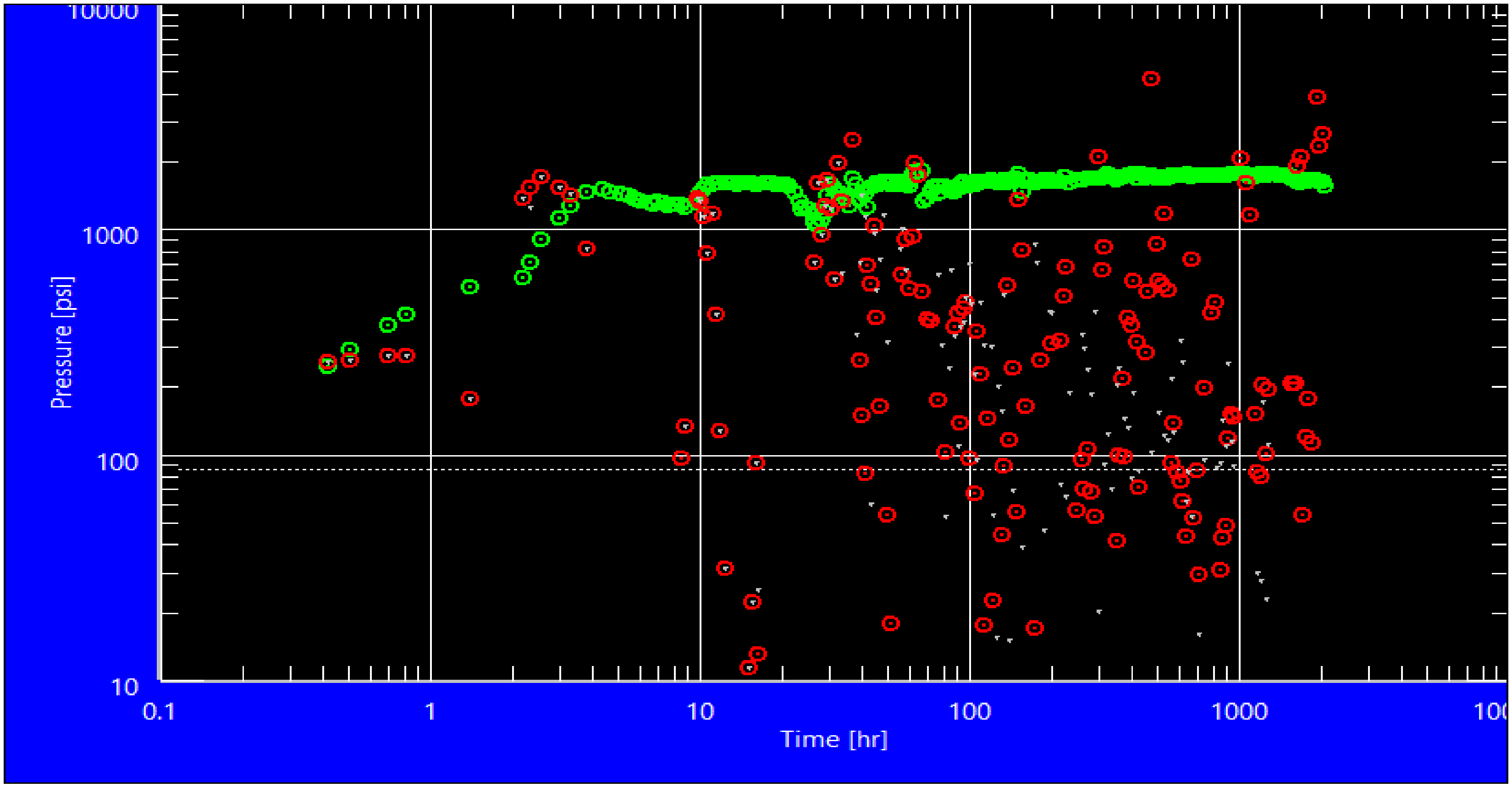
Compare Actual to Potential

Even where WC (Water Cut) is high and the absolute rate is relatively low, the value of skin remediation is high

	Before Stimulation	After Stimulation
Skin	6.4	0
PI	1.31 BPD/psi	2.21 BPD/psi
Pwf	740 psia	
Liquid Rate	1232 BPD	2089 BPD
Incremental Liquid Rate	0	857 BPD
WC	95%	95%
Incremental Oil Rate	0	43 BOPD
Incremental Annual Revenue @ 50 US$/bbl	0	782 k$

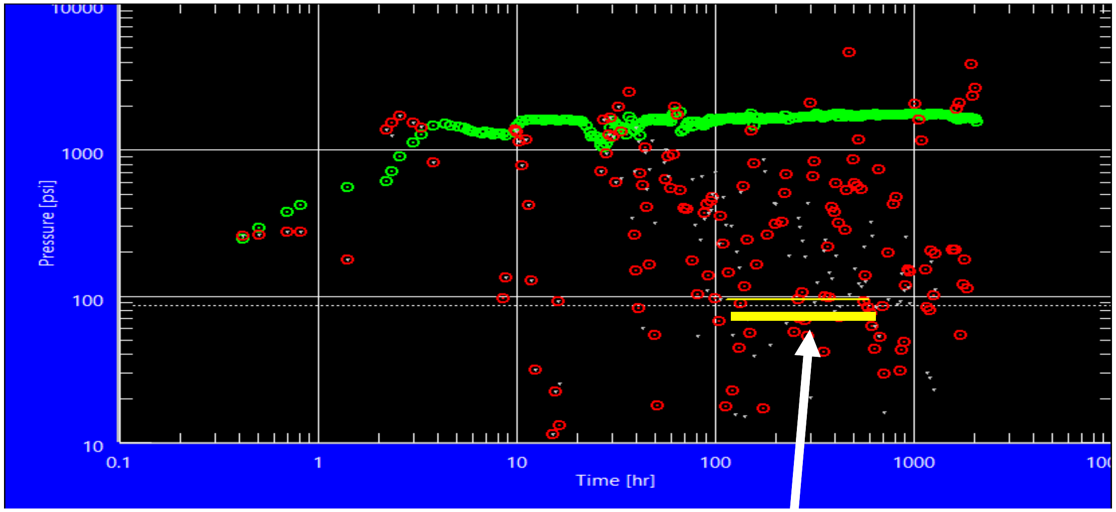
A common Problem

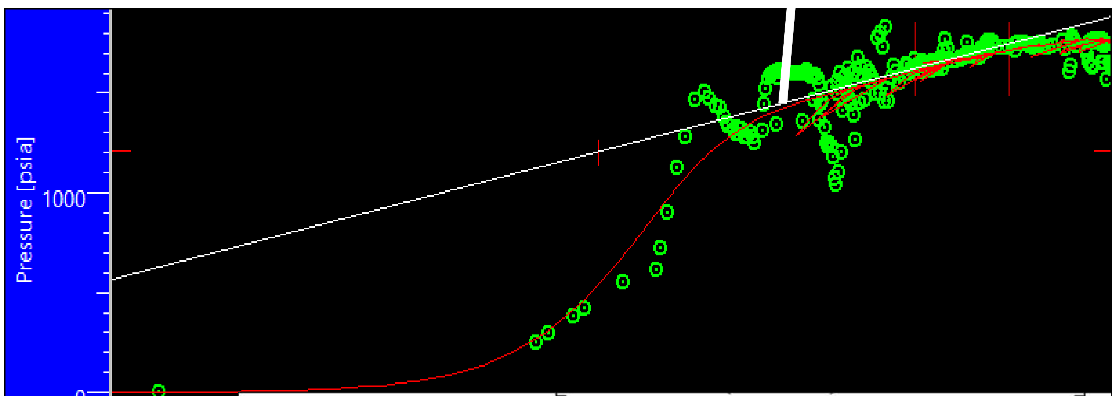
Derivative is too noisy in drawdown to identify IARF



Log-Log plot: (p-p@dt=0).Q/[qn-qn-1] and derivative [psi] vs dt [hr]

IARF identified using semi-log with Superposition time

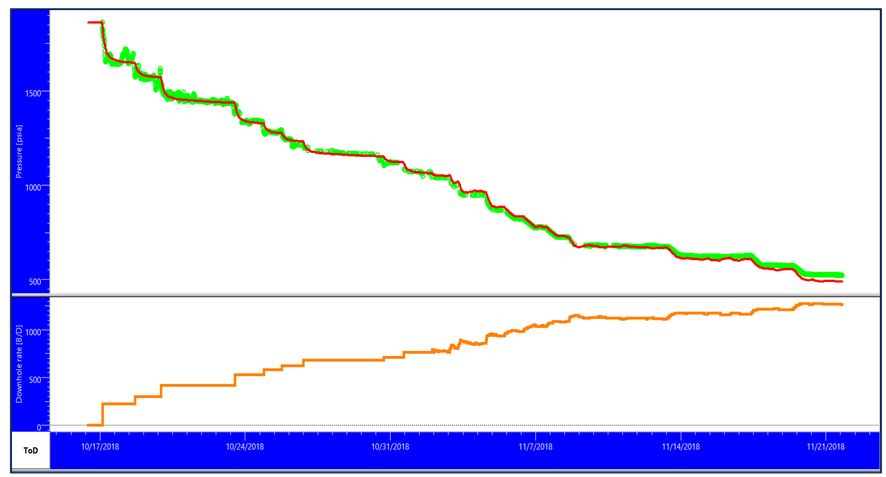




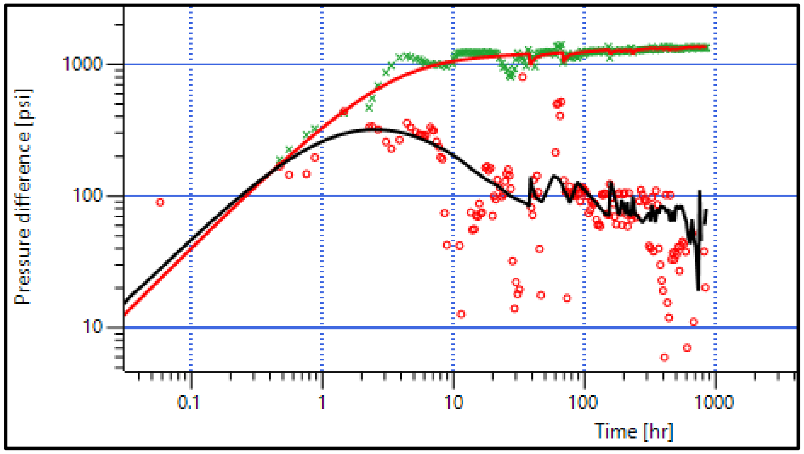
$$Sn(\Delta t)=\sum_{i=1}^{n-1}\frac{q_i-q_{i-1}}{q_n-q_{n-1}}\left(\log\left[\sum_{j=1}^{n-1}\Delta t_j-\Delta t\right]-\log\Delta t\right)$$

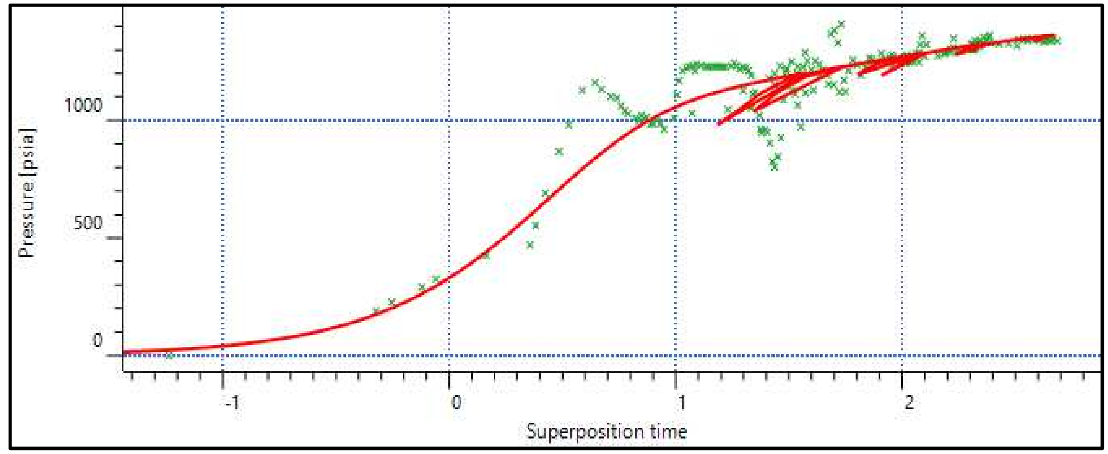
Obtain history match and measure:

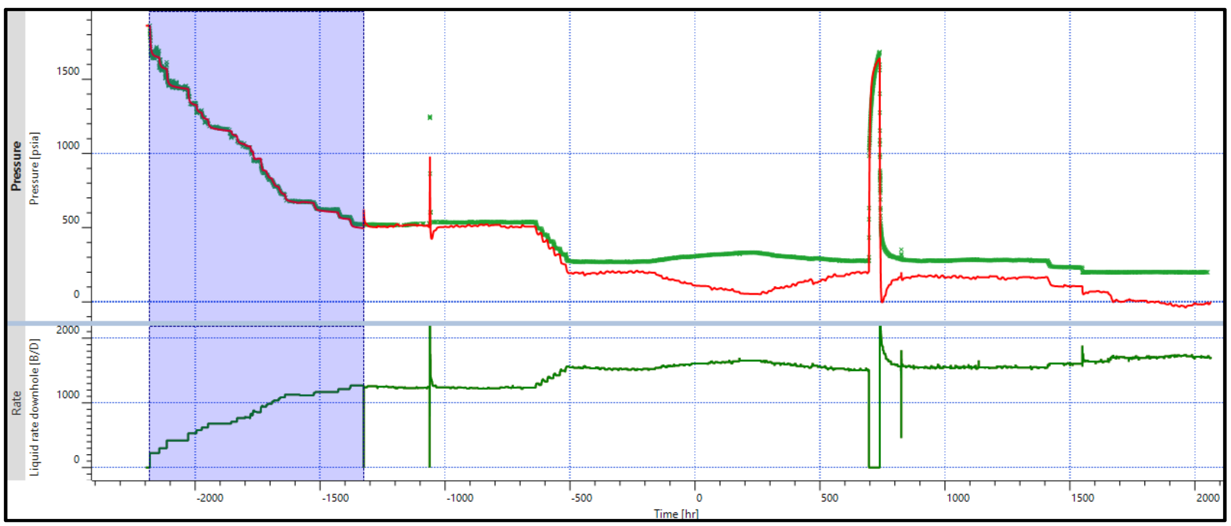
- Skin
- Distance to constant pressure boundary



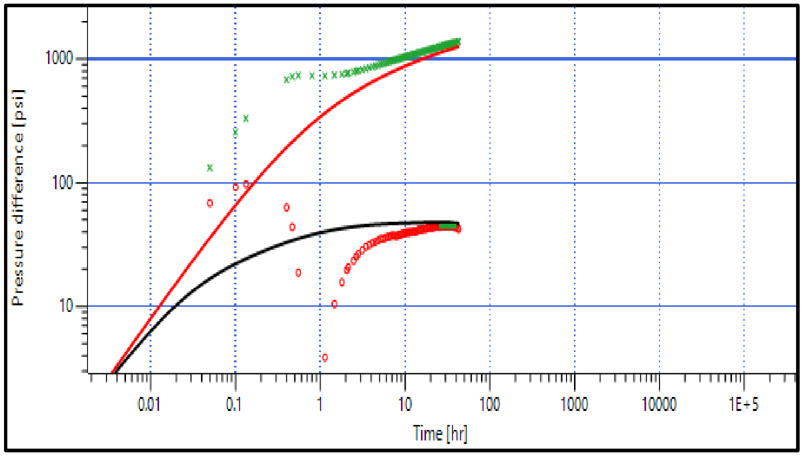
Initial Drawdown – Skin = 0.7

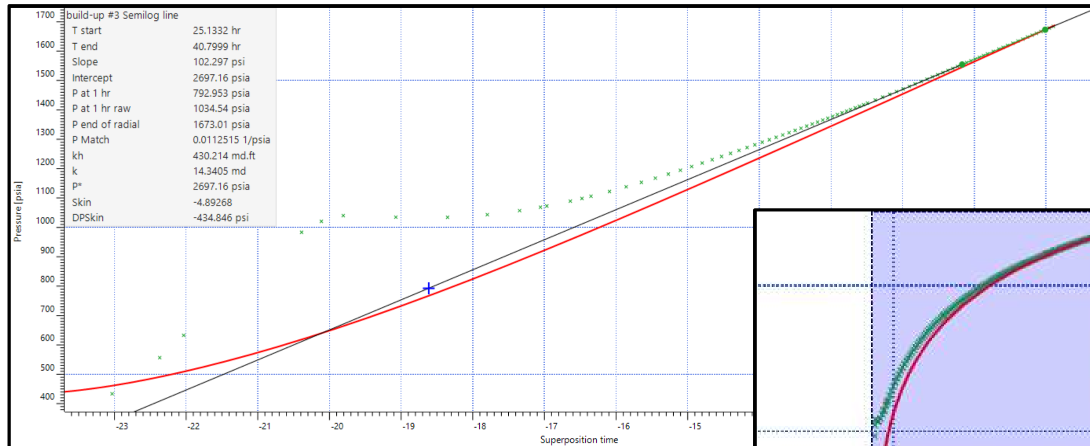


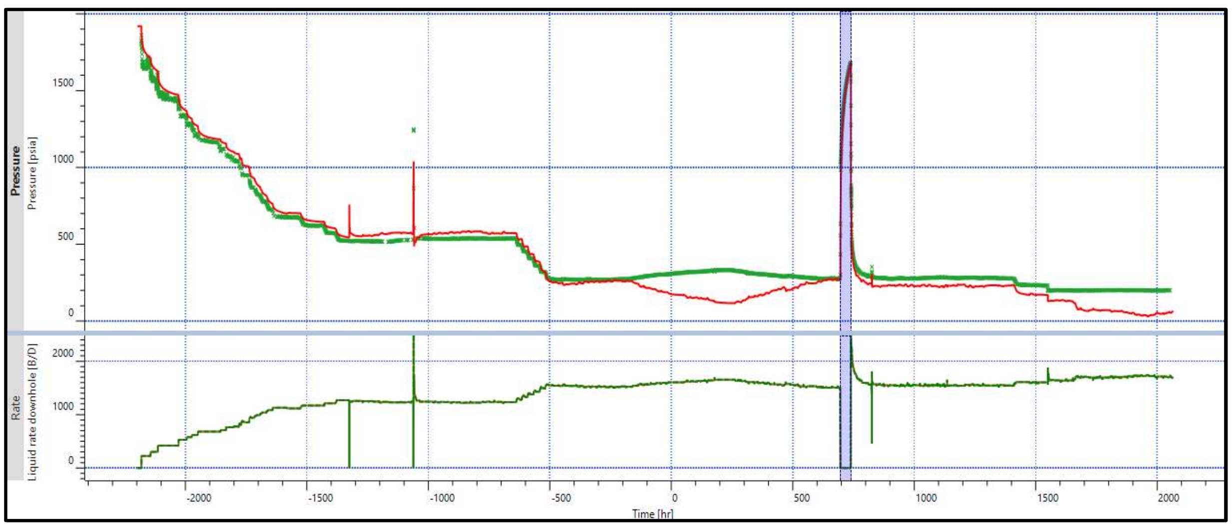


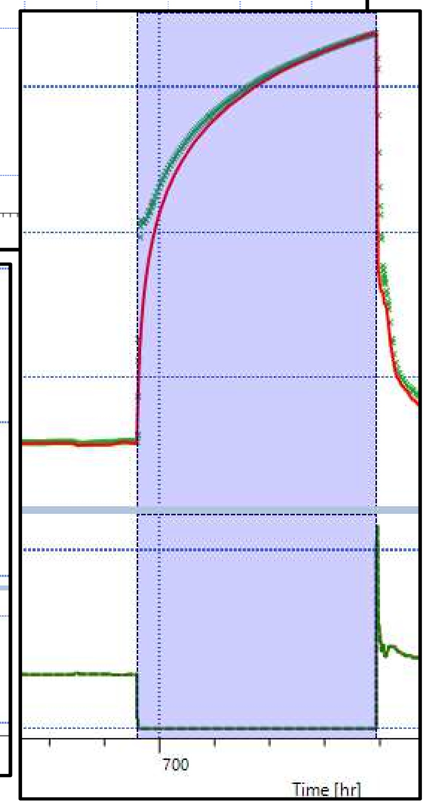


Build-Up – Skin = -4.3

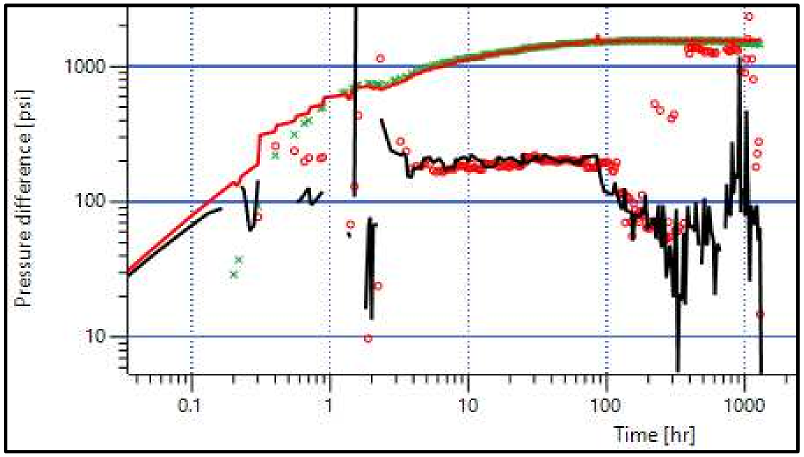


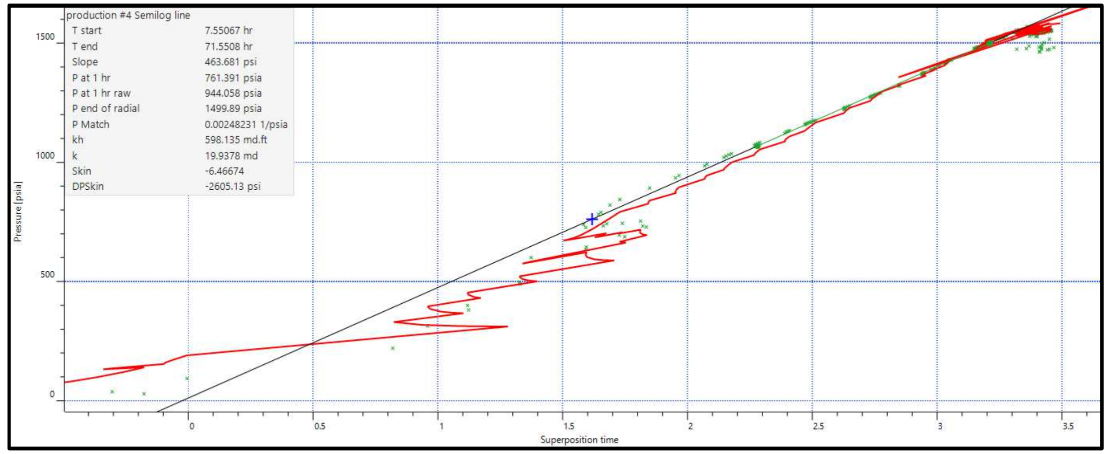


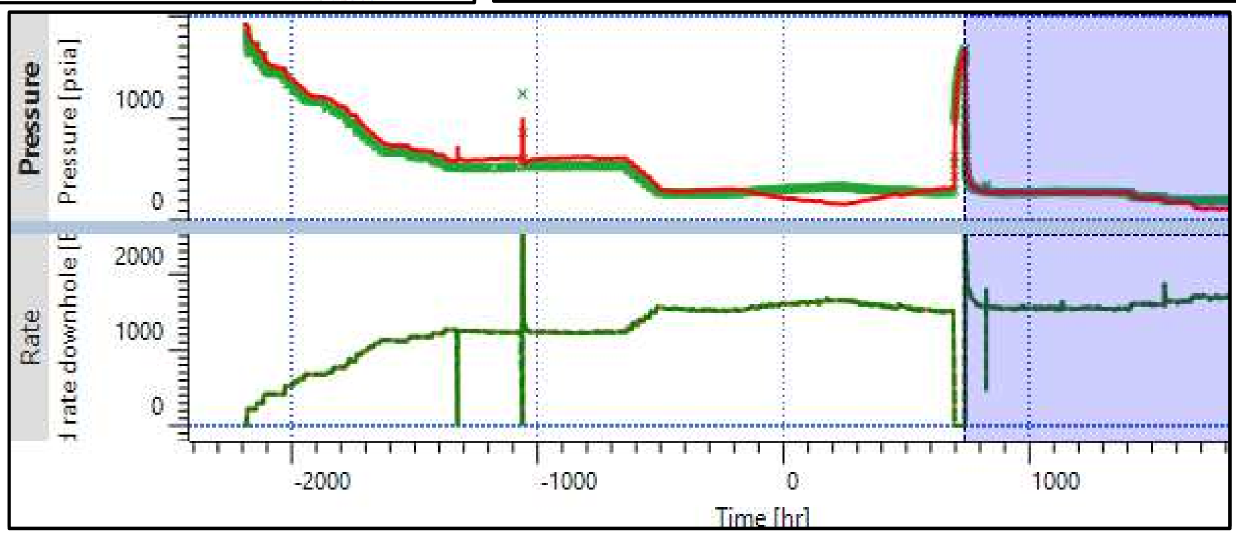




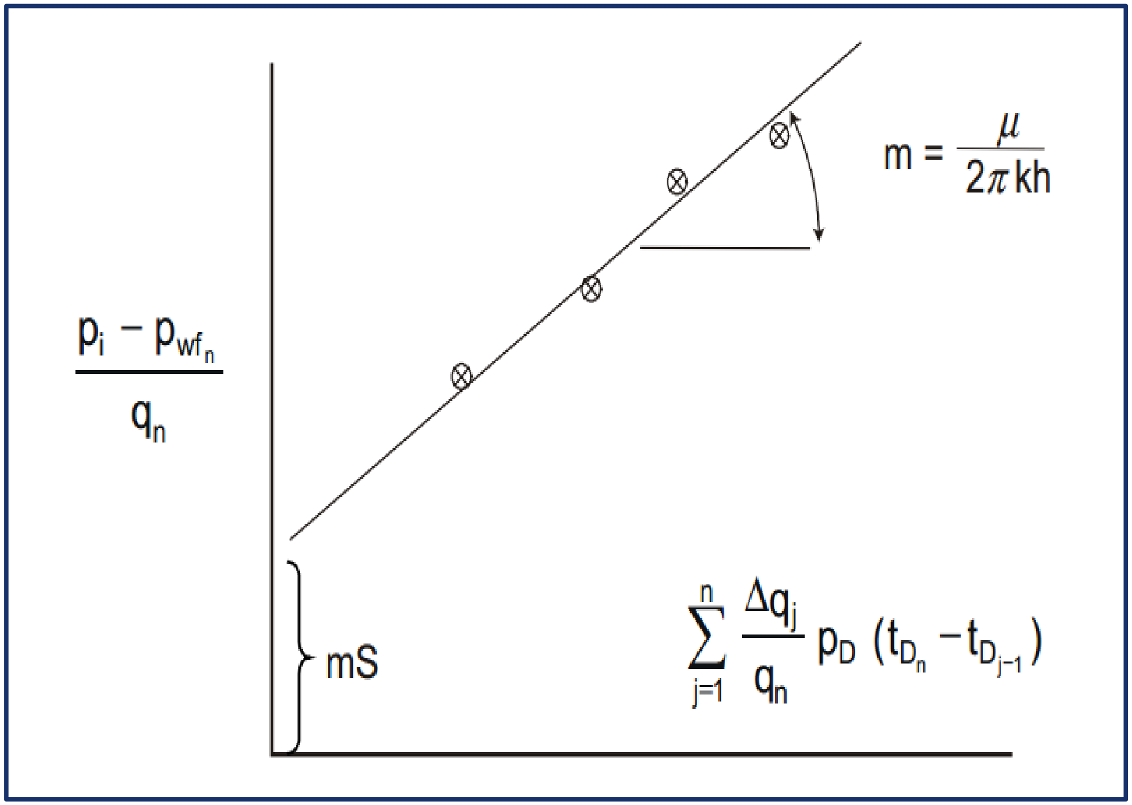
Second Drawdown – Skin = - 5.5







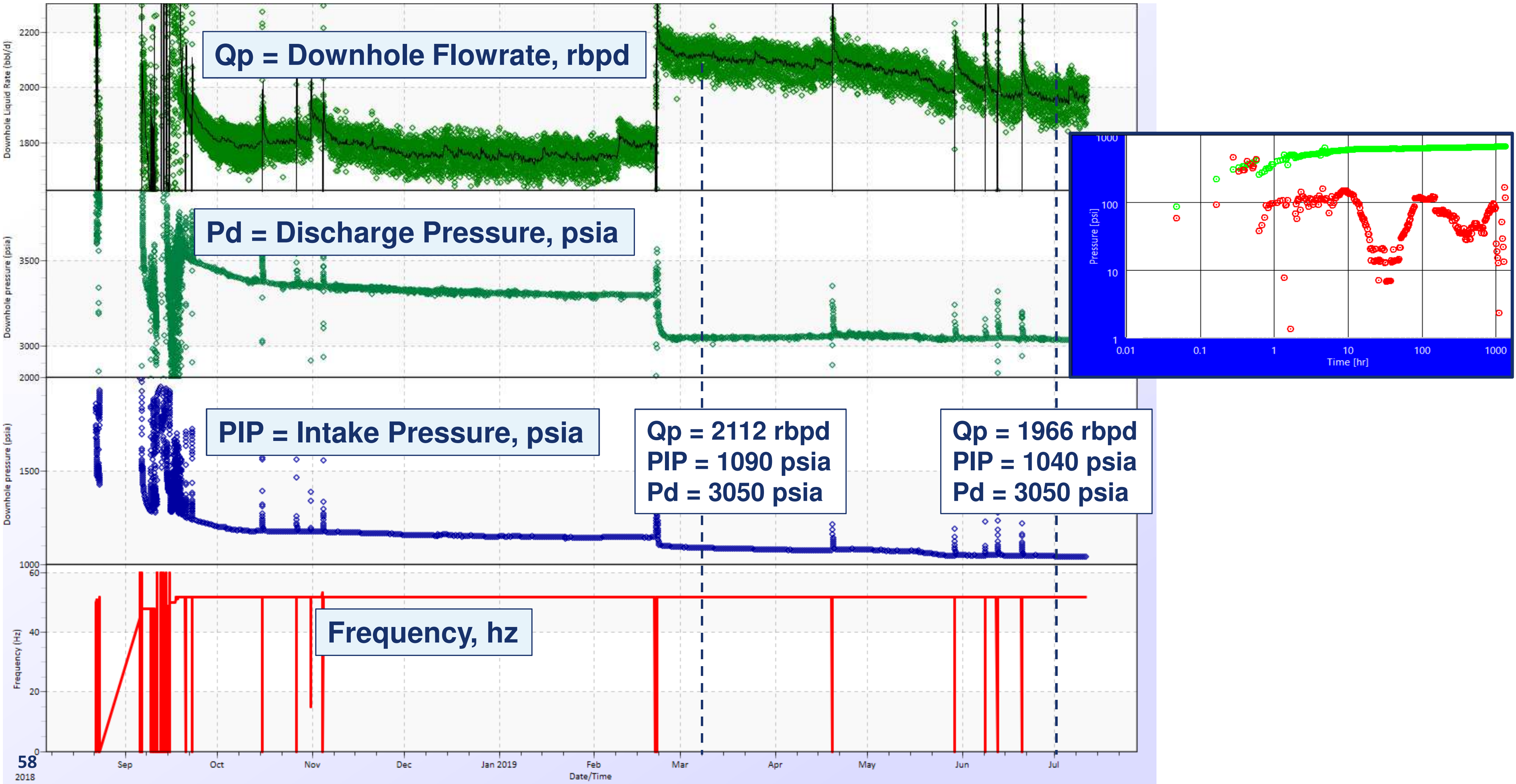
Why Skin is independent of absolute rate



If rate is inaccurate but with correct trend:

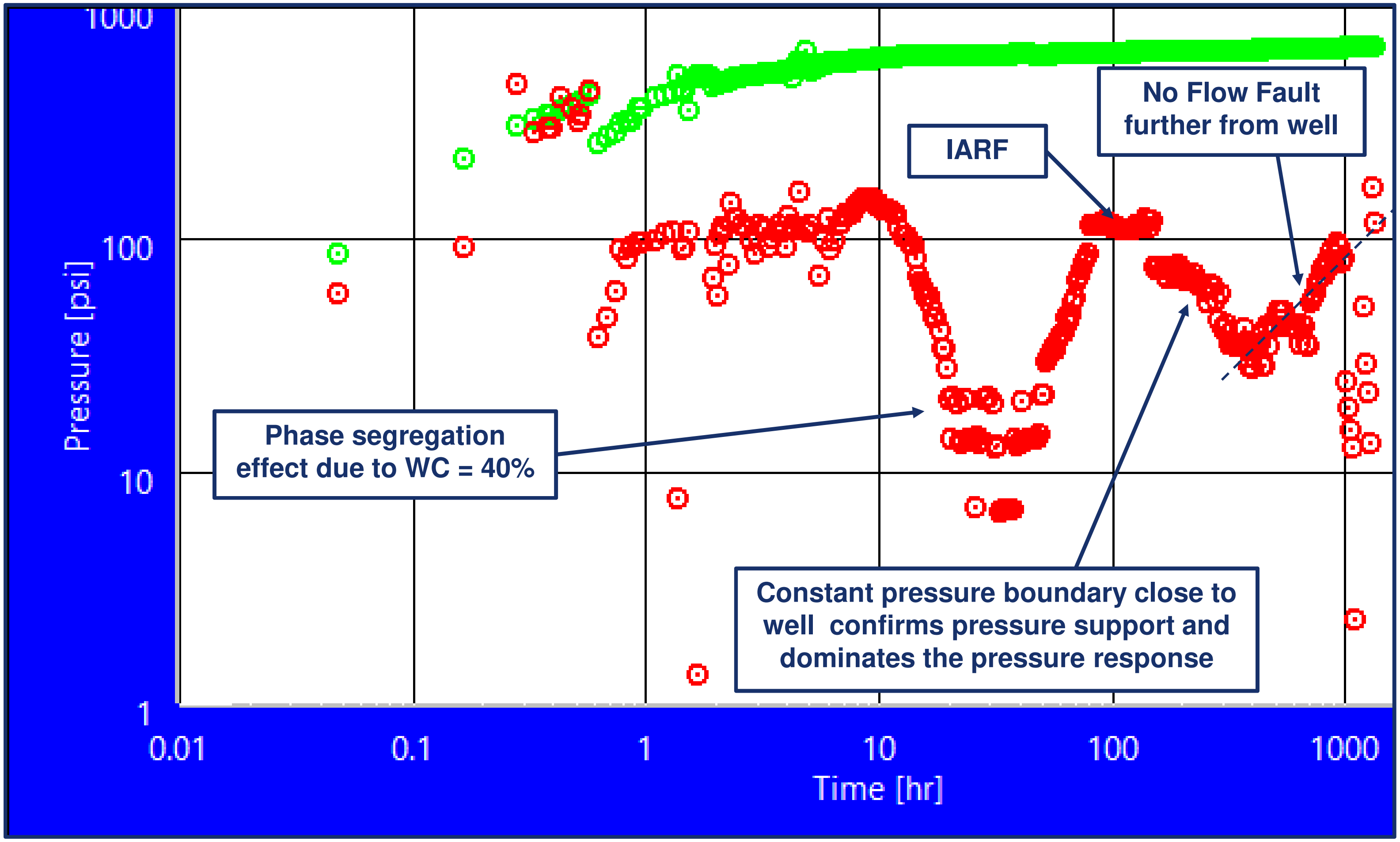
- permeability changes linearly with rate (m)
- Skin is independent of rate accuracy and only dependent on rate trend.

Identifying Depletion



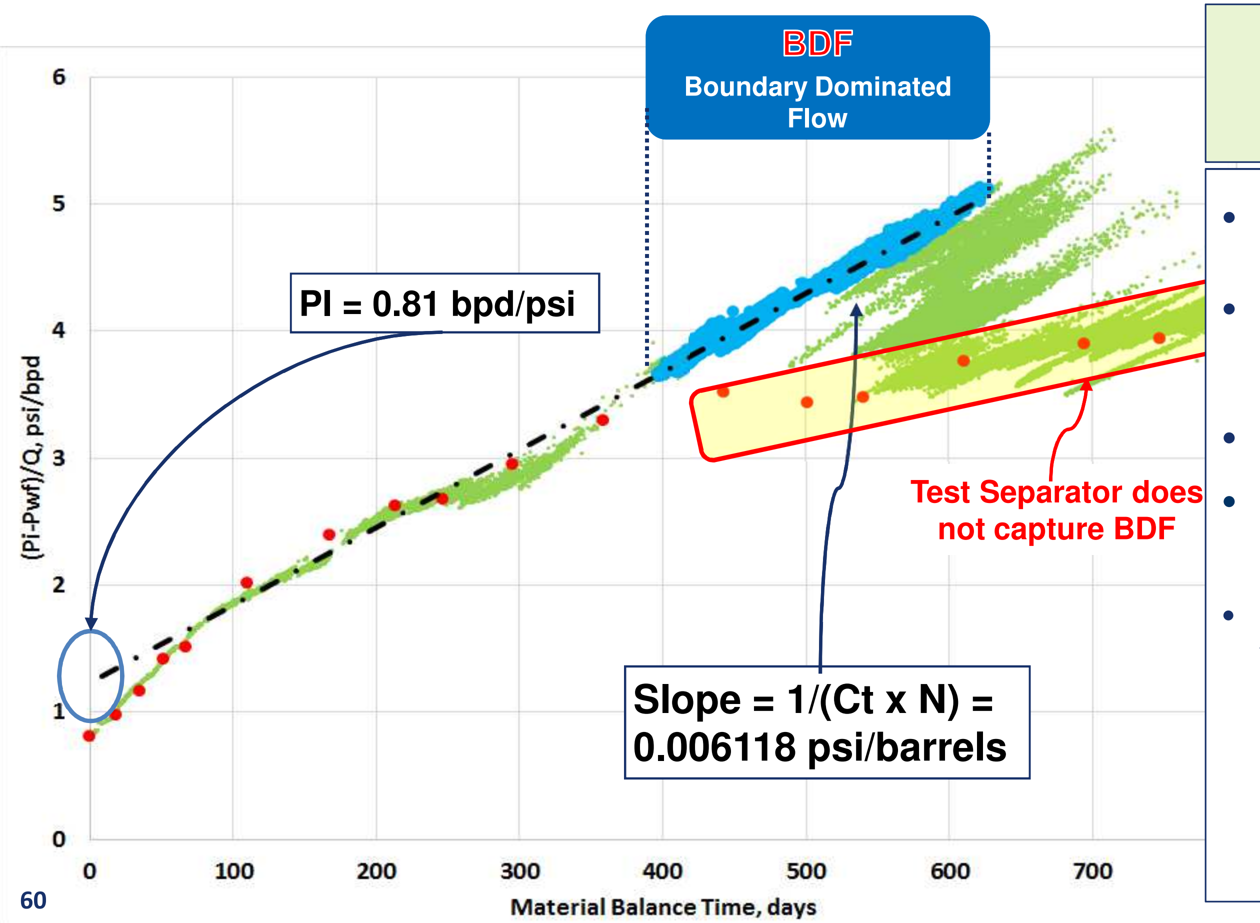
Confirming no flow boundary with PTA

Would require a 1000 hour (40 day) to visualise



Flowing Material Balance → Reserves & PI

Example from SPE paper 185144

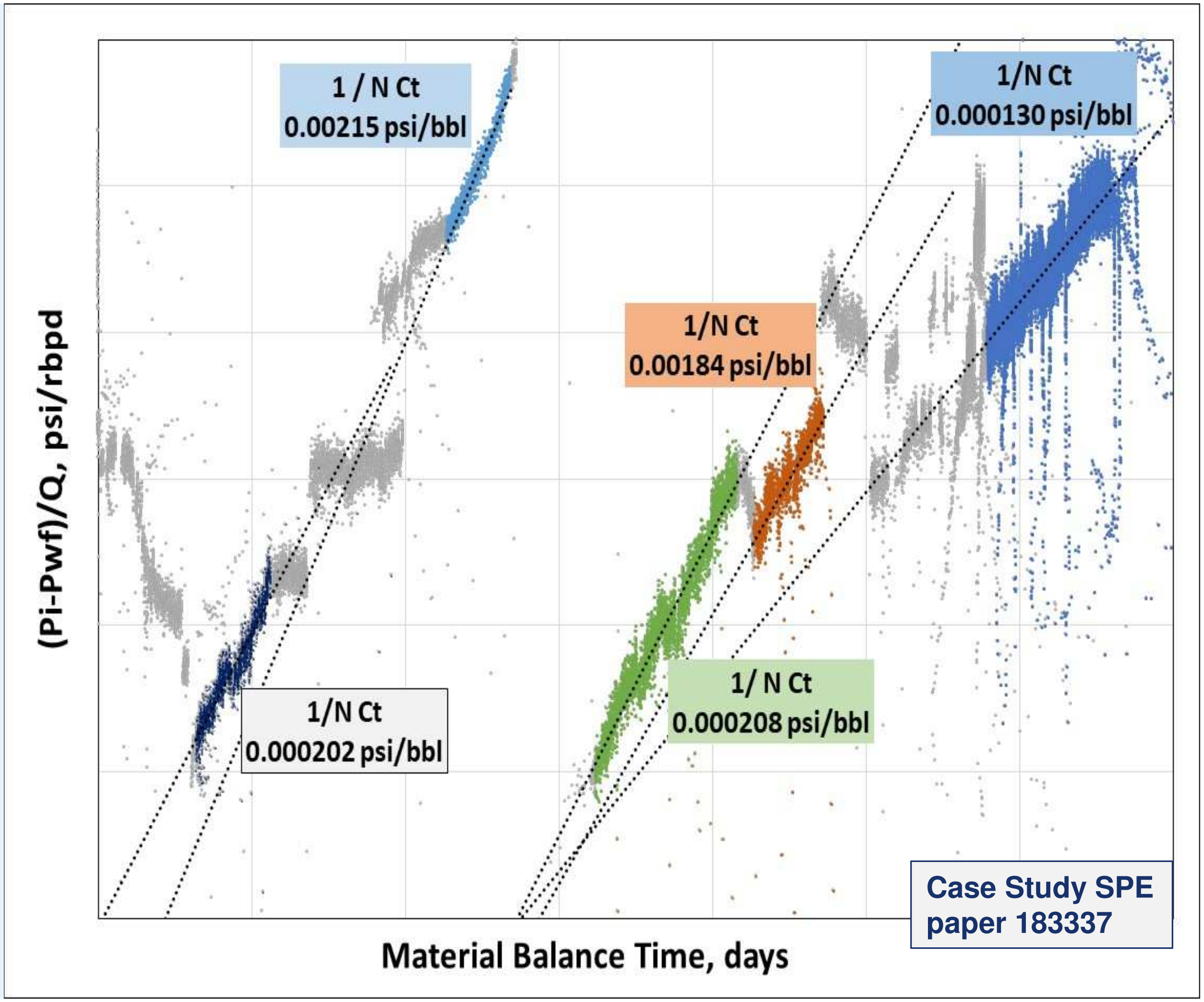


$$\frac{Pi - Pwf}{q} = \frac{1}{C_t \times N} t_{mb} + b_{pss}$$

- $t_{mb} = \frac{N_p}{q} = material\ balance\ time$
- $b_{pss} = \frac{1}{PI}$ = inverse of PI for pseudo steady-state condition
- Ct = compressibility, 1/psi
- **N = Pore Volume (Liquid in place), barrels**
- ***Blasingame, T.A. and Lee, W.J.,* 1986, Variable-Rate Reservoir Limits testing, presented at the Permian Basin Oil & Gas Recovery Conference held in Midland, TX March 13, 1986, SPE 15028**

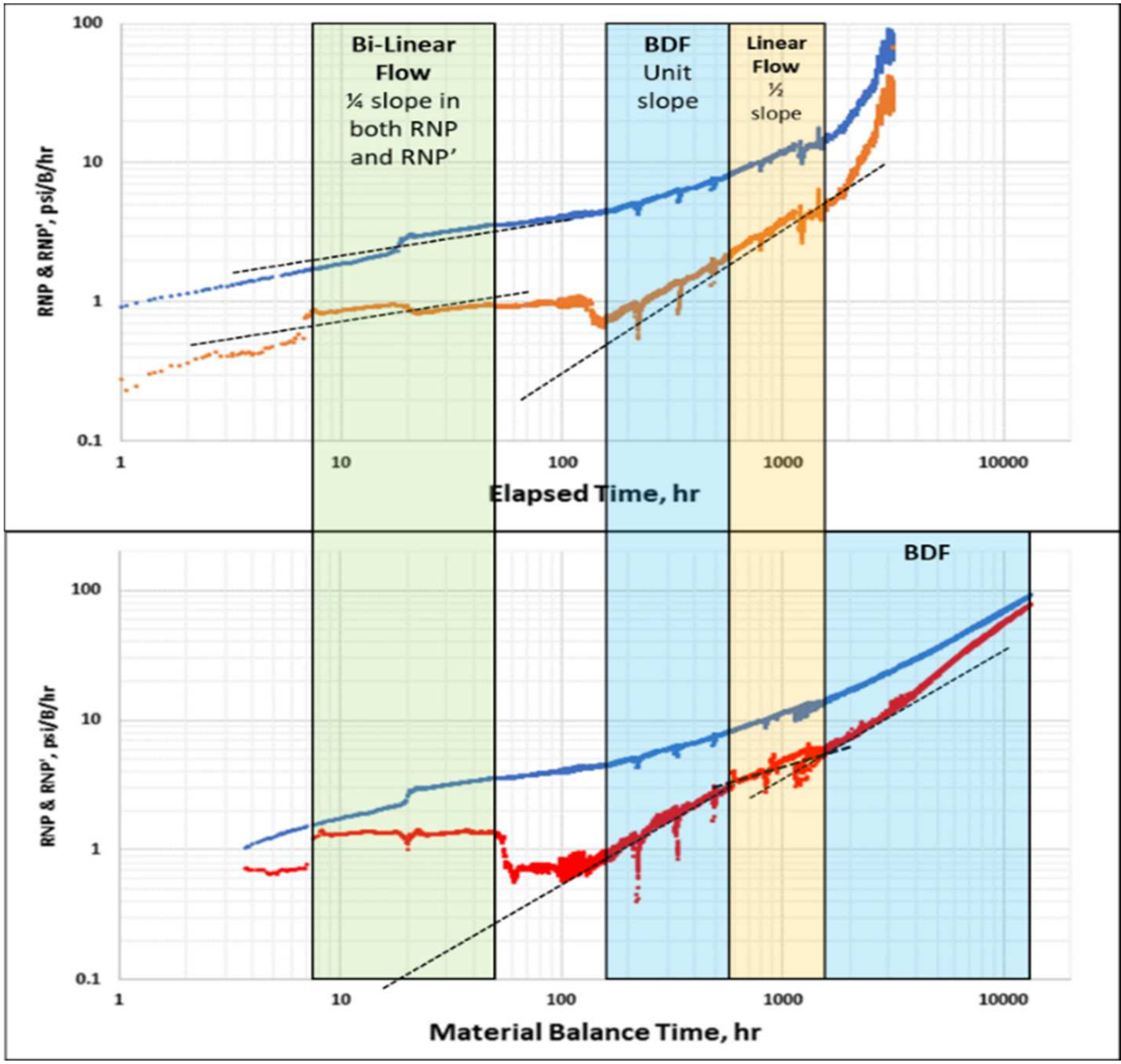
HCPV (Hydrocarbon Pore Volume) **& Drainage Area**

- Monitor well drainage area reservoir pressure and evaluate impact of:
  - Drawdown
  - Production rates of offset wells
- In this example, HCPV is increasing, which suggests that the well recovery factor is increasing.
- Ct = compressibility
- N = HCPV

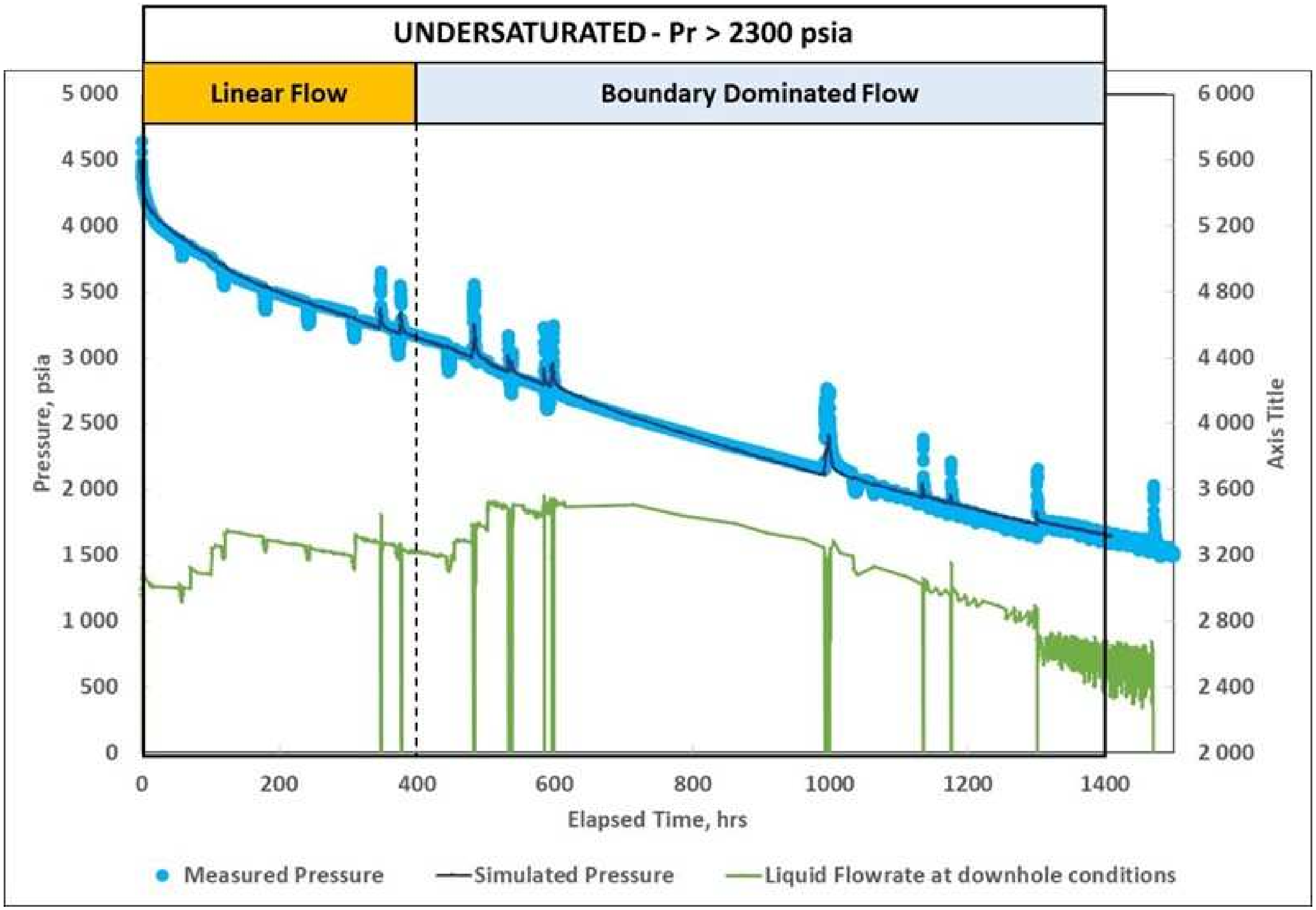


Flow Regime MFHW Horizontal Well

Rate measurement has enough frequency, resolution and repeatability to calculate derivative without noise in elapsed time! ➔ visualize & confirm bi-linear flow



History Matching….

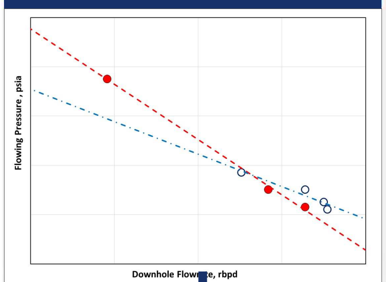


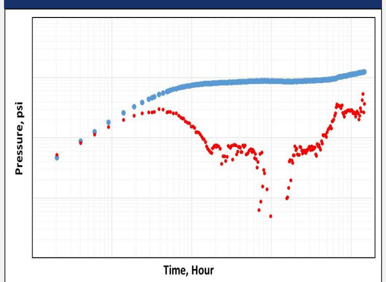
Analytical model yields an excellent match despite numerous step changes in flowrate ➔ testimony to the resolution and repeatability of the downhole flowrate

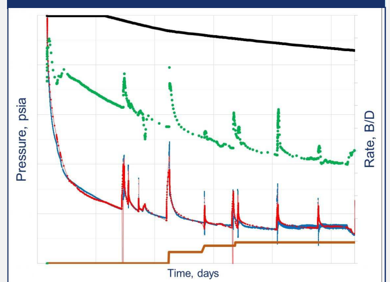
- **Fracture half-length**
- **Pore Volume**
- **Permeability**
- **Skin**

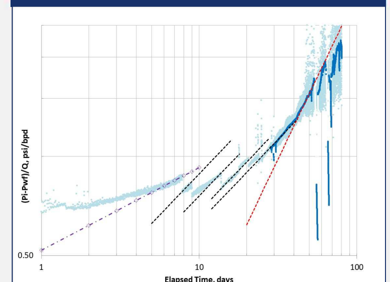
Value = Decisions

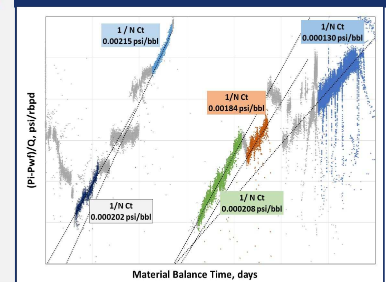
IPR on the fly	PTA in drawdown	Skin and depletion evolution	Reservoir Flow regime (e.g. Fractures)	Reserves & Drainage area evolution











Pump Sizing
Drawdown Management

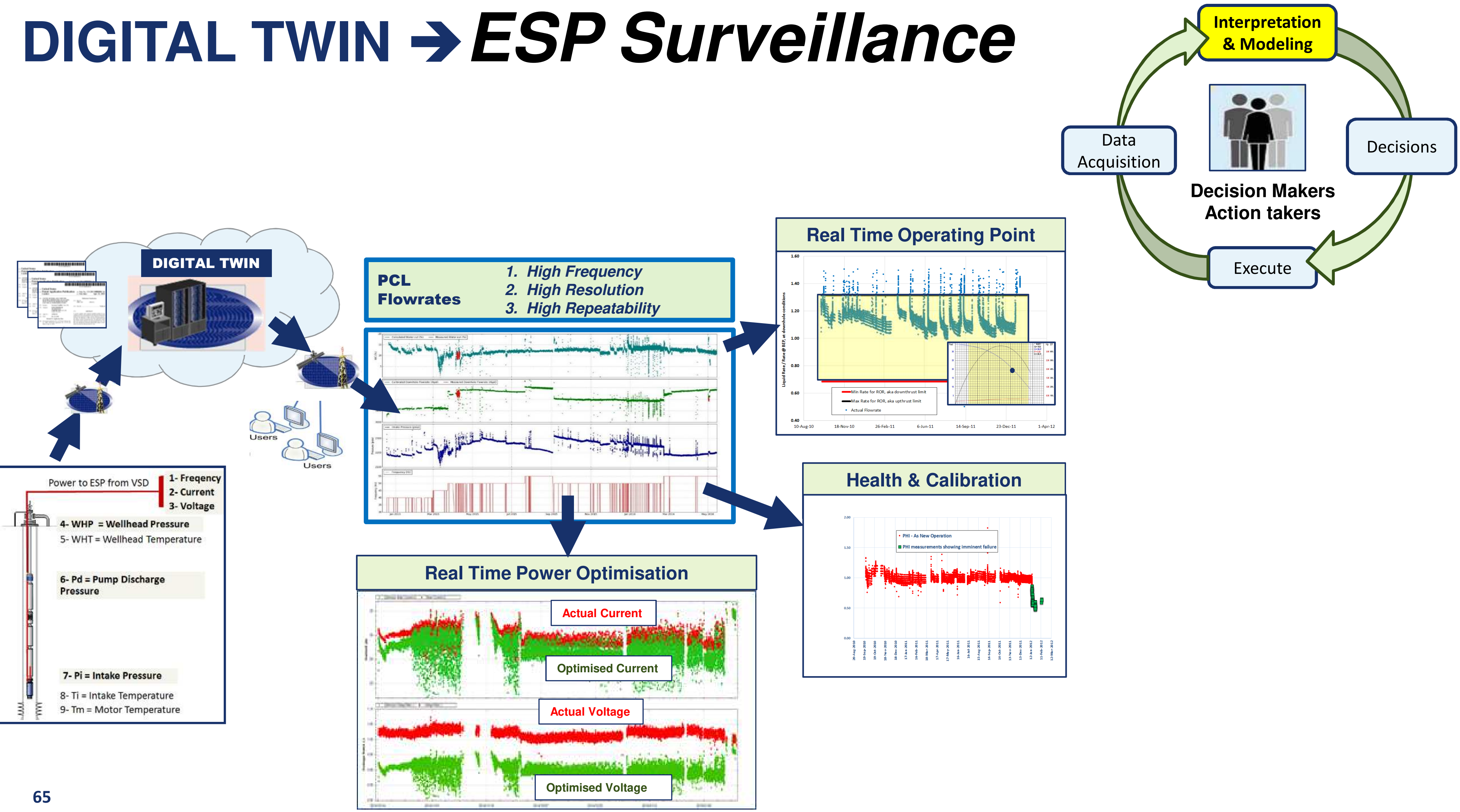
Skin / Stimulation Candidates

Water Injection Management

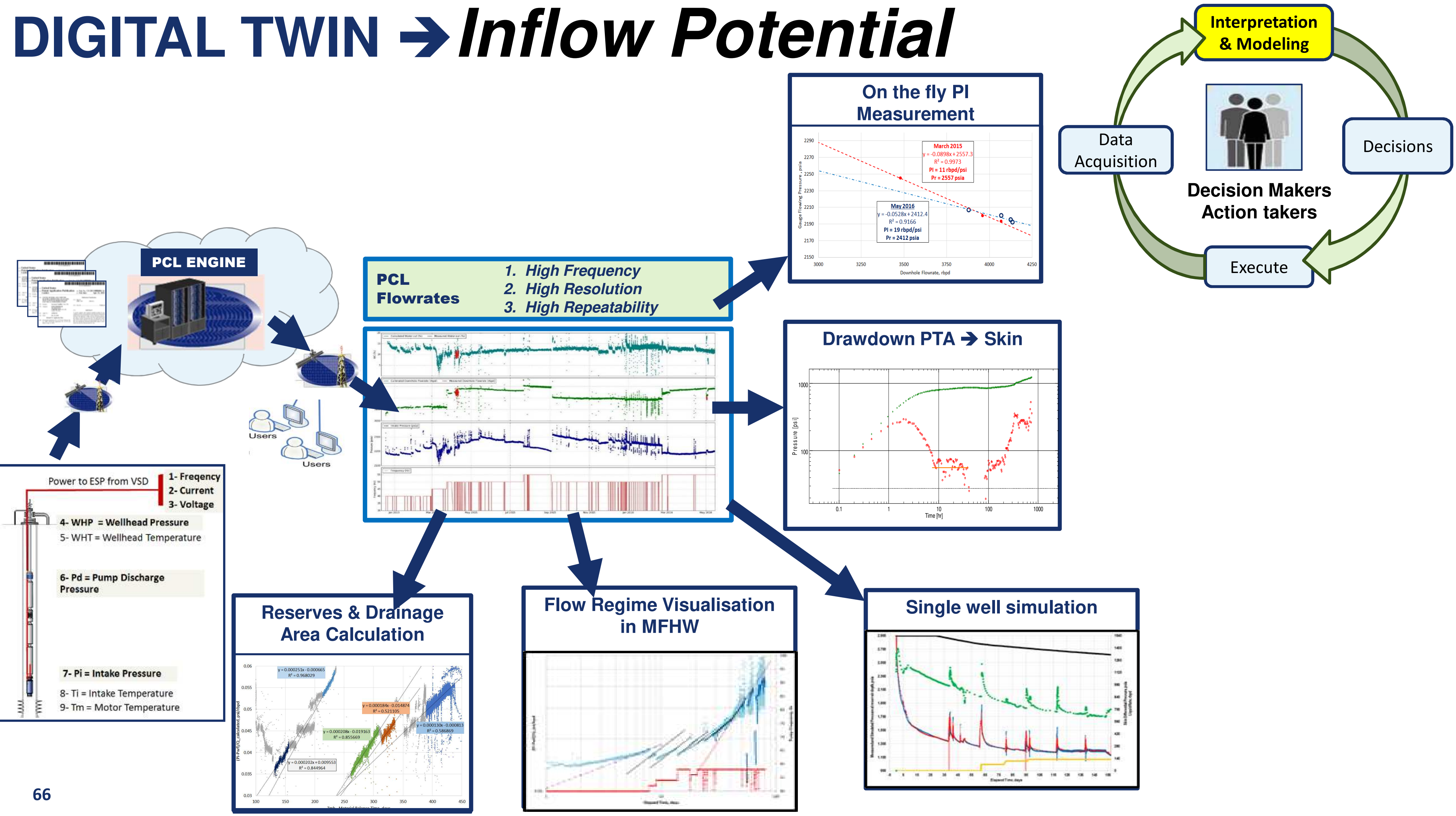
Fracture Design Optimisation

Infield Drilling Placement

DIGITAL TWIN → *ESP Surveillance*



DIGITAL TWIN → *Inflow Potential*



Data to Information Map

Data

1. Openhole logs
2. Geological maps
3. PVT data

Static, **Contextual Data**

4. Permanent Gauges (P, T, Q, etc…)

Real-time Data

Digital Twins
Virtual Flowmeters

5. **Rate history**
6. **Cased Hole (PLT, RST)**
7. **Build-ups**

Episodic **Data**

Data which does not stream automatically in real-time and requires intervention

Analytical Tools

- Equipment Models
- NODAL
- Pressure transient
- Rate transient
- Simulation
- Lab analysis
- Etc…

Information

1. Equipment health check
2. IPR curve
3. Skin
4. Pr trend
5. Recovery factor
6. Scale Treatment
7. Etc…

Will episodic data become a thing of the past to be replaced by high frequency data available on all wells, especially for flowrate?

Key Take-Aways

Real-Time Data drives Production Optimisation

1. **Uptime and MTBF:** Improved by identifying the cause of trips & implementing remedial action:
   - FAST LOOP = choke, pump speed and/or control settings
   - SLOW LOOP = Changing operating procedures and/or ESP design

2. **Power Optimisation:** Field average power savings of up to 20% are documented with individual case studies showing 40% saving.

3. **Production Enhancement:**
   - **Key Enabler** = high frequency / high resolution liquid rates & pressure data
   - **Value =**
     - IPR Curve on the fly ➔ Establish well potential and update on a regular basis
     - PTA – Identify skin ➔ Stimulation candidates
     - History Matching ➔ evolution of reservoir pressure & skin
     - Flow Regime ➔ fracture protocol Design
     - Monitor evolution of drainage area

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