Ask Echometer 20 Online Seminar – September 30, 2020

SUCKER ROD PUMPING SYSTEM DESIGN – QRod 3.1

https://www.echometer.com/Software/QRod

"SUCKER ROD PUMPING SYSTEM DESIGN TOOLS FOR QROD" SWPSC, 2013

"USE OF THE PUMP SLIPPAGE EQUATION TO DESIGN PUMP CLEARANCES", Rowlan, McCoy, Lea, SWPSC 2012

"Rod String Design Software – Well Simulation Using Sandia's Downhole Load Cell", Hein, Rowlan, Malone, SWPSC 2015

"QRod , a Practical Beam Pumping Design Program" Jennings, SWPSC 1994

Presenters: O. Lynn Rowlan and Carrie-Anne Taylor

Q & A: Gustavo Fernandez and Echometer Engineering and Support

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Download the Session 20 PDF Bundle and TAM Example Data from

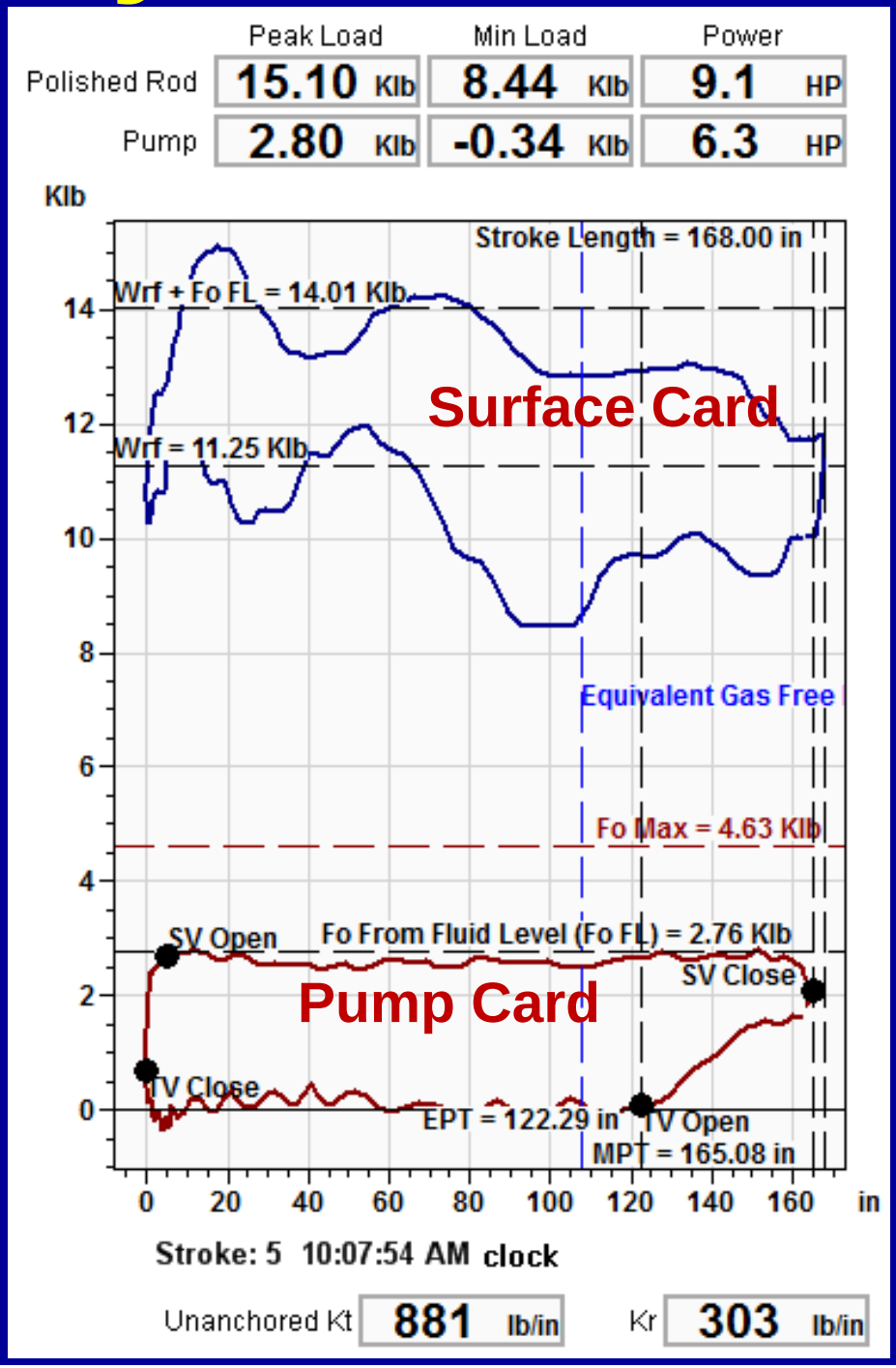
https://echometer.com/Support/AskEchometer

QRod - Free Simple User-friendly Practical Beam Pumping Design Program

- State of the Art Beam Pumping Design Technology
- Design and Predict Performance of Sucker Rod Pumping Systems
- Wave Equation Predicts Surface Dynamometer Loads and Polished Rod Position
- Immediately Evaluate Effect of Changing Tubing Anchor, Stroke Length, SPM, Pump Diameter
- Results can be shown in any system of units.

Download free of charge from:
www.echometer.com\software\index.html

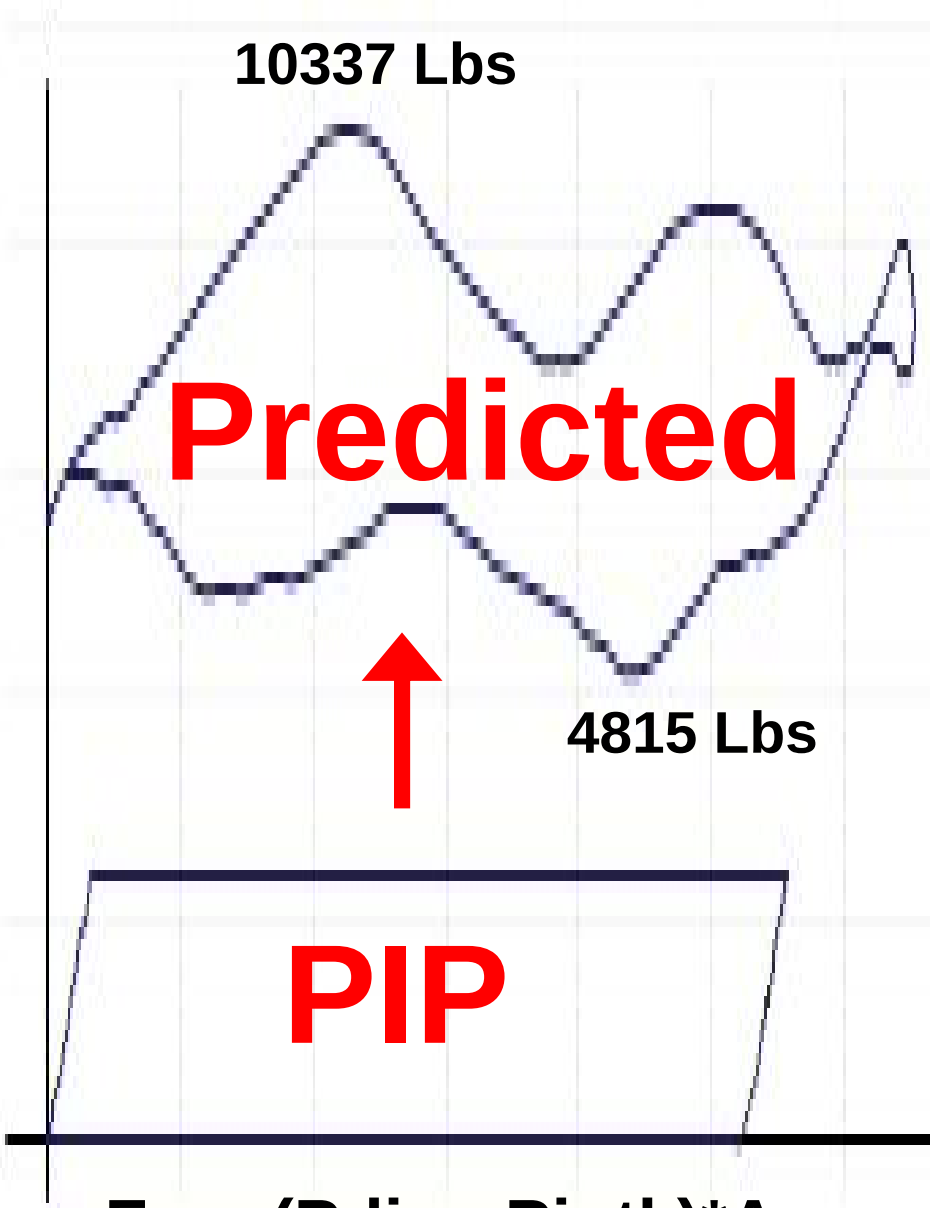
Dynamometer Card Definition



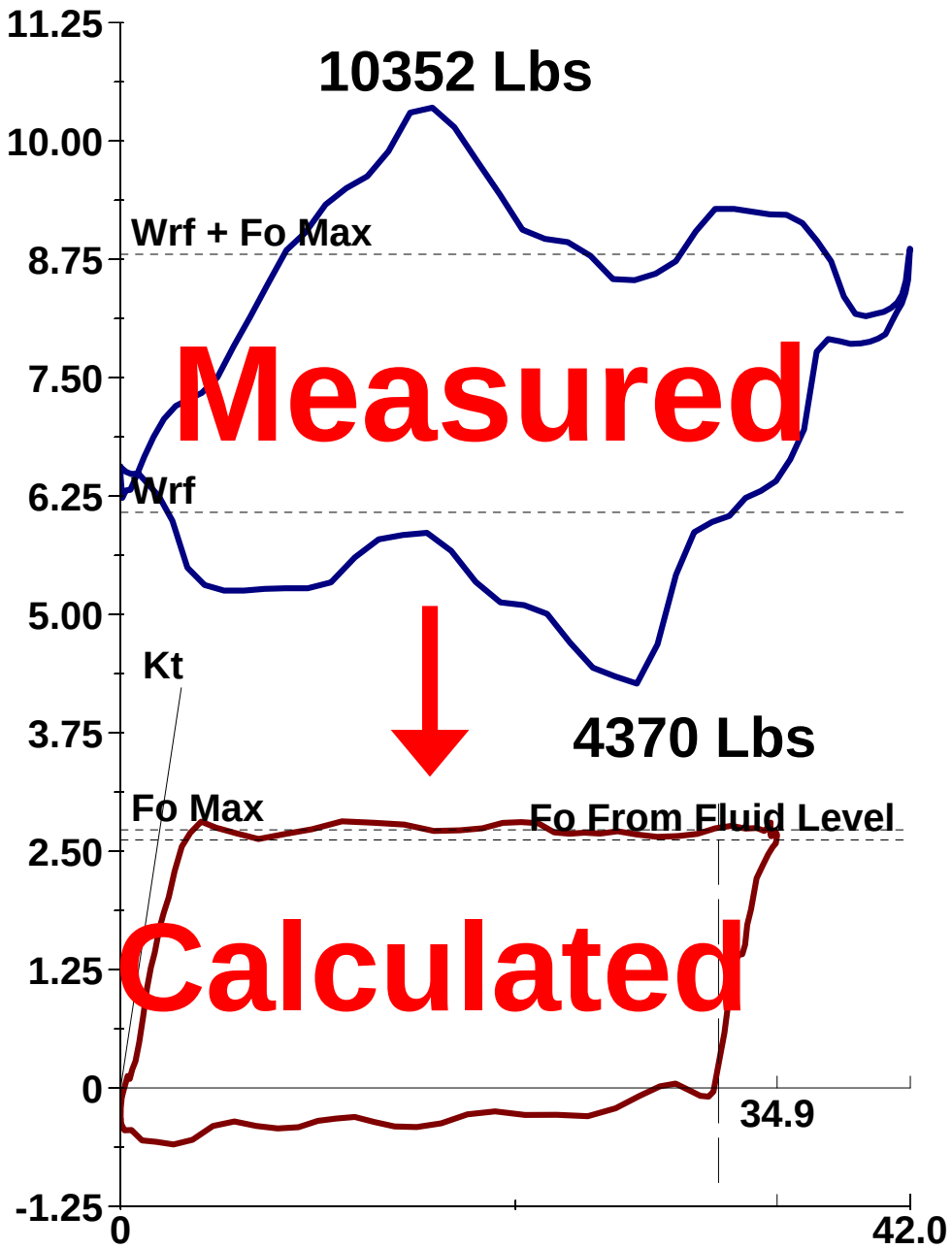
1) <u>Surface dynamometer card</u> is the plot of the measured rod loads at the various positions throughout a complete stroke; the load is usually displayed in pounds of force and the position is usually displayed in inches.

2) <u>Pump dynamometer card</u> is a plot of the calculated loads at various positions of pump stroke and <u>represents the fluid load the pump applies to the bottom of the rod string</u>.

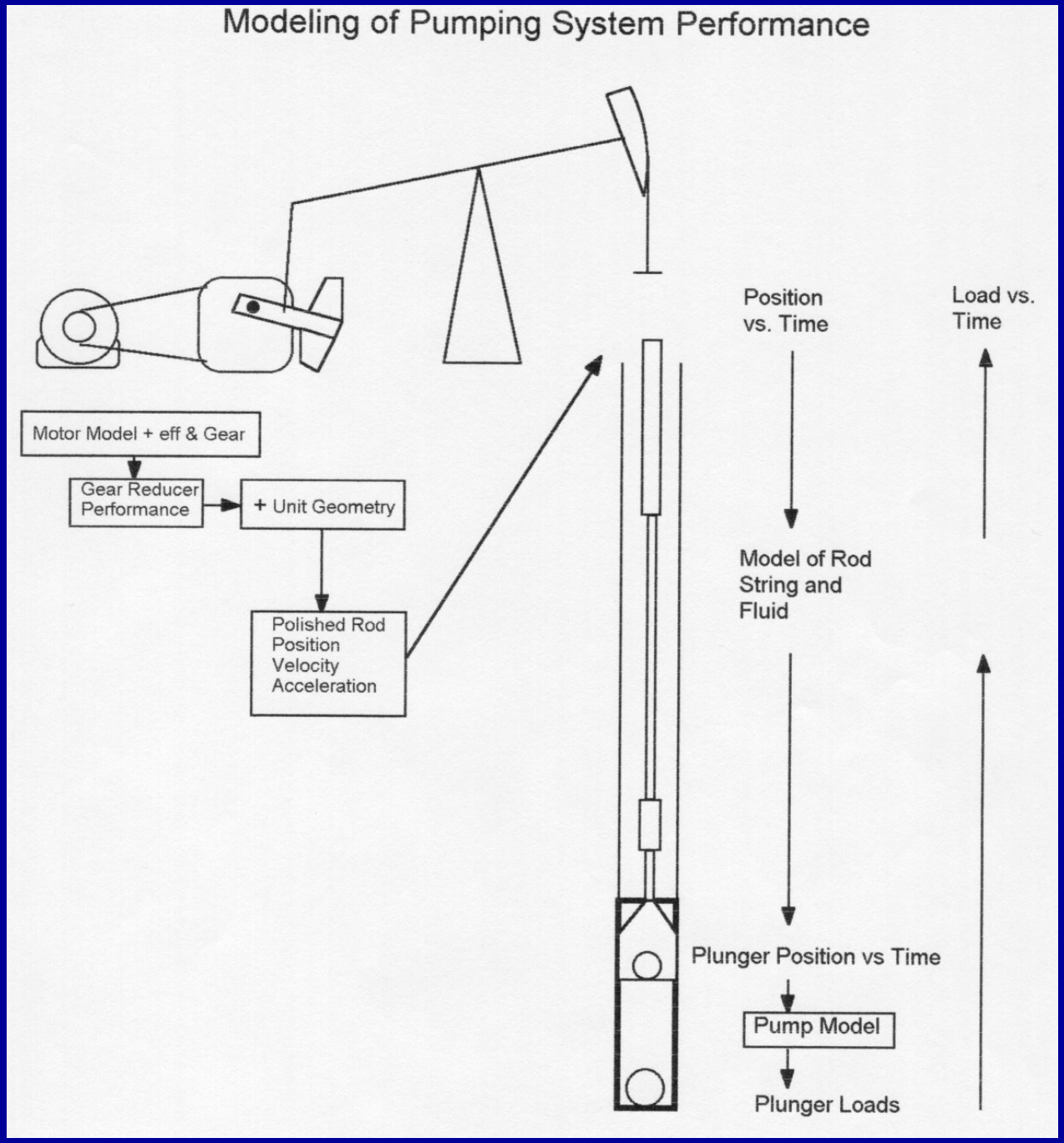
Predictive and Diagnostic Models



Fo = (Pdis - Pintk)*Ap



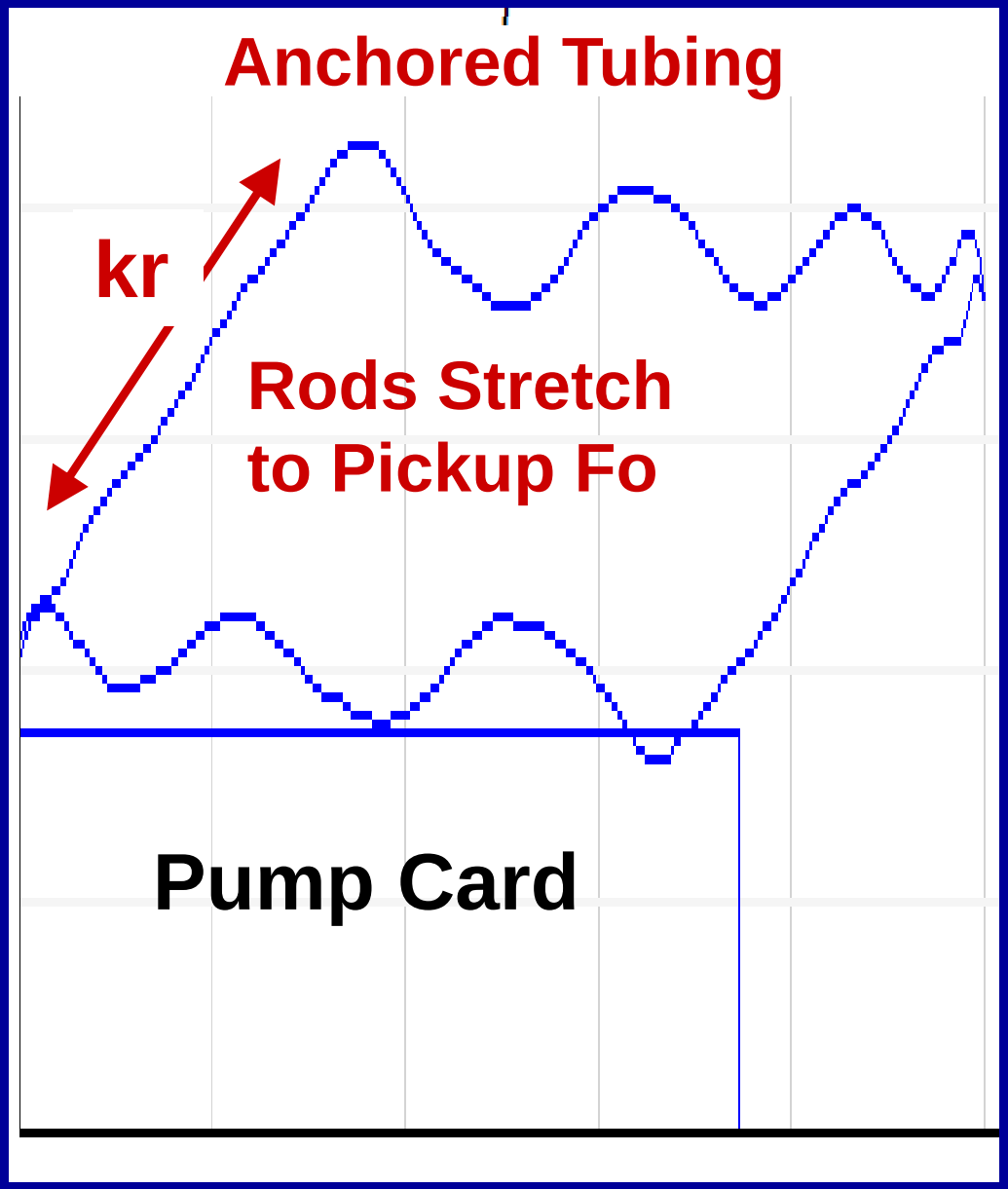
Beam Pumping Simulator

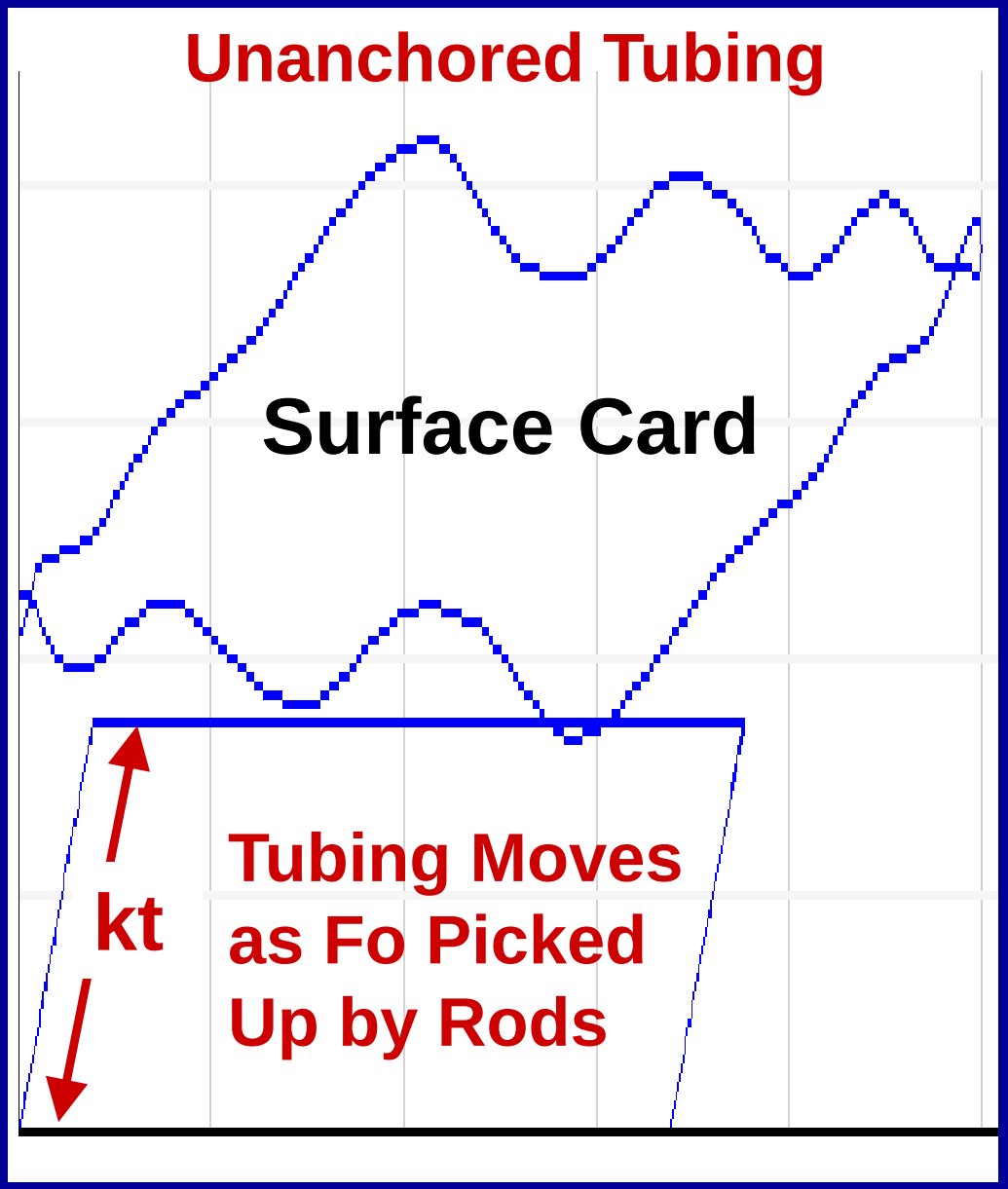


1. Uses the pump intake pressure to determine the load the pump applies to the rods.
2. Mathematically simulates the motion of the surface unit
3. Solves the partial differential equation describing the motion of the rod string
4. Calculates the surface loads, pump velocity and position.
5. Determines gear box torque and proper counter balance

QRod Calculates Full Pump Cards:

1. Pump full of Liquid with NO gas in Pump.
2. Valves Not Leaking and pump functioning properly.





PUMPING PERFORMANCE GUIDE

From Predictive Dynamometer Design Programs:

1. **Is the pumping system operating as expected?**
2. **Is the predicted dynamometer in agreement with accurately measured horseshoe dynamometer data?**
3. **If not, the design program may have incorrect data, or the software is not properly predicting well performance.**
4. **Can the performance be improved by a change in pump size, polished rod stroke length, SPM or other factors?**

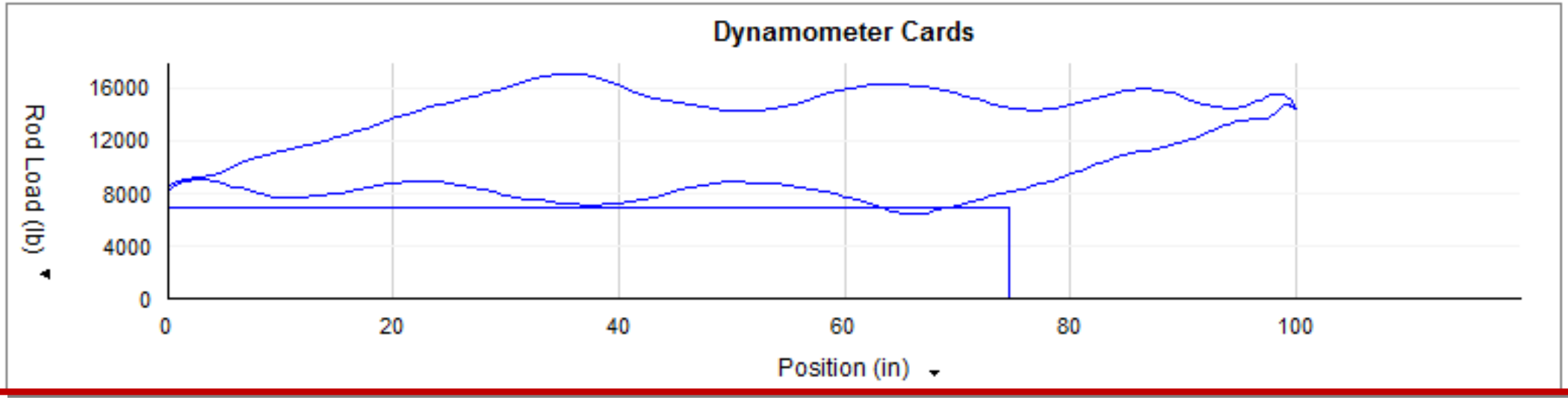
Example Well

1. 5000 ft pump depth, 100 in surface stroke (s), 50 psi tubing and pump intake pressure
2. 2 inch diameter plunger with anchored tubing
   a) Fo, Fluid Load 6896 lbs
3. Tubing Fluid Gradient 0.433 psi/ft
4. 76 API Designation Rod String Taper
   a) 41.2% - 7/8” and 58.8% - 3/4” rods
   b) Weight Rods in Fluid – 8,288 Lbs
   c) Kr = 254 lb/in & SKr = 25400 lb
   d) Fo/SKr=0.271 ~ 27.1% of Surface Stroke lost to Stretch

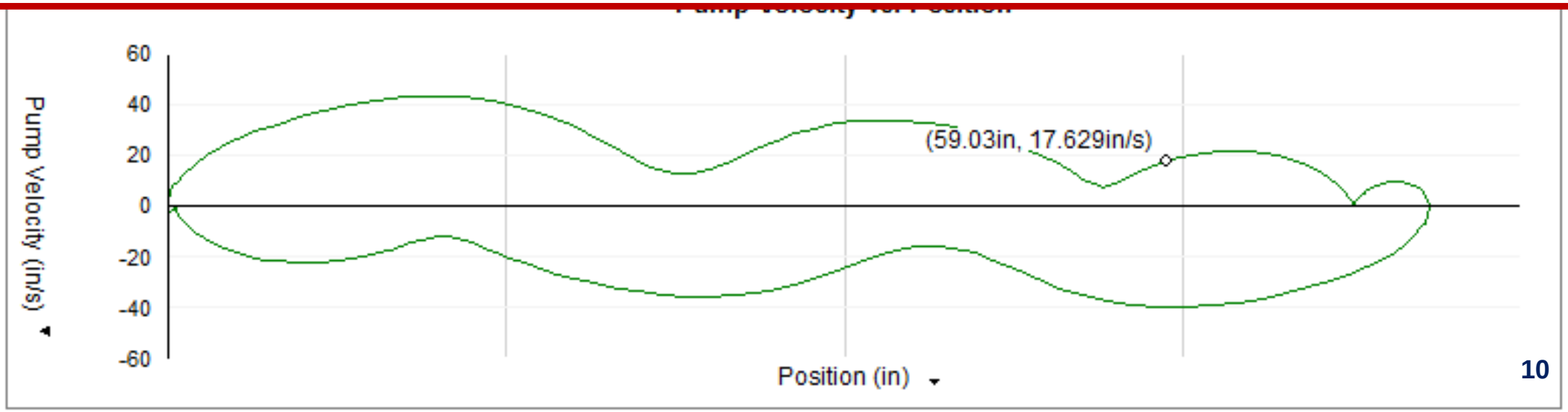
Rod String from API Rod Number

mm =>	32	29	25	22	19	16	
API Rod Number	1 1/4"	1 1/8"	1"	7/8"	3/4"	5/8"	
55						✓	All 5/8"
65					✓	✓	Top 3/4" with 5/8" on bottom
66					✓		All 3/4"
75				✓	✓	✓	Top 7/8" with 3/4" in Middle and 5/8" on bottom
76				✓	✓		Top 7/8" with 3/4" on bottom
77				✓			All 7/8"
86			✓	✓	✓		Top 1" with 7/8" in Middle and 3/4" on bottom
87			✓	✓			Top 1" with 7/8" on bottom
88			✓				All 1"
97		✓	✓	✓			Top 1 1/8" with 1" in Middle and 7/8" on bottom
98		✓	✓				Top 1 1/8" with 1" on bottom
99		✓					All 1 1/8"
108	✓	✓	✓				Top 1 1/4" with 1 1/8" in Middle and 1" on bottom
109	✓	✓					Top 1 1/4" with 1 1/8" on bottom

Simple User-Friendly Practical Beam Pumping Design Program



PPRL	17,112	psi	MPRL	6,496.5	lb	Fo	6,895.8	lb
Pump Stroke Length	74.57	in	Static Stretch	27.12	in	Overtravel	1.70	in
Fo/Skr	0.271		Kr	254	lb/in	Kt	894	lb/in



File Tools Help

Title

Design Inputs

Unit: CWConv

Pump Depth: 5,000 ft

Surface Stroke Length: 100.00 in

Pump Diameter (D): 2.000 in

Tubing Size: 2.875" (6.40 lb/ft) 2.441" ID

☑ Anchored Tubing

Rods

- ◉ Steel Rods
- ○ Fiberglass and Steel Rods

Rod Number: 76

Rod Grade: D

Results

Rate (100% pump volumetric eff.)	173.84 BBL/D
Rate (95% pump volumetric eff.)	165.14 BBL/D
Rod Taper	41.2%, 58.8%
Top Rod Loading	81.7%
Min API Unit Rating	456-173-100
Min NEMA D Motor Size	10.730 HP
Polished Rod Power	7.111 HP
TVLoad	15,184 lb
SVLoad	8,288 lb

Calculate from SPM or Target Rate

◉ Stroke Rate (SPM) << 5 >> SPM

○ Target Rate << 165.14 >>

Calculate

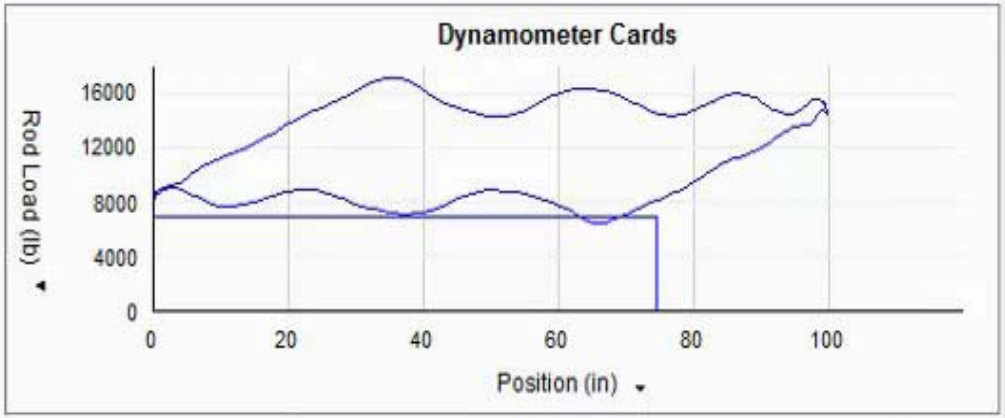
Default Settings

Total Sinker Bar Weight	0.0	lb	Damping Factor	0.10	
Fluid Specific Gravity	1.00	Sp.Gr.H2O	Surface Unit Efficiency	95.00	%
Tubing Pressure	80.00	psi	Pump Volumetric Efficiency	95.00	%
Casing Pressure	45.00	psi			

You may enter Pump Intake Pressure directly, or calculate it from Reservoir Pressure and Productivity Index.

◉ Pump Intake Pressure 50.00 psi ○ Reservoir Pressure 1,000.00 psi

Productivity Index 0.200 STB/D/psi



PPRL	17,111.7 lb	MPRL	6,496.5 lb	Fo	6,895.8 lb
Pump Stroke Length	74.57 in	Static Stretch	27.12 in	Overtravel	1.70 in
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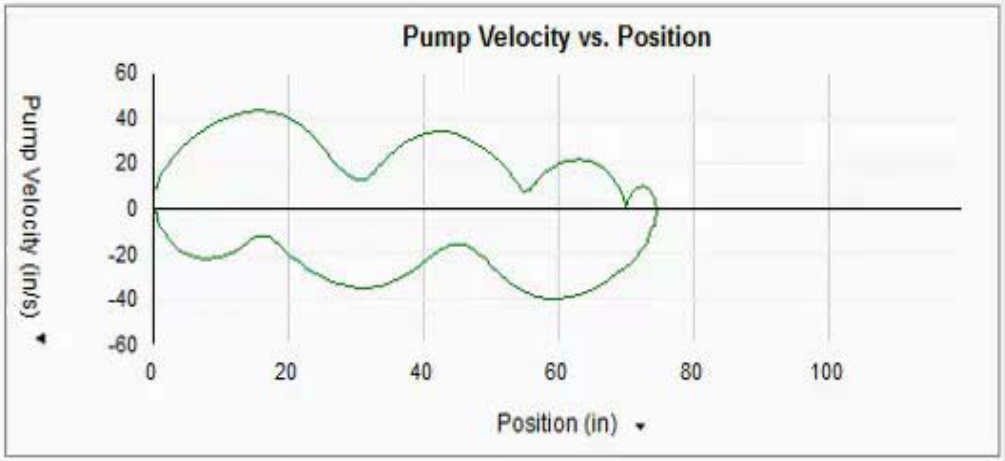

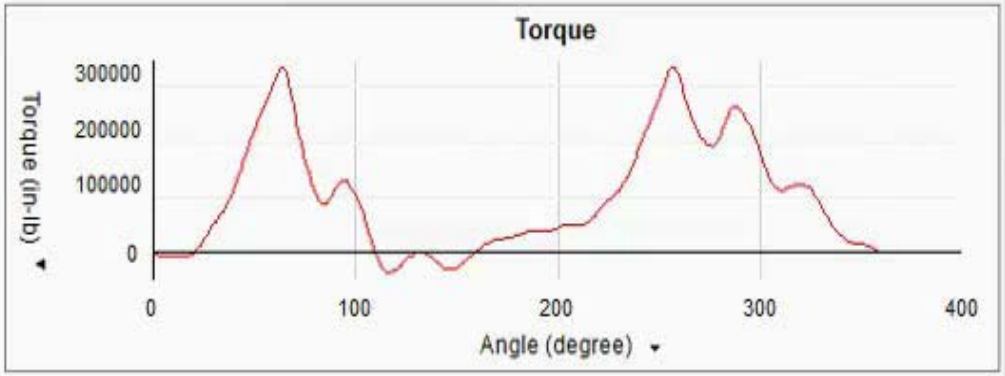

Peak GearBox Torque	335	Kin-lb
Counter Balance Moment	702	Kin-lb
Counter Balance Effect	11,942.6	lb

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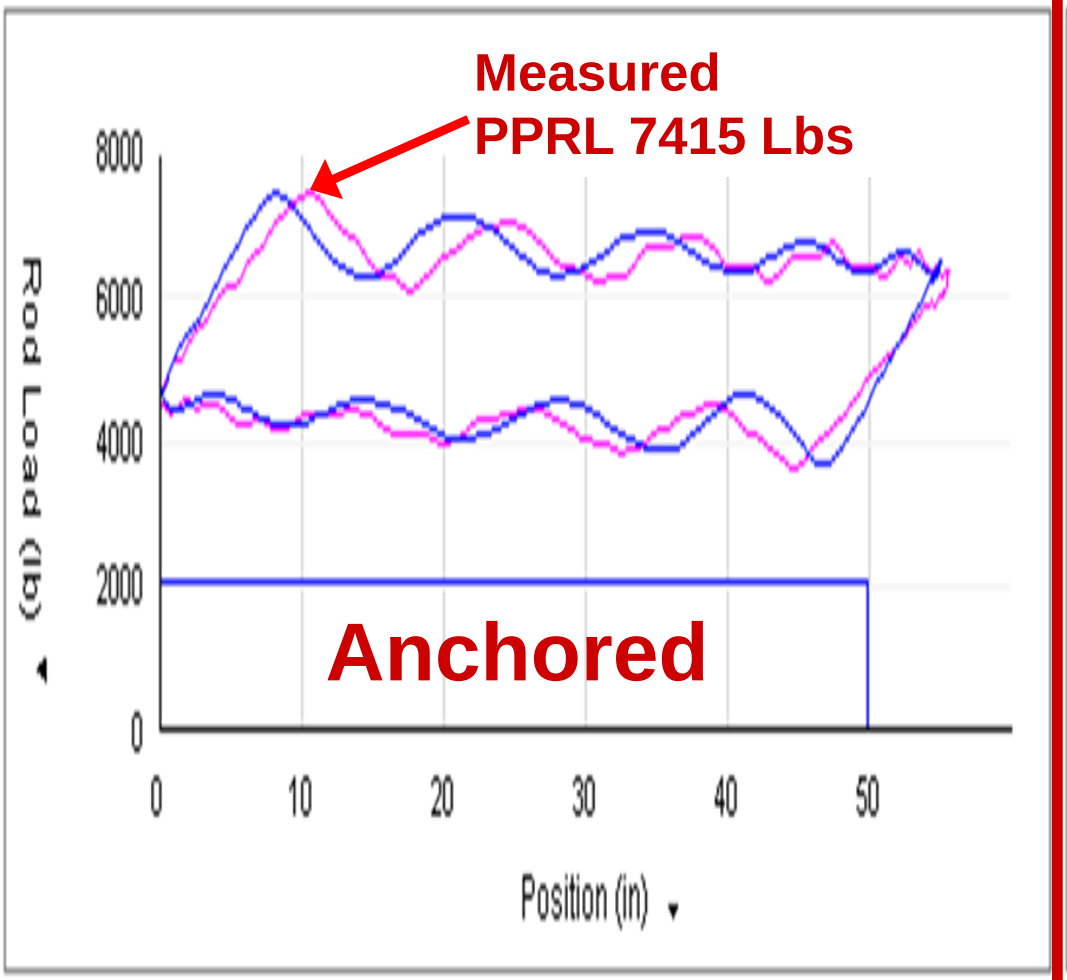
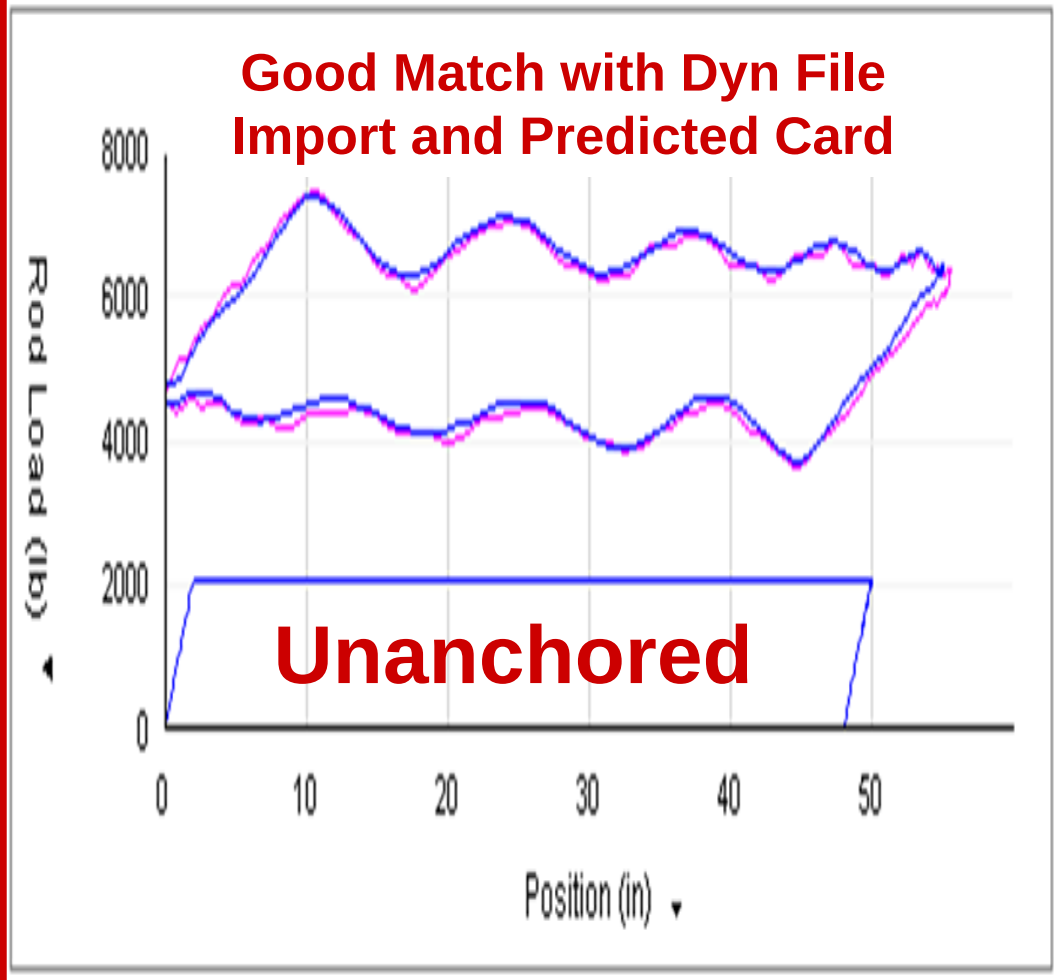
Tubing Unanchored?

Pump Intake pressure is 319 and pump is full of fluid. Tubing Anchor depth is 2914, but anchor appears to not be set.

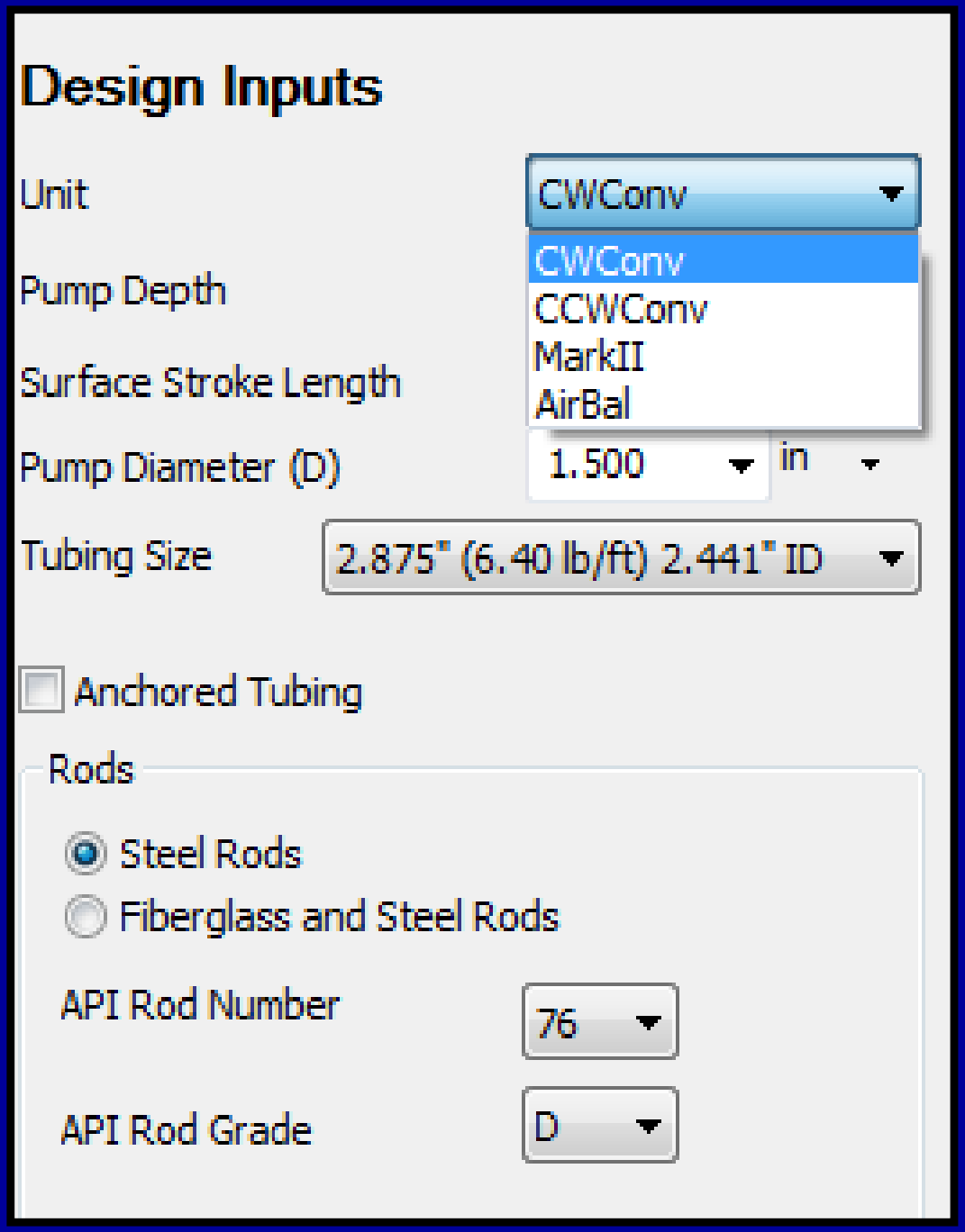


PPRL	7,421 psi	MPRL	3,675.9 lb	Fo	2,042.8 lb
Pump Stroke Length	49.82 in	Static Stretch	5.63 in	Overtravel	0.44 in
Fo/Skr	0.102	Kr	363 lb/in	Kt	1032 lb/in



PPRL	7,373 psi	MPRL	3,725.6 lb	Fo	2,042.8 lb
Pump Stroke Length	47.92 in	Static Stretch	5.63 in	Overtravel	0.52 in
Fo/Skr	0.102	Kr	363 lb/in	Kt	1032 lb/in

Pumping Unit Design and Selection



CWConv - selects the conventional unit with clockwise rotation of the crank**.**

CCWConv - selects the conventional unit with counter-clockwise rotation of the crank.

MarkII - selects the MarkII unit with counter-clockwise rotation of the crank.

AirBal - selects the air-balanced unit with clockwise rotation of the crank.

Pumping Unit Description

C-320D-256-100

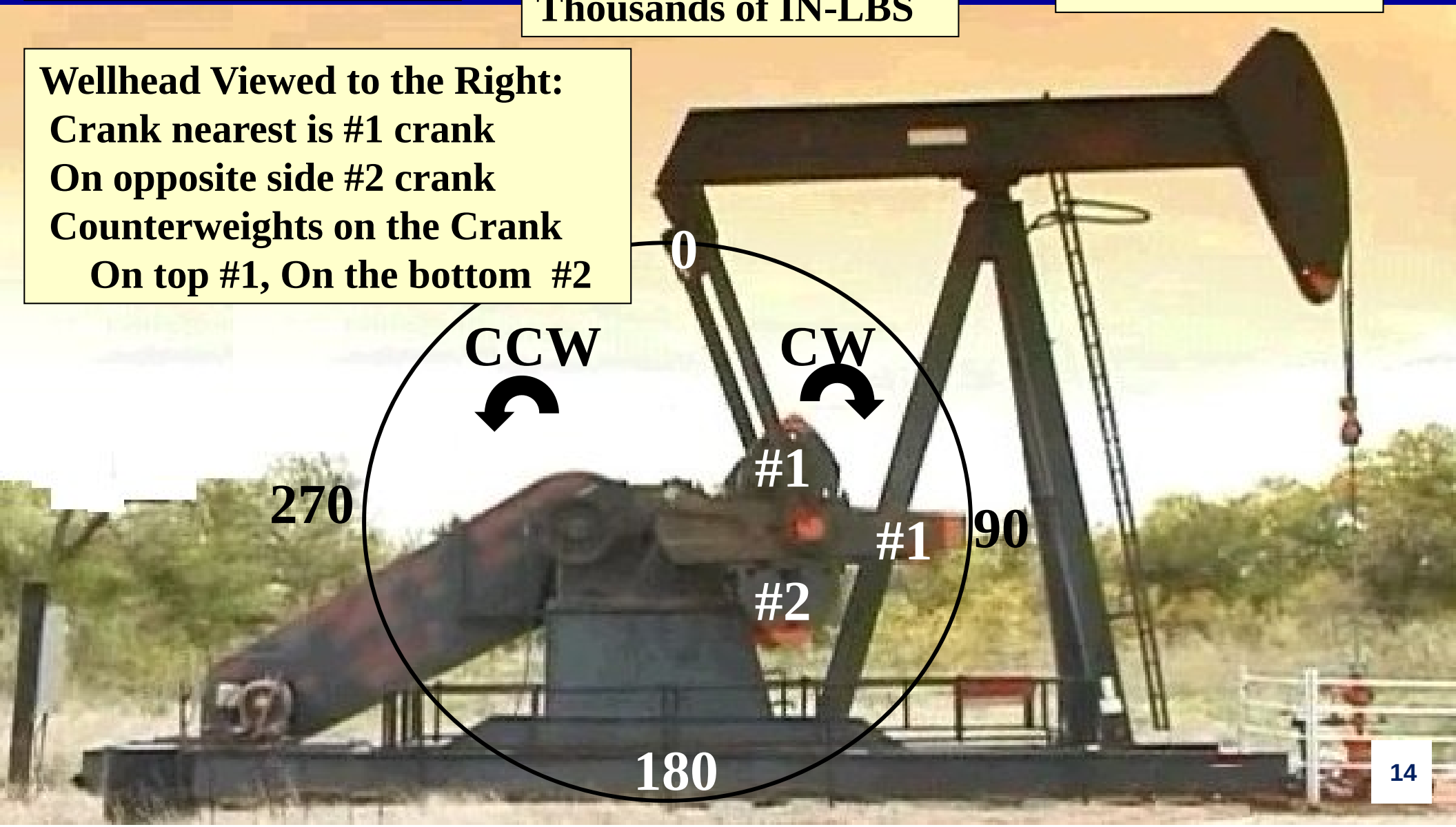
Type:
A - AIR BALANCE
B – BEAM BALANCE
C – CONVENTIONAL
M – MARK II

Maximum Stroke Length in Inches

Peak Torque Rating in Thousands of IN-LBS

Structure Rating in 100s of LBS

Wellhead Viewed to the Right:
Crank nearest is #1 crank
On opposite side #2 crank
Counterweights on the Crank
On top #1, On the bottom #2



Minimum API Pumping Unit Description

Min API Unit Rating 228-119-105

Design Inputs

Unit CWConv

Pump Depth 3,896 ft

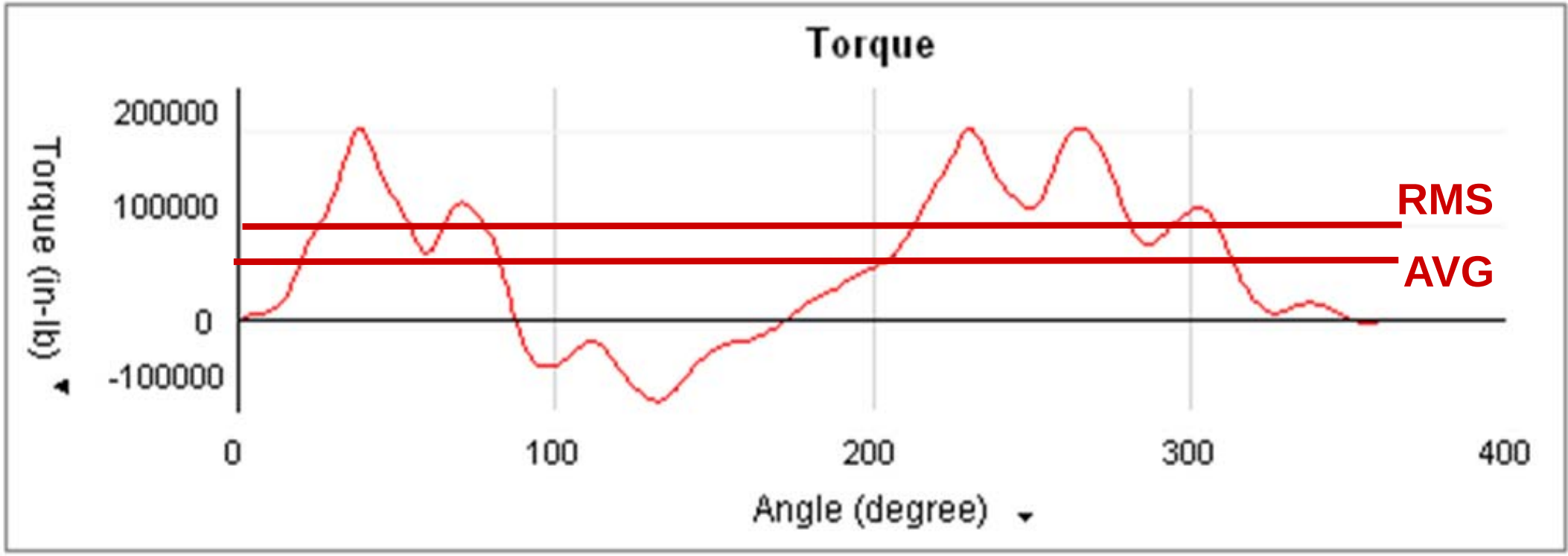
Results

Rate (100% pump volumetric eff.) 182 BBL/D

Rate (90% pump volumetric eff.) 164 BBL/D

Rod Taper 34.0%, 66.0%

Min API Unit Rating 228-119-105



Peak GearBox Torque	204	Kin-lb
Counter Balance Moment	509	Kin-lb
Counter Balance Effect	10,222.6	lb

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Peak GearBox Torque 204 Kin-lb
Counter Balance Moment 509 Kin-lb
Counter Balance Effect 10,222.6 lb

Design Minimum Required NEMA D Motor Horsepower Size

Computer: HP = CLF * PRHP / Unit Efficiency

QRod uses:

CLF = *RMS Torque/ Average Torque*

RMS Power/ Average Power is OK.

(don't use CLF based on motor current)

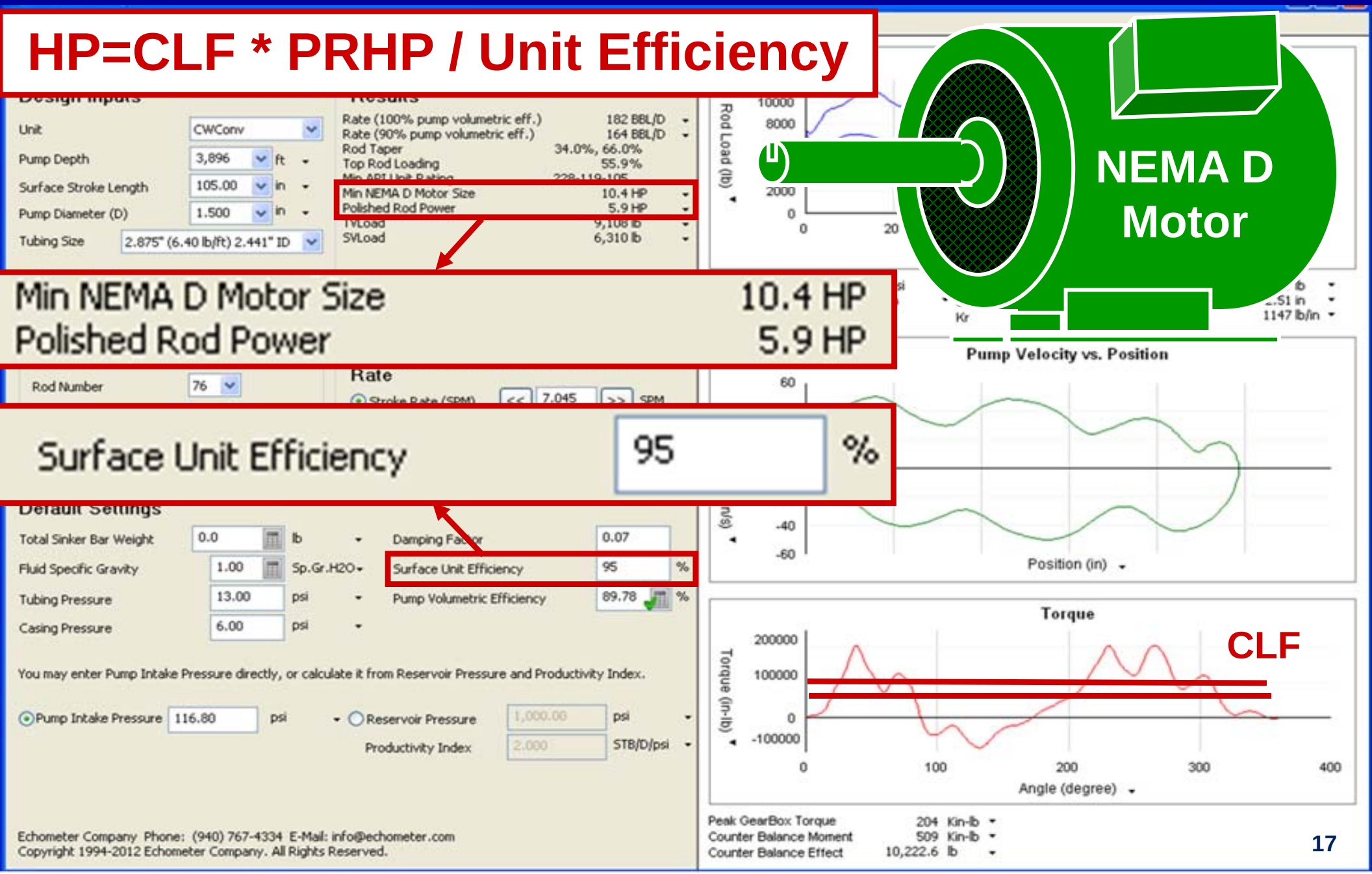
OR:

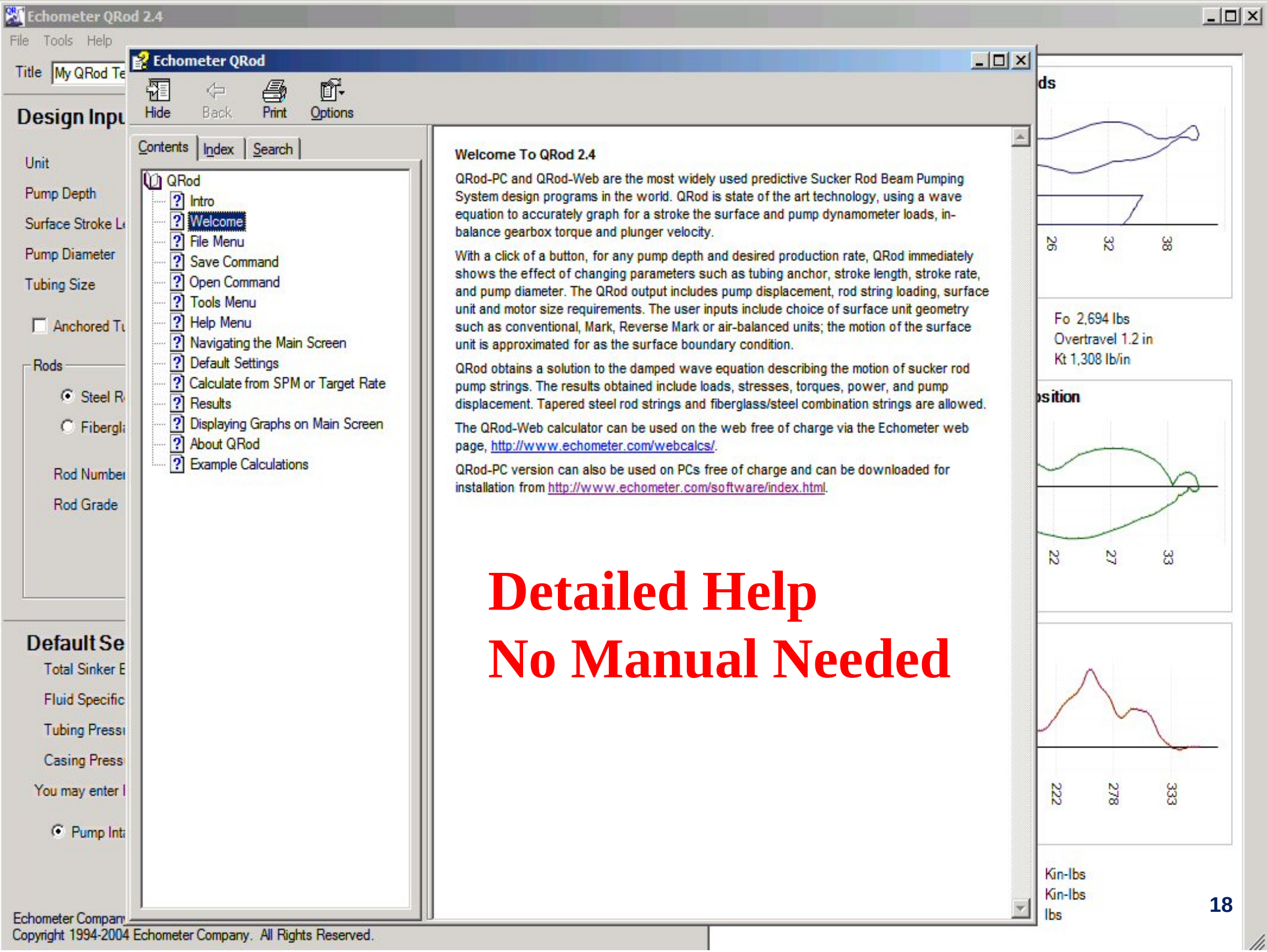
Gault: HP = 2. * PRHP

Unit Efficiency: 95 % for "Large" Units
80 % for "Small" Units

NEMA D Efficient Under Cyclic Loads
8-13% Slip ~ 275% Starting Torque

HP=CLF * PRHP / Unit Efficiency




Echometer QRod 2.4
File Tools Help
Title My QRod Te
Design Inpu
Unit
Pump Depth
Surface Stroke L
Pump Diameter
Tubing Size
Anchored Tu
Rods
Steel R
Fibergl
Rod Numbe
Rod Grade
Default Se
Total Sinker E
Fluid Specific
Tubing Pressu
Casing Press
You may enter
Pump Int
Echometer QRod
Hide
Back
Print
Options
Contents
Index
Search
QRod
Intro
Welcome
File Menu
Save Command
Open Command
Tools Menu
Help Menu
Navigating the Main Screen
Default Settings
Calculate from SPM or Target Rate
Results
Displaying Graphs on Main Screen
About QRod
Example Calculations
Welcome To QRod 2.4
QRod-PC and QRod-Web are the most widely used predictive Sucker Rod Beam Pumping System design programs in the world. QRod is state of the art technology, using a wave equation to accurately graph for a stroke the surface and pump dynamometer loads, in-balance gearbox torque and plunger velocity.
With a click of a button, for any pump depth and desired production rate, QRod immediately shows the effect of changing parameters such as tubing anchor, stroke length, stroke rate, and pump diameter. The QRod output includes pump displacement, rod string loading, surface unit and motor size requirements. The user inputs include choice of surface unit geometry such as conventional, Mark, Reverse Mark or air-balanced units; the motion of the surface unit is approximated for as the surface boundary condition.
QRod obtains a solution to the damped wave equation describing the motion of sucker rod pump strings. The results obtained include loads, stresses, torques, power, and pump displacement. Tapered steel rod strings and fiberglass/steel combination strings are allowed.
The QRod-Web calculator can be used on the web free of charge via the Echometer web page, http://www.echometer.com/webcalcs/.
QRod-PC version can also be used on PCs free of charge and can be downloaded for installation from http://www.echometer.com/software/index.html.
Detailed Help
No Manual Needed
Fo 2,694 lbs
Overtravel 1.2 in
Kt 1,308 lb/in
Kin-lbs
Kin-lbs
lbs
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Echometer QRod 2.4

Archivo Útiles Ayuda

Título: Mi Prueba en QRod

Parametros de Entrada

Tipo de Balancín	CWConv	
Profundidad de la Bomba	5,000	ft
Carrera del balancín	100	in
Diámetro del Pistón	1.500	in
Diámetro de la Tubería	2.875" (6.4 lb/ft) 2.441" ID	

☐ Tubería anclada

Varillas

◉ Varillas de acero

○ Varillas fibra de vidrio y acero

Número API	76
Clase de varillas	D

Resultados

Caudal (100% eficiencia bomba)	180	bbl/day
Caudal (95 % eficiencia bomba.)	171	bbl/day
% varillas para cada secciór	34.0, 66.0	
Carga de las varillas en superfici	72.3	%
Capacidad (API) mínima balancín	320-173-100	
Capacidad mínima potencia motor	15.8	hp
Potencia en barra pulida	8.5	hp
Carga válvula viajera	11,977	lbs
Carga válvula fija	8,098	lbs

Spanish

Calcular en base a SPM o Caudal deseado

◉ Velocidad de bombeo < 8.3 > SPM

○ Caudal deseado < 171 > bbl/day

Calcular

Valores de Ajuste Predeterminados

Peso total barras de lastre	0	lbs	Factor de amortiguamento	0.1	
Gravedad específica del fluido	1	$H_2O = 1$	Eficiencia del balancín	95	%
Presión de la tubería	80	psi	Eficiencia de la bomba	95	%
Presión del revestidor	45	psi			

La presión de entrada de la bomba puede introducirse directamente o calcularse a partir de la presión de vacimiento e índice de productividad.

◉ Presión de entrada de la bomba 50

○ Presión de Yacimiento 1000 psi

Indice de Productividad 2.000 bbl/day/psi

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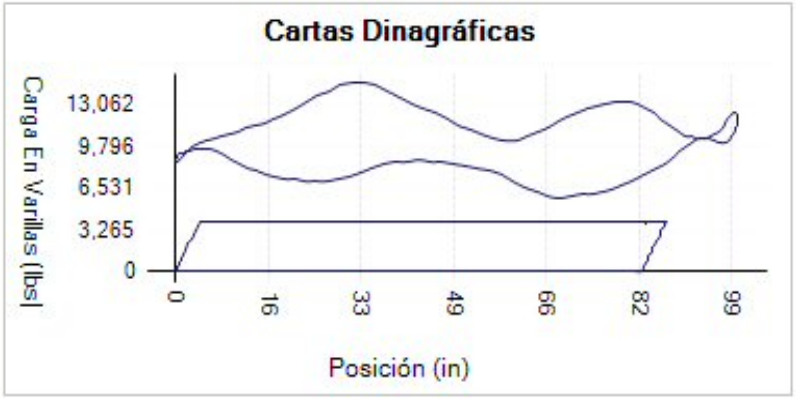
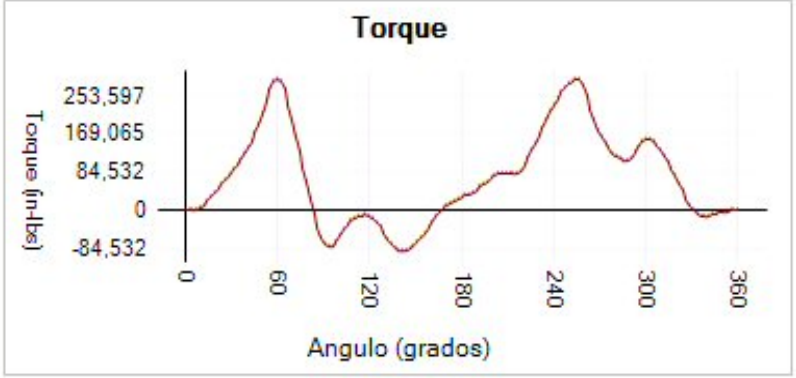


Carga Mínima 14,873 lbs	Carga Máxima 5,817 lbs	Fo 3,879 lbs
Carrera del piston 82.9 in	Elongación 15.6 in	Sobrecarrera 2.8 in
Fo/Skr 0.156	Kr 249 lb/in	Kt 894 lb/in



Torque máximo	291	Kin-lbs
Momento de Contrapesas	621	Kin-lbs
Efecto de Contrapesas	13,087	lbs

One Page Report

Programa QRod
Título: Mi Prueba en QRod

Resultados

Caudal (100% eficiencia bomba)	180 bbl/day
Caudal (95 eficiencia bomba)	171 bbl/day
% varillas para cada sección	34.0, 66.0
Carga de las varillas en superficie	72.3 %
Capacidad (API) mínima balancín	320-173-100
Capacidad mínima potencia motor	15.8 hp
Potencia en barra pulida	8.5 hp
Carga válvula viajera	11,977 lbs
Carga válvula fija	8,098 lbs

Parametros de Entrada

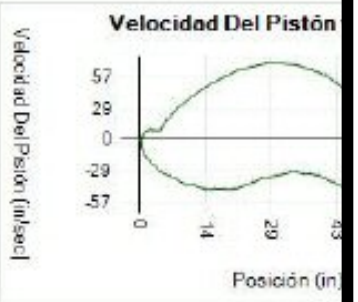
Tipo de Balancín	CWConv
Profundidad de la Bomba	5,000 ft
Caudal deseado	171 bbl/day
Velocidad de bombeo	8.3 SPM
Carrera del balancín	100 in
Diámetro del Pistón	1.500 in
Diámetro de la tubería	2.875" (6.4 lb/ft) 2.441" ID in
Tubería anclada	No
Tipo de varillas	Varillas de acero
Número API de las varillas	76
Clase de varillas	D

Valores de Ajuste Predeterminados

Peso total barras de lastre	0 lb
Gravedad especifica del fluido	1
Presión de la tubería	80 psi
Presión del revestidor	45 psi
Factor de amortiguamento	0.1
Eficiencia del balancín	95
Eficiencia de la bomba	95
Presión de entrada de la bomba	50 psi

Diagramas

Carga Máxima	14,873 lbs	Carga Minima	5, lb
Carrera del piston	82.9 in	Elongación	15
Fo/Skr	0.156	Kr	24



Torque máximo	
Momento de Contrapesas	
Efecto de Contrapesas	

en Venezuela: varilla = cabilla

QRod Version 2.3

Echometer Company

QRod Application
Title: My QRod Test Run

Results

Rate (100 % Pump Eff.)	180 bbl/day
Rate (95 Pump Eff.)	171 bbl/day
Rod Taper, %	34.0, 66.0
Top Rod Loading	72.3 %
Min API Unit Rating	320-173-100
Min Motor Size	15.8 hp
Polished Rod Power	8.5 hp
TVLoad	11,977 lbs
SVLoad	8,098 lbs

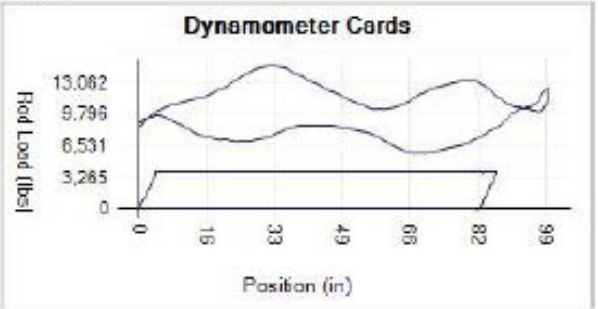
Design Inputs

Unit Type	CWConv
Pump Depth	5,000 ft
Target Rate	171 bbl/day
Stroke Rate	8.3 SPM
Surface Stroke Length	100 in
Pump diameter	1.500 in
Tubing Size	2.875" (6.4 lb/ft) 2.441" ID in
Anchored Tubing	No
Rod Type	Steel Rods
Rod Number	76
Rod Grade	D

Default Settings

Total Sinker Bar Weight	0 lb
Fluid Specific Gravity	1
Tubing Pressure	80 psi
Casing Pressure	45 psi
Damping Factor	0.1
Unit Efficiency	95
Pump Efficiency	95
Pump Intake Pressure	50 psi

Plots



PPRL	14,873 lbs	MPRL	5,817 lbs	Fo	3,879 lbs
Pump Stroke Length	82.9 in	Static Stretch	15.6 in	Overtravel	2.8 in
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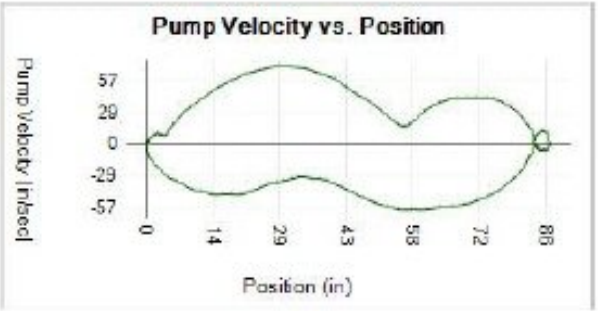

Peak GearBox Torque	291 Kin-lbs
Counter Balance Moment	621 Kin-lbs
Counter Balance Effect	13,087 lbs

QRod Version 2.3

Echometer Company
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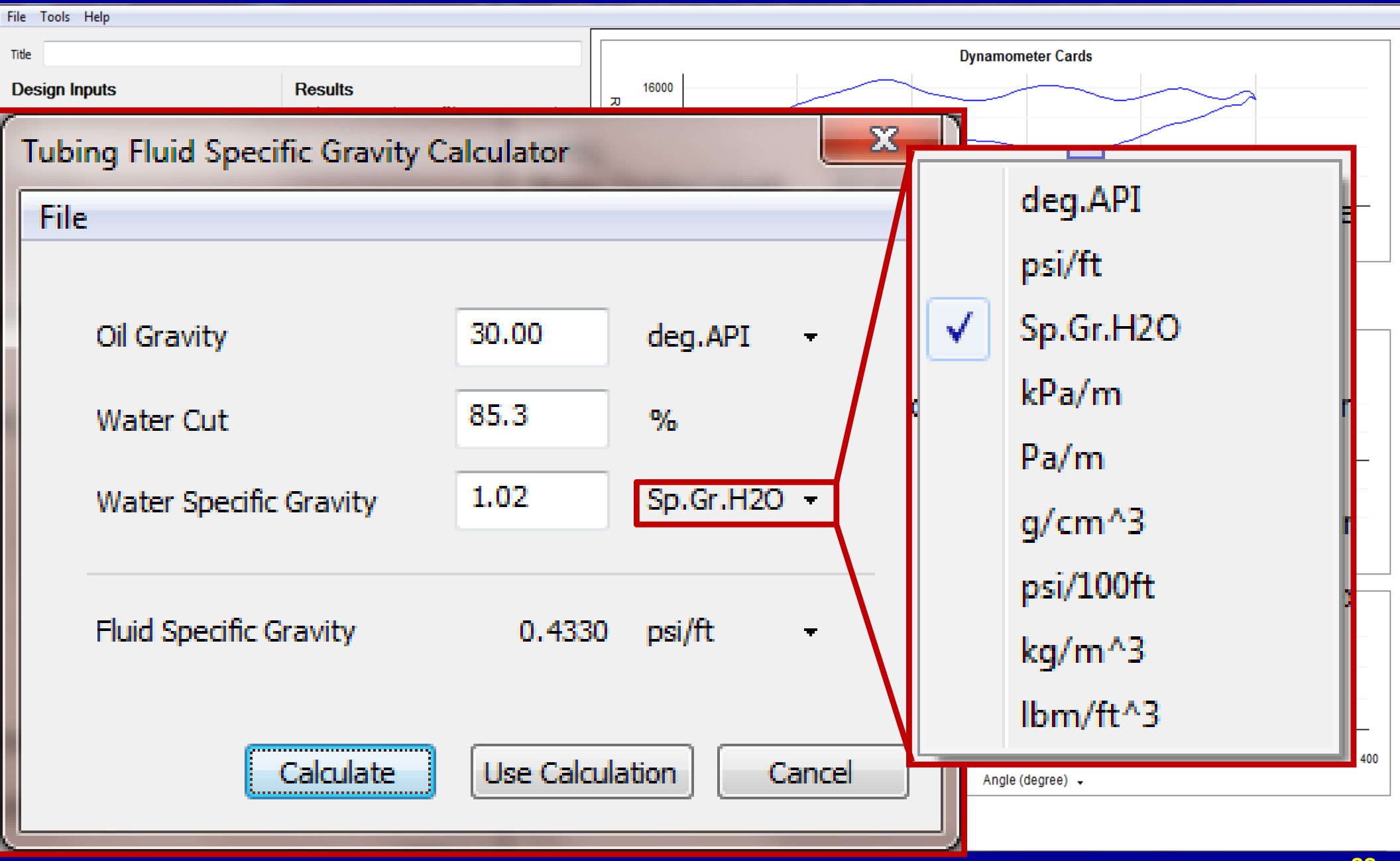
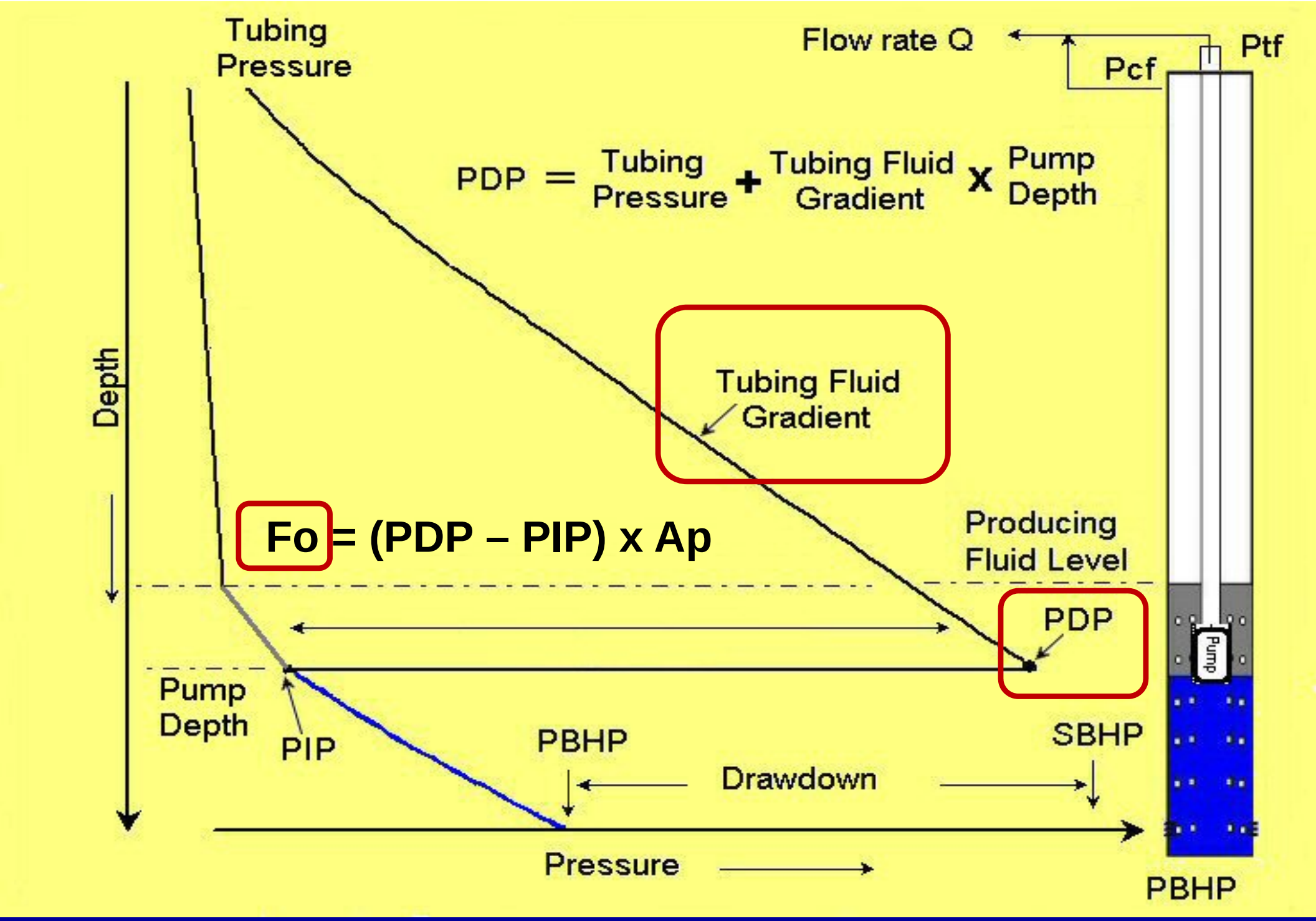
New design tools include:

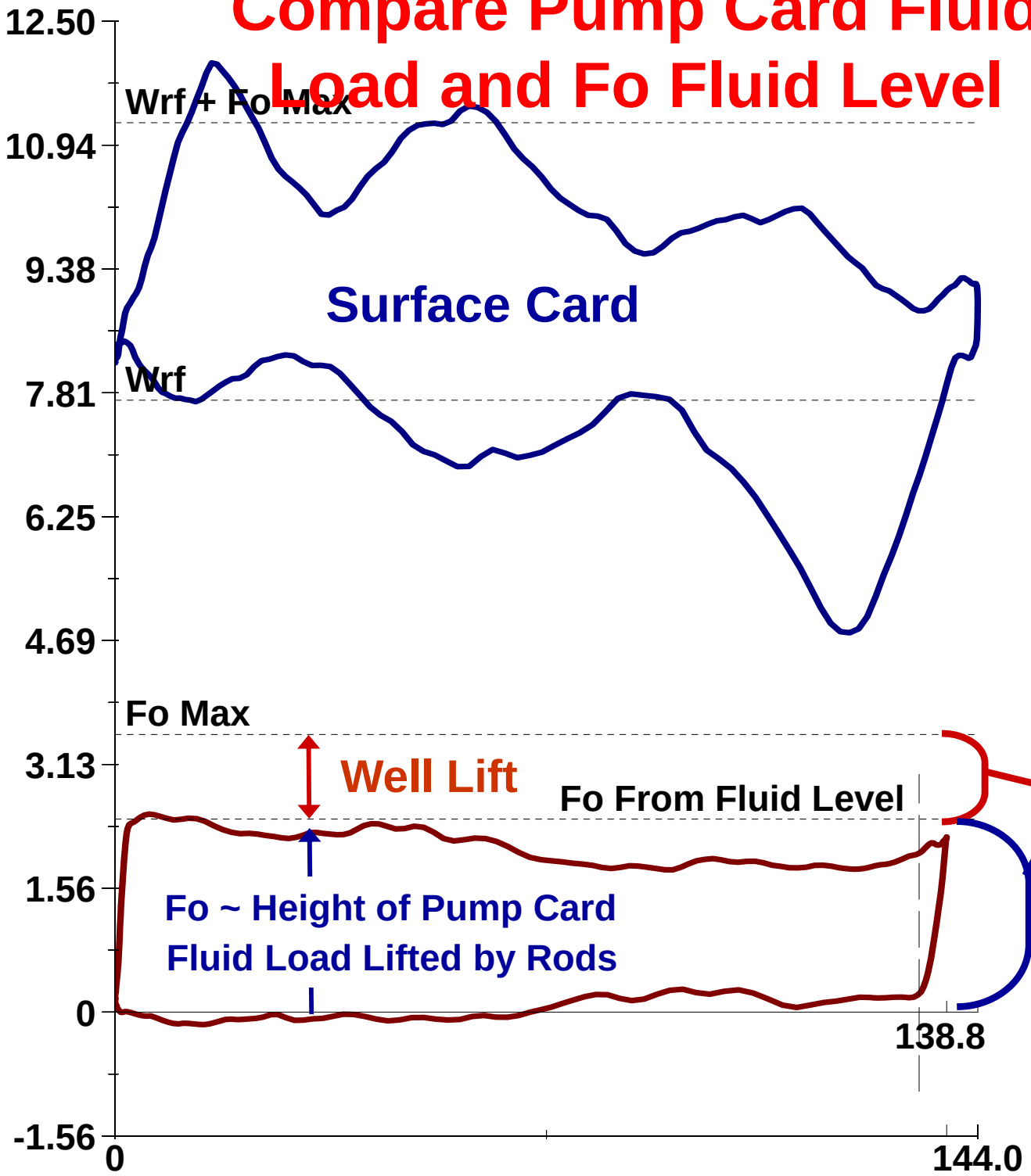
1. Slippage Calculator uses pump clearances tying the pump efficiency to the predicted pump displacement.
2. Sinker Bar length calculator determines the sinker bar length as pump diameter or pump depth changes.
3. Tubing Fluid specific gravity calculator.
4. Dynamometer measured surface DYN files can be imported and plotted on top of the predicted surface dynamometer card.

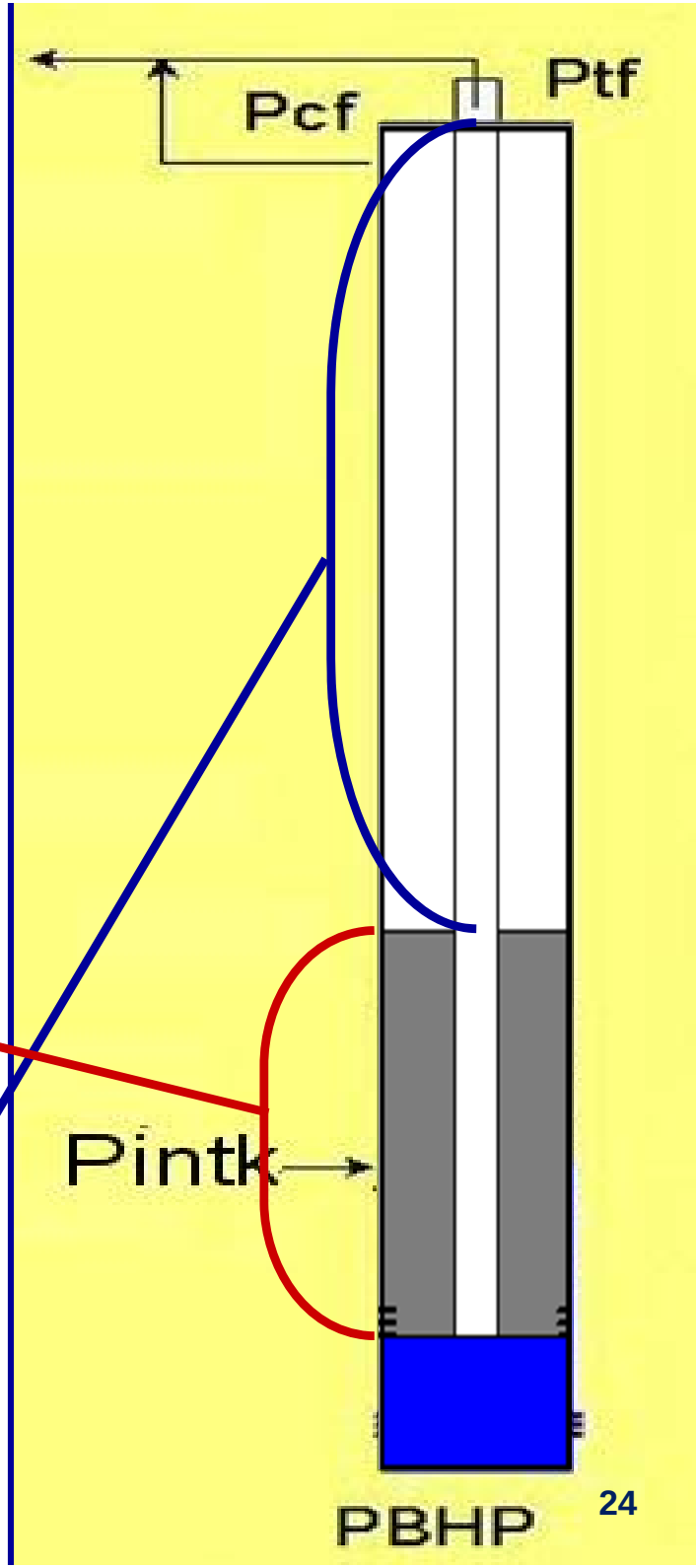
Tool: Tubing Fluid Specific Gravity Calculator Simple to Determine for any System of Units




Tubing Pressure
Flow rate Q
Pcf
Ptf
PDP = Tubing Pressure + Tubing Fluid Gradient x Pump Depth
Depth
Tubing Fluid Gradient
Fo = (PDP – PIP) x Ap
Producing Fluid Level
PDP
Pump
Pump Depth
PIP
PBHP
SBHP
Drawdown
Pressure
PBHP

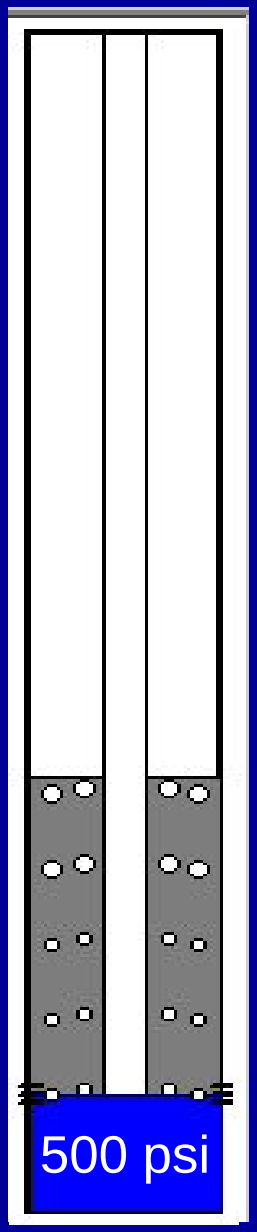
Compare Pump Card Fluid Load and Fo Fluid Level





Fluid Load, Fo, Decreases as Pump Intake Pressure, PIP, Increases

Fluid Load Function of PIP.qrd



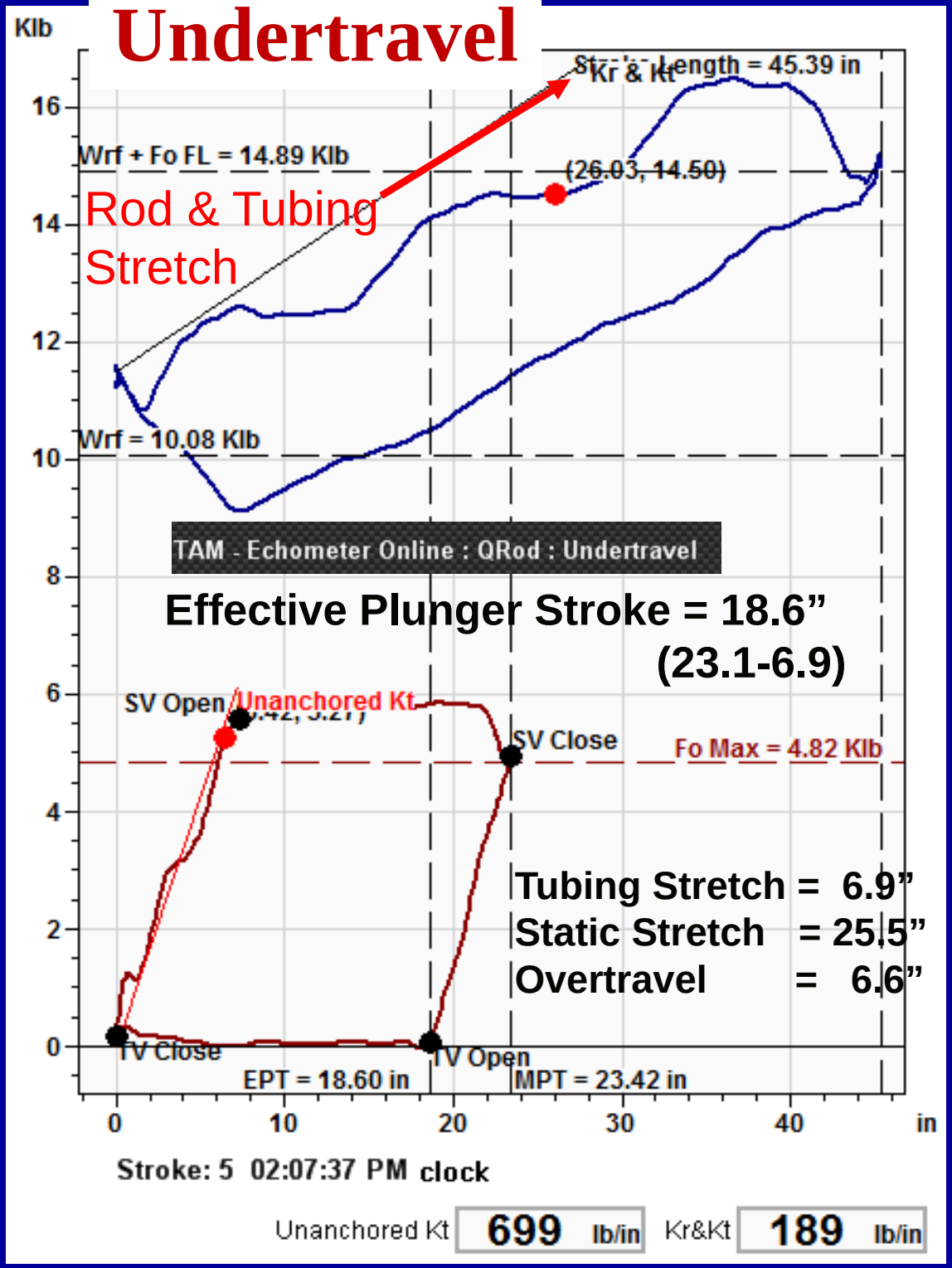
PPRL	15,617	psi	MPRL	6,575.9	lb	Fo	5,482.1	lb
Pump Stroke Length	80.72	in	Static Stretch	21.56	in	Overtravel	2.28	in
Fo/Skr	0.216		Kr	254	lb/in	Kt	894	lb/in

Overtravel ~ Undertravel

- **Overtravel** - Pump Stroke Will Increase, when the Dynamic Motion of the Beam Pump System adds momentum that impact the elongation of the rod string
- **Undertravel** - Pump stroke shortens, when the rods stretch to pick up pump load and/or mechanical fiction. Pump plunger moves less than the polished rod stroke. Includes: stuck pumps, plunger is too large for the rod string, sand or scale problems, too tight stuffing box and/or paraffin.

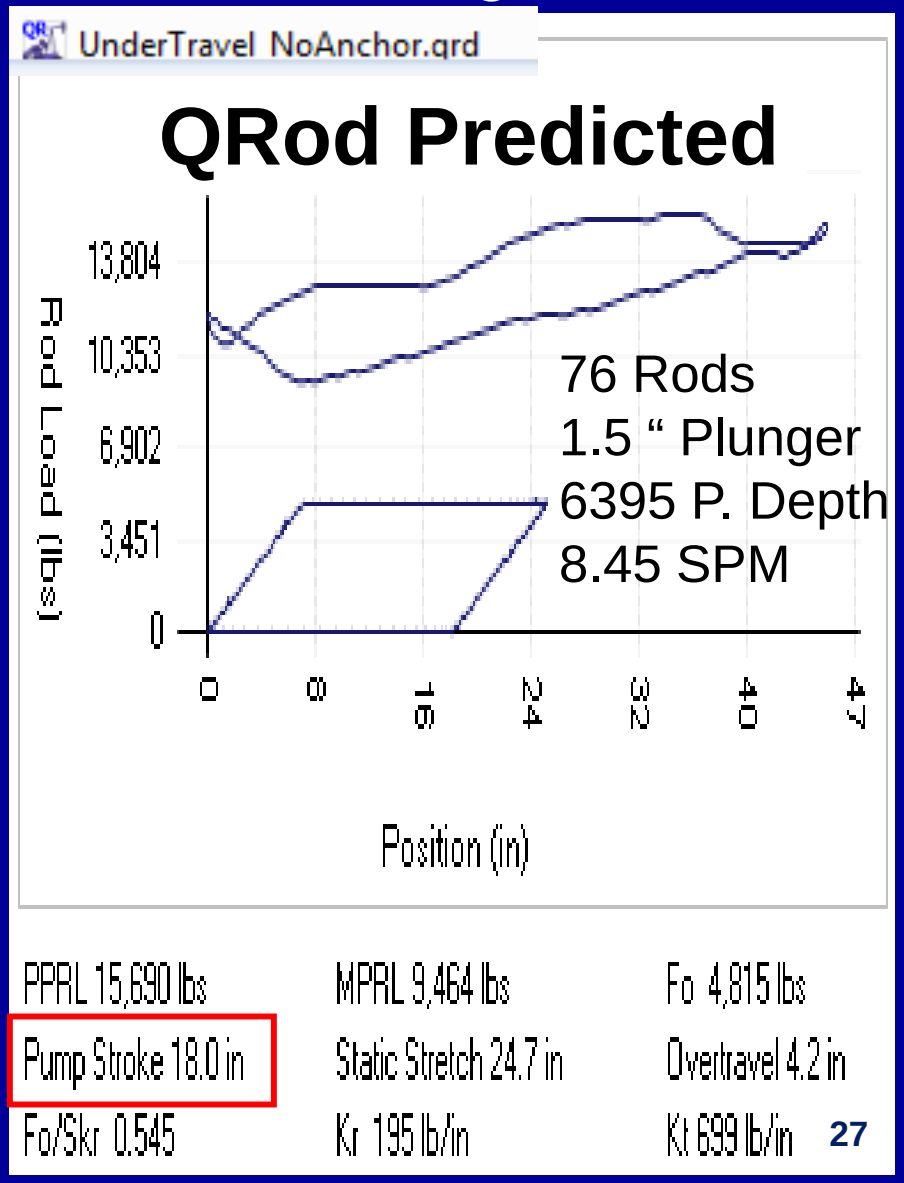
- Surface Dynamometer Card Sloping Up or Down from Left to Right Defines:
  - Up an "Overtravel Card“
  - Down an “Undertravel Card”

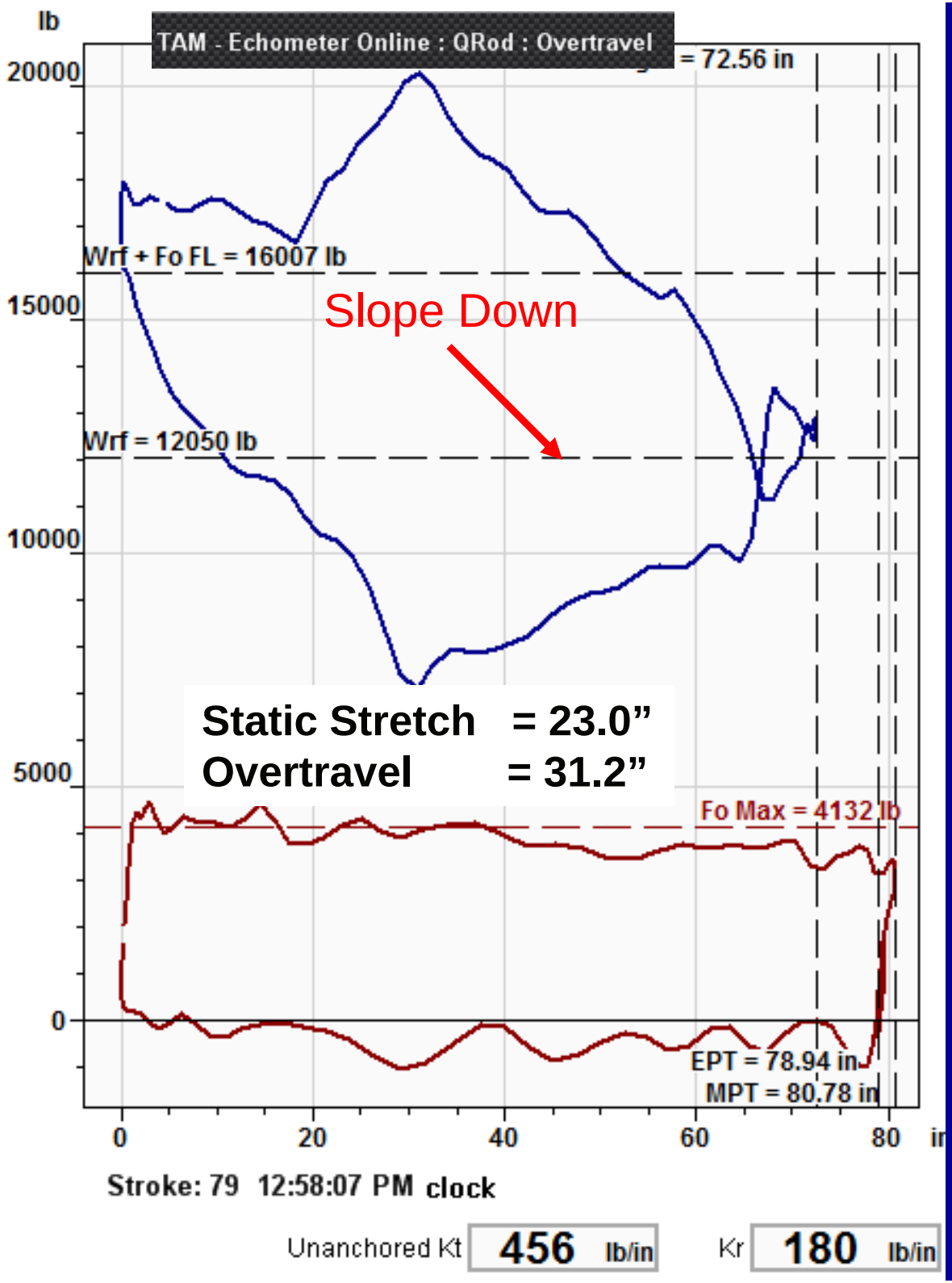
Undertravel



Plunger too Large for Rods

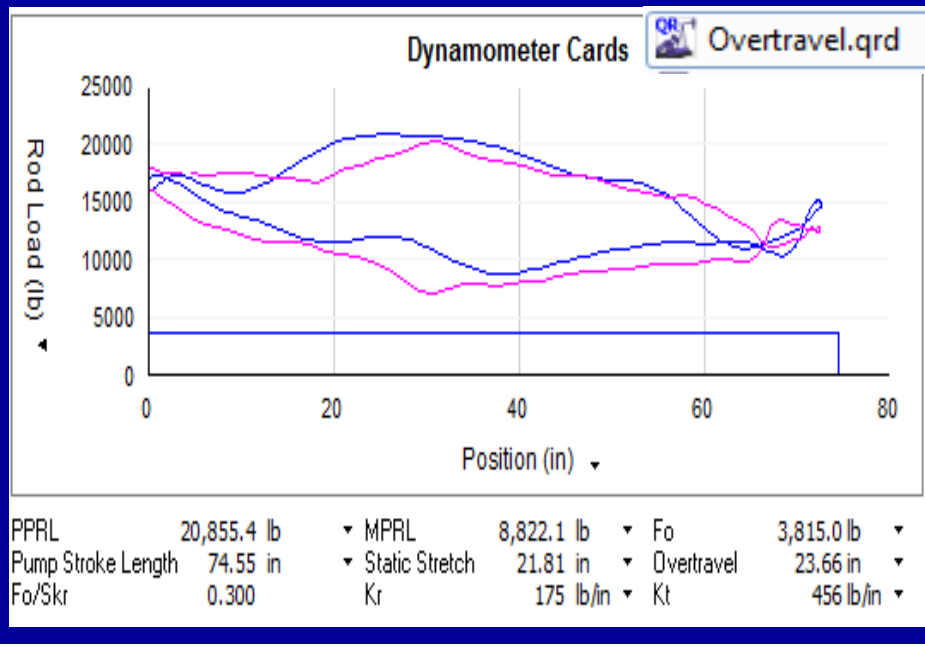
Severe under travel occurs when the sub surface pump diameter is too large for the sucker rod string.

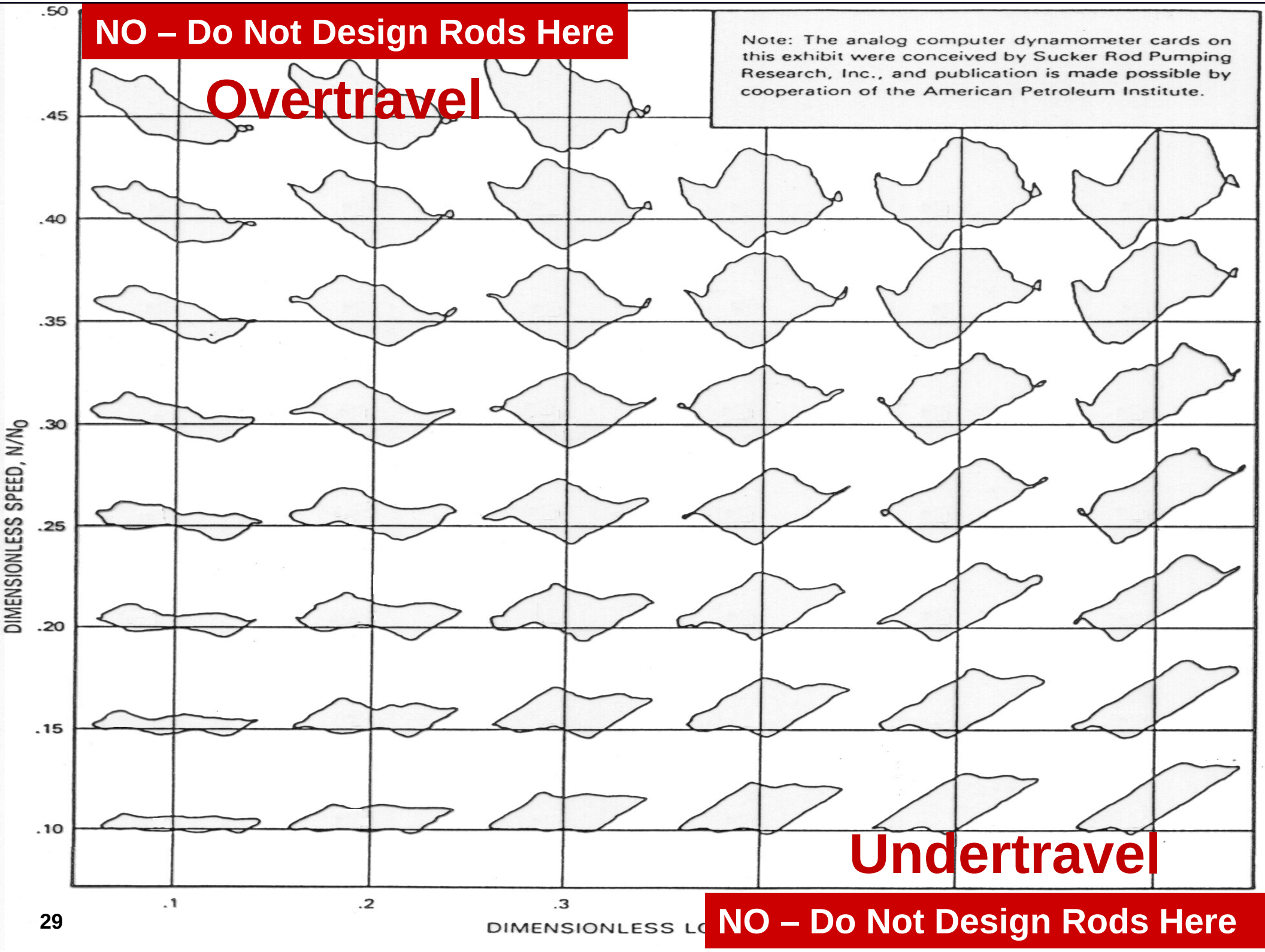




Overtravel

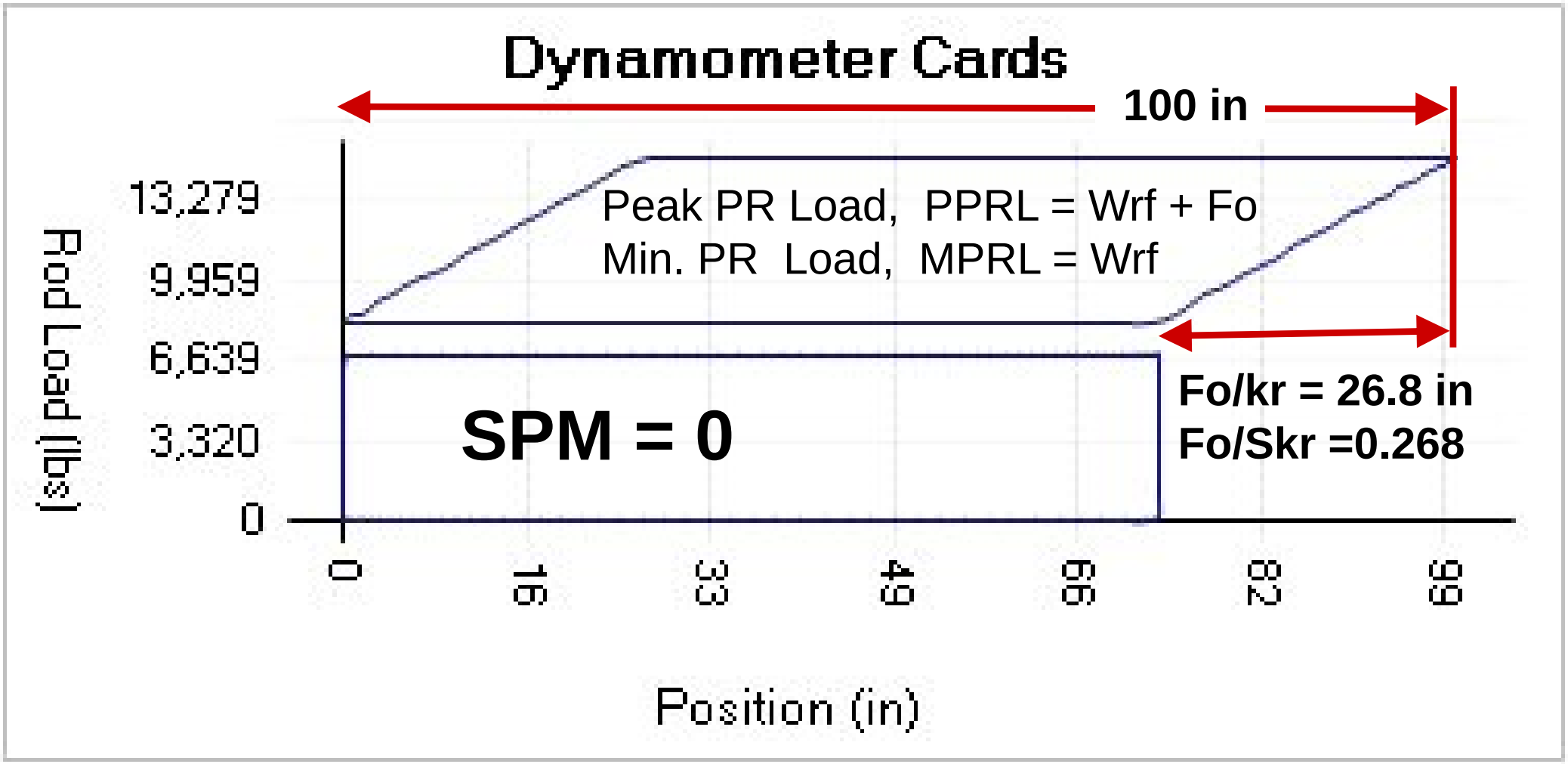
- Plunger stroke increases due to pumping speed.
- Surface card slopes downward from left to right.
- The 13.74 SPM adds momentum to the rods increasing stroke by 31.2”.
- Overtravel cards include: parted rods, flowing wells, unseated pumps, gas locks, worn pumps, fiberglass rod strings or very fast SPM.




NO – Do Not Design Rods Here
Overtravel
Note: The analog computer dynamometer cards on this exhibit were conceived by Sucker Rod Pumping Research, Inc., and publication is made possible by cooperation of the American Petroleum Institute.
DIMENSIONLESS SPEED, N/N0
.50
.45
.40
.35
.30
.25
.20
.15
.10
.1
.2
.3
DIMENSIONLESS LO
Undertravel
NO – Do Not Design Rods Here

Pump Stroke Less by Static Stretch

Dynamometer Cards at Pumping Speed of approximately 0 SPM

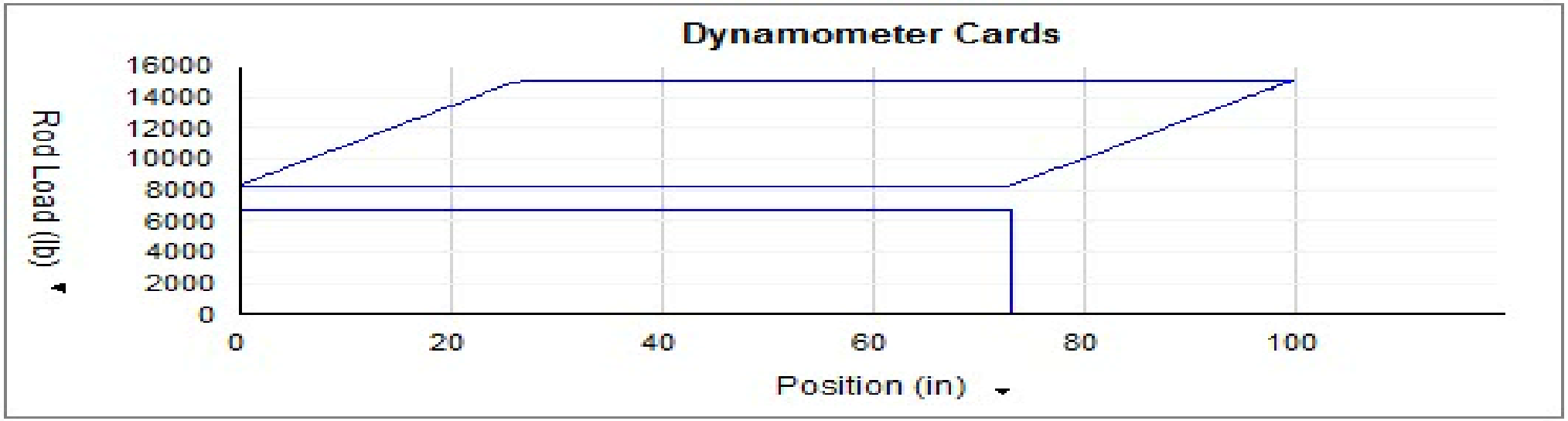


PPRL 15,089 lbs
Pump Stroke 73.2 in
Fo/Skr 0.268

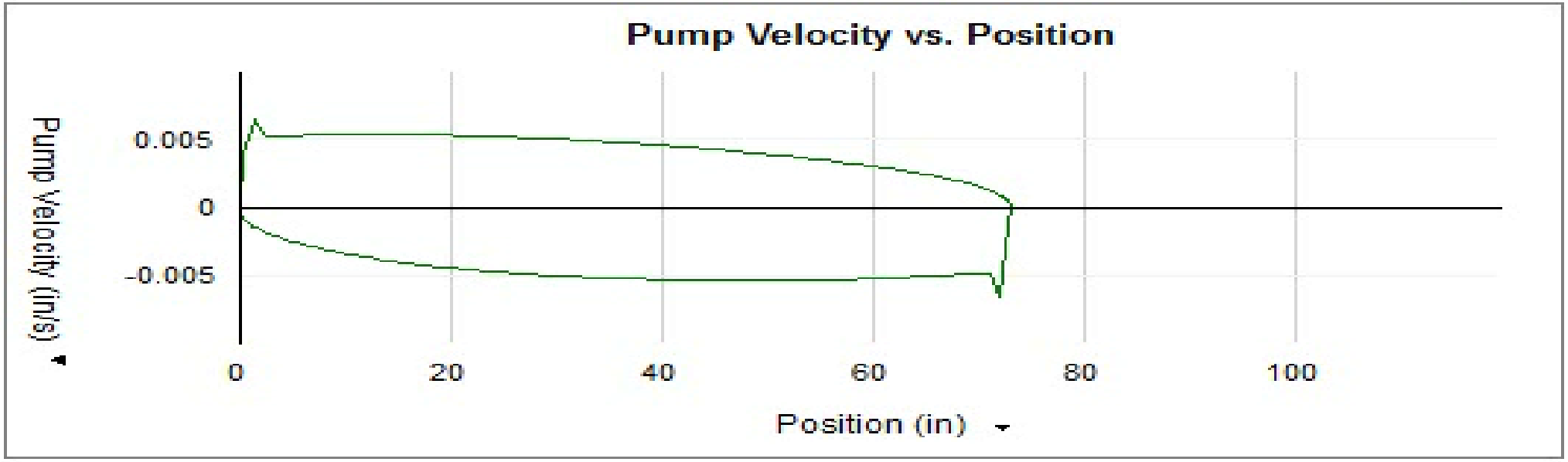
MPRL 8,288 lbs
Static Stretch 26.8 in
Kr 254 lb/in

Fo 6,802 lbs
Overtravel 0.0 in
Kt 894 lb/in

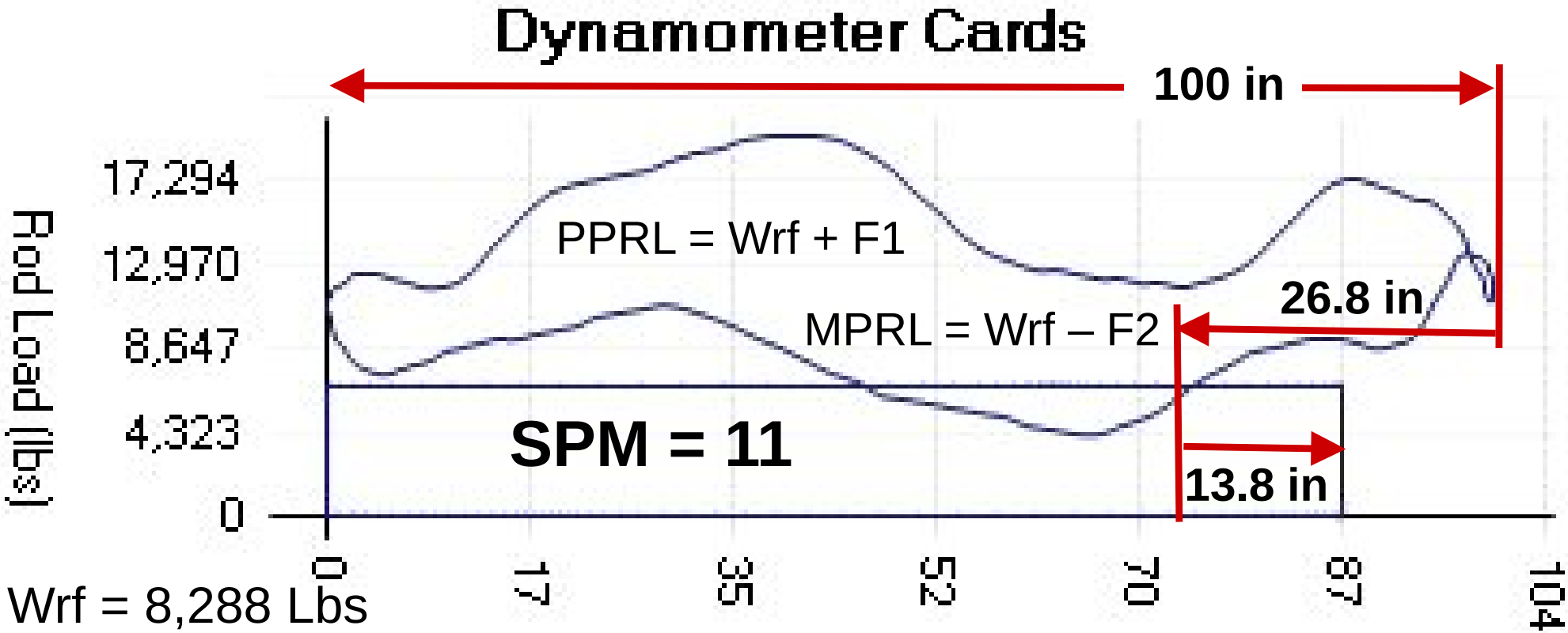
Plunger Stroke Lengthens (Overtravel) Due to Higher Velocity as SPM Increases from 0 to 11



PPRL	15,089.5	lb	MPRL	8,287.8	lb	Fo	6,801.5	lb
Pump Stroke Length	73.20	in	Static Stretch	26.75	in	Overtravel	-0.05	in
Fo/Skr	0.268		Kr	254	lb/in	Kt	894	lb/in



Rod String 76 Design loaded to 100% of the Allowable Modified Goodman Stress



Wrf = 8,288 Lbs
F1 = 11,378 Lbs
F2 = 4,100 Lbs

PPRL 19,666 lbs
Pump Stroke 87.1 in
Fo/Skr 0.268

MPRL 4,188 lbs
Static Stretch 26.8 in
Kr 254 lb/in

Fo 6,802 lbs
Overtravel 13.8 in
Kt 894 lb/in

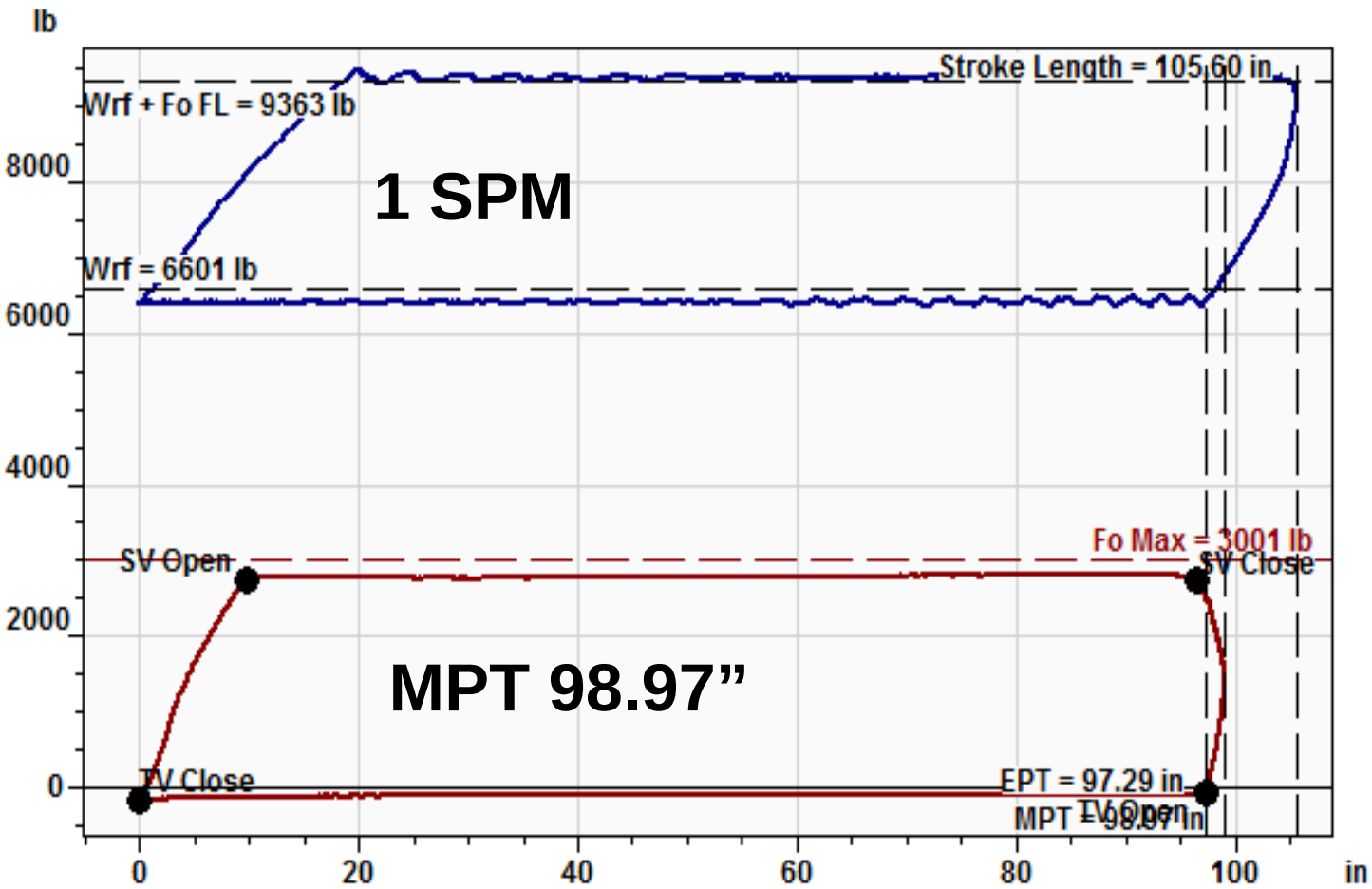
TTU Test Well 1 to 9.6 SPM

08/25/2006 Stroke:105.6” Plunger:1.5” Clearance:0.005 API #: 76 PIP:135

	Peak Load	Min Load	Power
Polished Rod	9500 lb	6362 lb	0.7 HP
Pump	2815 lb	-181 lb	0.7 HP

Replay | Events

< Stroke 1 of 1 >



Stroke: 1 07:35:44 PM clock

Unanchored Kt 1147 lb/in

Kr 327 lb/in

Adj Pump Displacement	14 BBL/D
Calculated Fluid Load Max	3001 lb
Surface Efficiency	9.56 %
Pumping Speed	0.962 spm
Motor to Pump Efficiency	9.30 %
Pump Intake Pressure	120 psi (g)
Damp Up	0.062
Damp Down	0.070
Adj Fillage	55.75 %
Adj EPT	55.2 in
Enter Tubing Pressure	13.0 psi (g)

Annotations

Pump Card Analysis

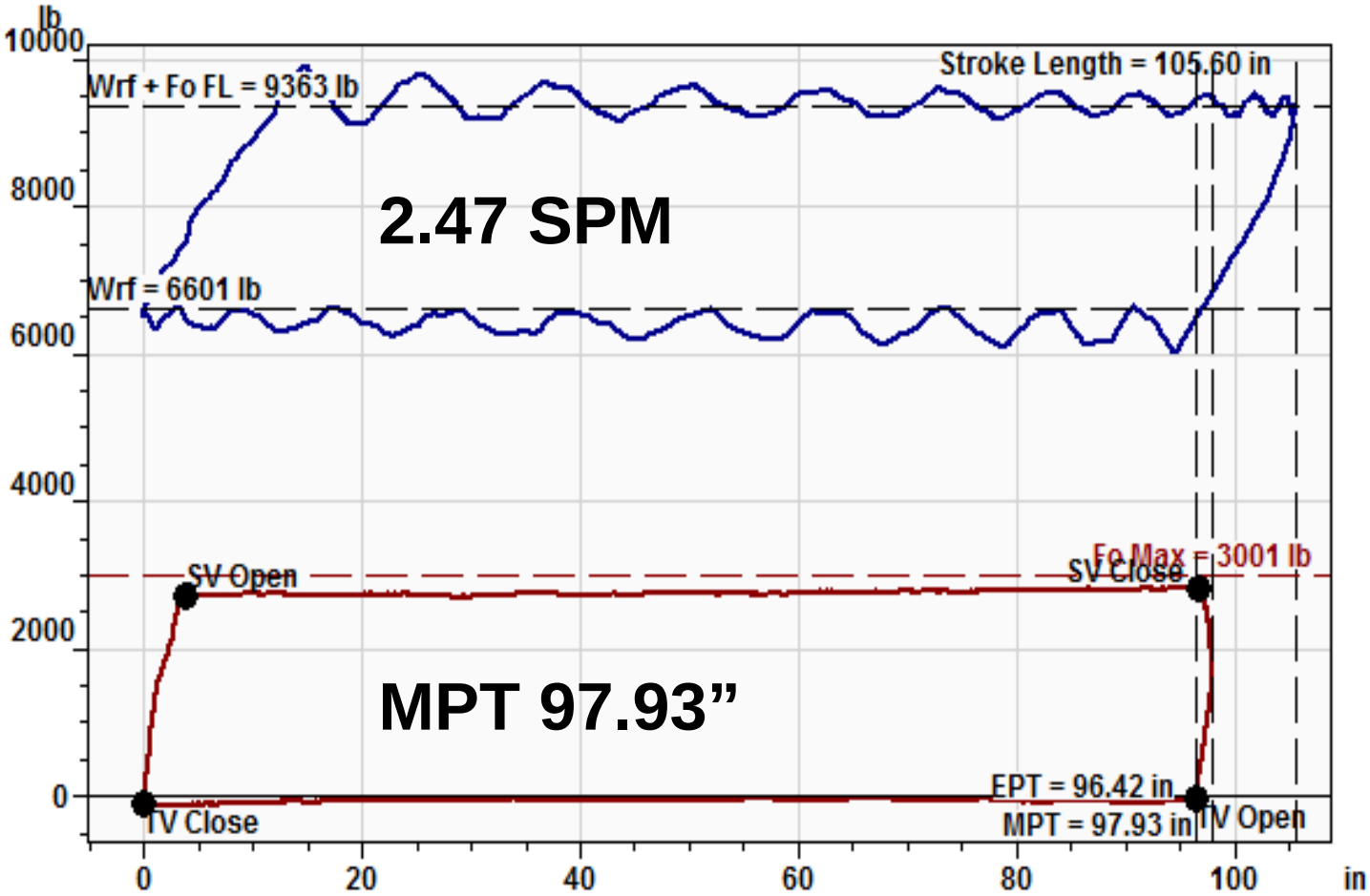
TTU Test Well 1 to 9.6 SPM

08/25/2006 Stroke:105.6” Plunger:1.5” Clearance:0.005 API #: 76 PIP:135

	Peak Load	Min Load	Power
Polished Rod	9904 lb	6018 lb	1.8 HP
Pump	2835 lb	-161 lb	1.7 HP

Replay | Events

< Stroke 16 of 16 >



Stroke: 16 07:29:32 PM clock

Unanchored Kt 1147 lb/in

Kr 327 lb/in

Adj Pump Displacement	50	BBL/DD
Calculated Fluid Load Max	3001	lb
Surface Efficiency	19.99	%
Pumping Speed	2.473	spm
Motor to Pump Efficiency	18.62	%
Pump Intake Pressure	136	psi (g)
Damp Up	0.062	
Damp Down	0.070	
Adj Fillage	78.77	%
Adj EPT	77.1	in
Enter Tubing Pressure	13.0	psi (g)

Annotations

Pump Card Analysis

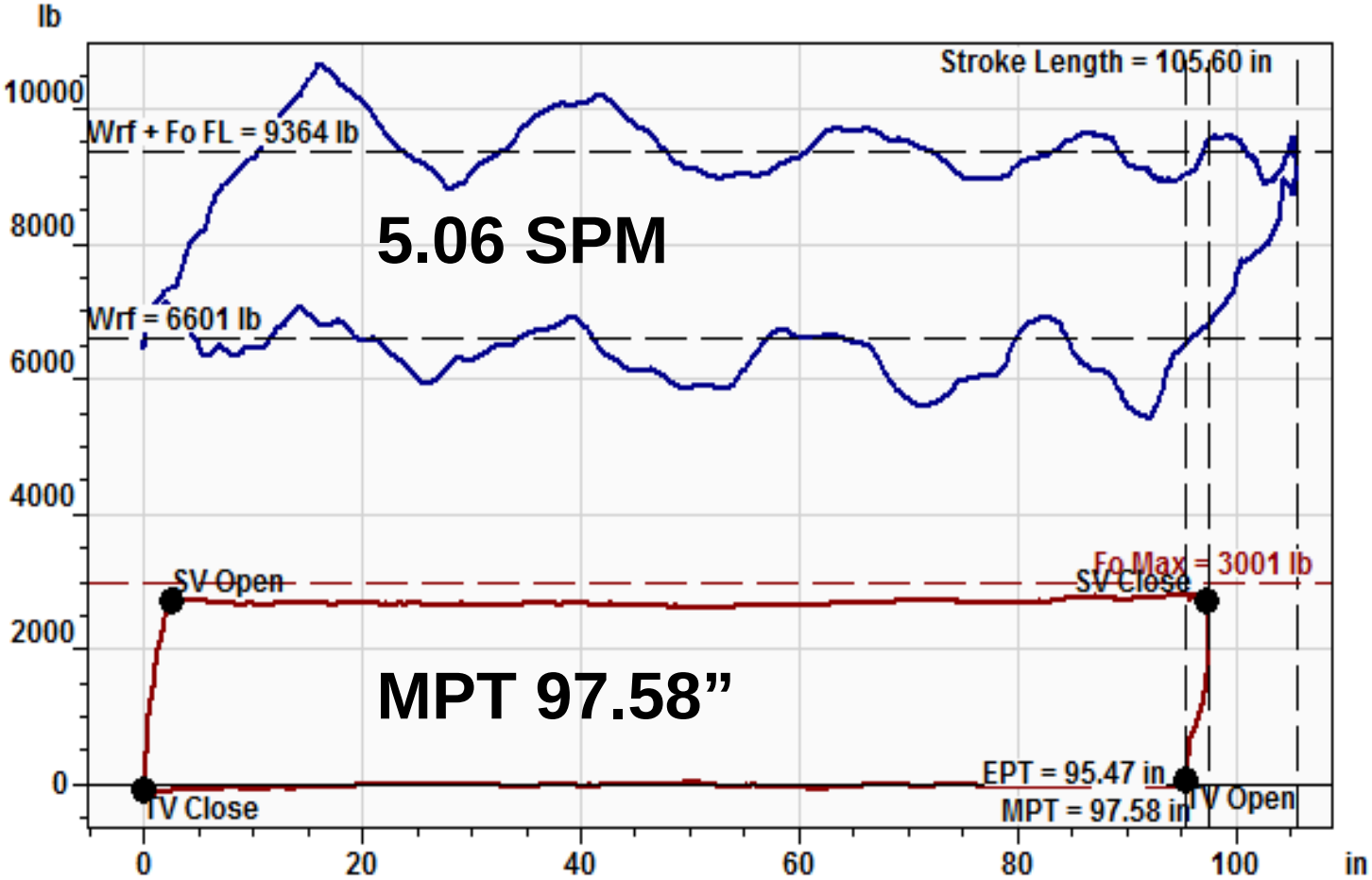
TTU Test Well 1 to 9.6 SPM

08/25/2006 Stroke:105.6” Plunger:1.5” Clearance:0.005 API #: 76 PIP:135

	Peak Load	Min Load	Power
Polished Rod	10657 lb	5418 lb	3.9 HP
Pump	2821 lb	-181 lb	3.3 HP

Replay | Events

< Stroke 100 of 100 >



Stroke: 100 07:25:25 P clock

Unanchored Kt 1147 lb/in

Kr 327 lb/in

Adj Pump Displacement	120 BBL/D
Calculated Fluid Load Max	3001 lb
Surface Efficiency	30.28 %
Pumping Speed	5.063 spm
Motor to Pump Efficiency	26.14 %
Pump Intake Pressure	187 psi (g)
Damp Up	0.062
Damp Down	0.070
Adj Fillage	92.24 %
Adj EPT	90.0 in
Enter Tubing Pressure	13.0 psi (g)

Annotations

Pump Card Analysis

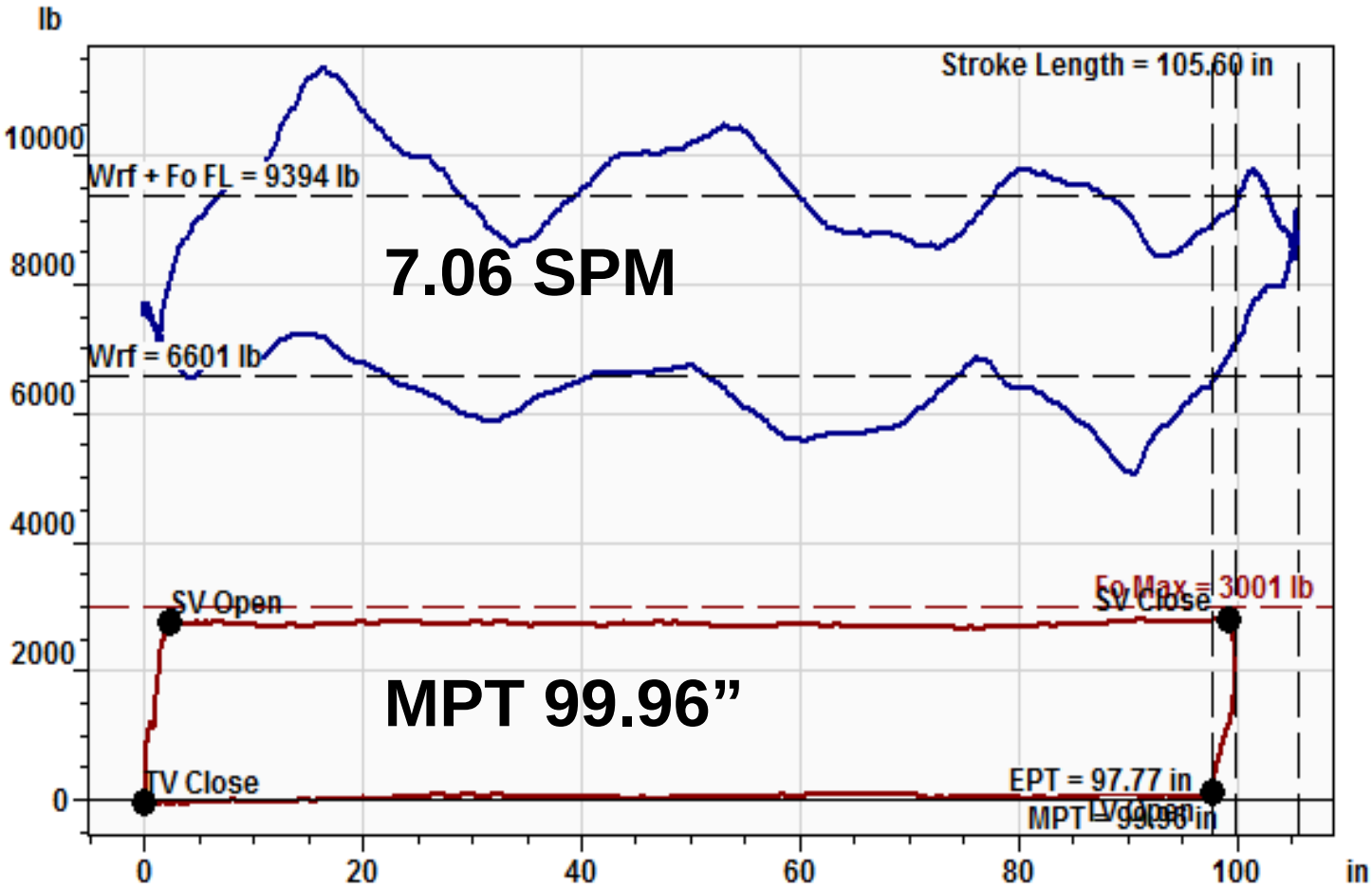
TTU Test Well 1 to 9.6 SPM

08/25/2006 Stroke:105.6” Plunger:1.5” Clearance:0.005 API #: 76 PIP:135

	Peak Load	Min Load	Power
Polished Rod	11365 lb	5038 lb	5.7 HP
Pump	2808 lb	-71 lb	4.7 HP

Replay | Events

< Stroke 140 of 140 >



Stroke: 140 06:44:48 P clock

Unanchored Kt 1147 lb/in

Kr 327 lb/in

Adj Pump Displacement	172 BBL/D
Calculated Fluid Load Max	3001 lb
Surface Efficiency	35.64 %
Pumping Speed	7.059 spm
Motor to Pump Efficiency	29.22 %
Pump Intake Pressure	172 psi (g)
Damp Up	0.062
Damp Down	0.070
Adj Fillage	93.10 %
Adj EPT	93.1 in
Enter Tubing Pressure	13.0 psi (g)

Annotations

Pump Card Analysis

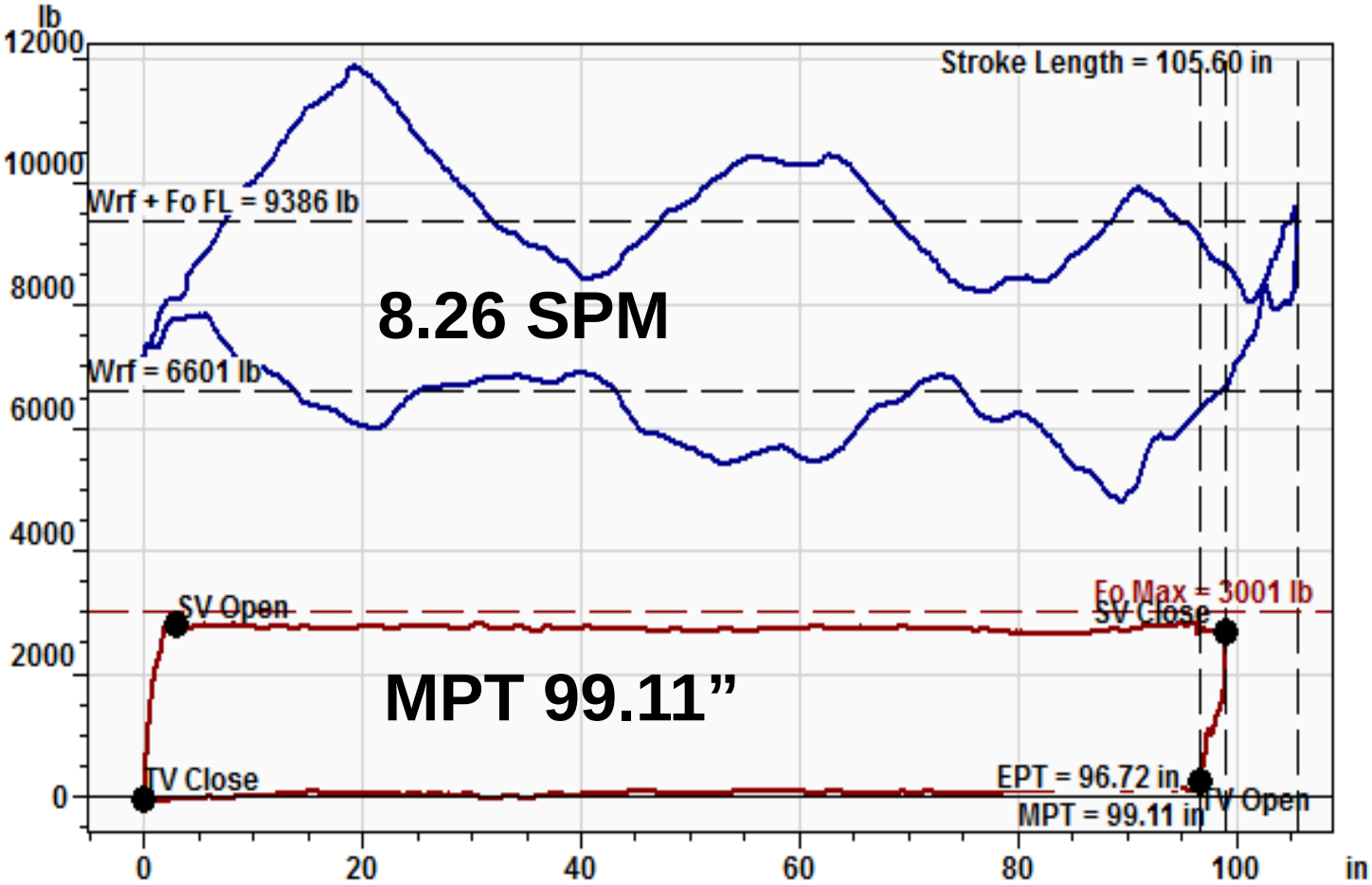
TTU Test Well 1 to 9.6 SPM

08/25/2006 Stroke:105.6” Plunger:1.5” Clearance:0.005 API #: 76 PIP:135

	Peak Load	Min Load	Power
Polished Rod	11904 lb	4794 lb	6.9 HP
Pump	2836 lb	-89 lb	5.4 HP

Replay | Events

< Stroke 164 of 164 >



Adj Pump Displacement	200	BBL/D
Calculated Fluid Load Max	3001	lb
Surface Efficiency	37.64	%
Pumping Speed	8.257	spm
Motor to Pump Efficiency	29.83	%
Pump Intake Pressure	165	psi (g)
Damp Up	0.062	
Damp Down	0.070	
Adj Fillage	93.24	%
Adj EPT	92.4	in
Enter Tubing Pressure	13.0	psi (g)

Stroke: 164 06:02:33 P clock

Unanchored Kt 1147 lb/in Kr 327 lb/in

Annotations

Pump Card Analysis

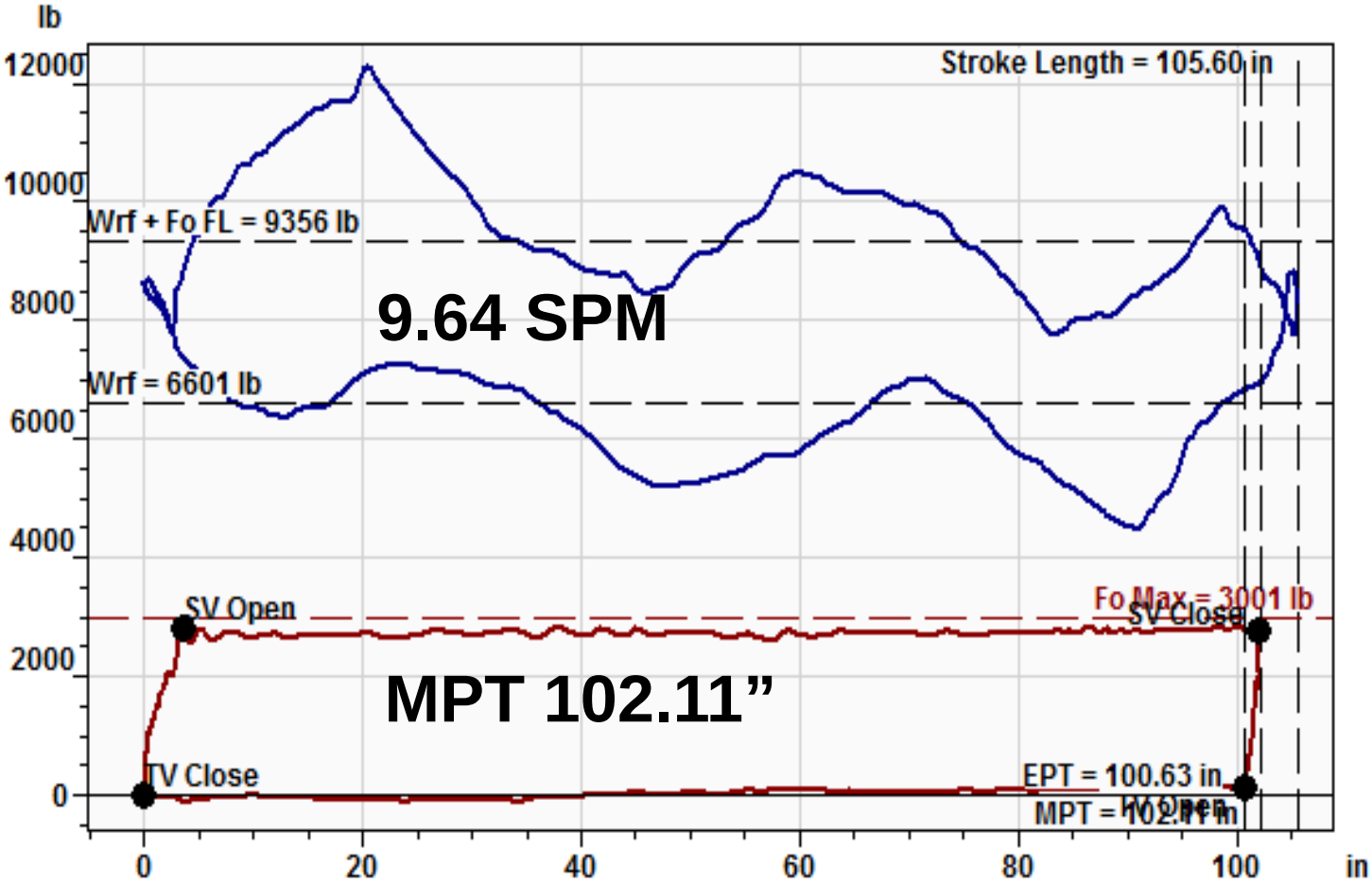
TTU Test Well 1 to 9.6 SPM

08/25/2006 Stroke:105.6” Plunger:1.5” Clearance:0.005 API #: 76 PIP:135

	Peak Load	Min Load	Power
Polished Rod	12296 lb	4480 lb	8.4 HP
Pump	2845 lb	-110 lb	6.6 HP

Replay | Events

< Stroke 192 of 192 >



Stroke: 192 04:32:31 P clock

Unanchored Kt 1147 lb/in Kr 327 lb/in

Adj Pump Displacement	244 BBL/D
Calculated Fluid Load Max	3001 lb
Surface Efficiency	39.20 %
Pumping Speed	9.639 spm
Motor to Pump Efficiency	30.75 %
Pump Intake Pressure	155 psi (g)
Damp Up	0.062
Damp Down	0.060
Adj Fillage	94.64 %
Adj EPT	96.6 in
Enter Tubing Pressure	13.0 psi (g)

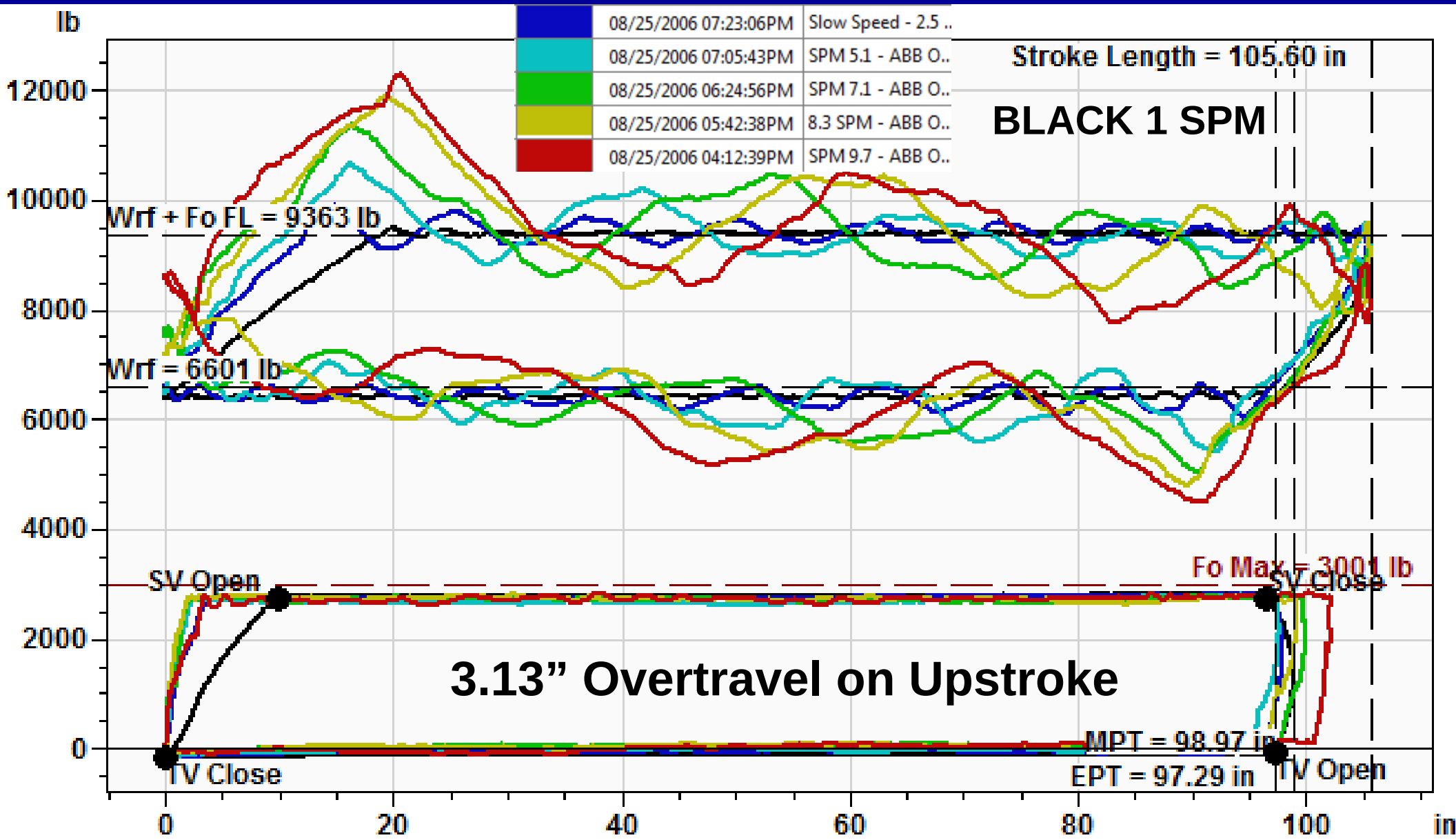
Annotations

Pump Card Analysis

TTU_TestWell.qrd

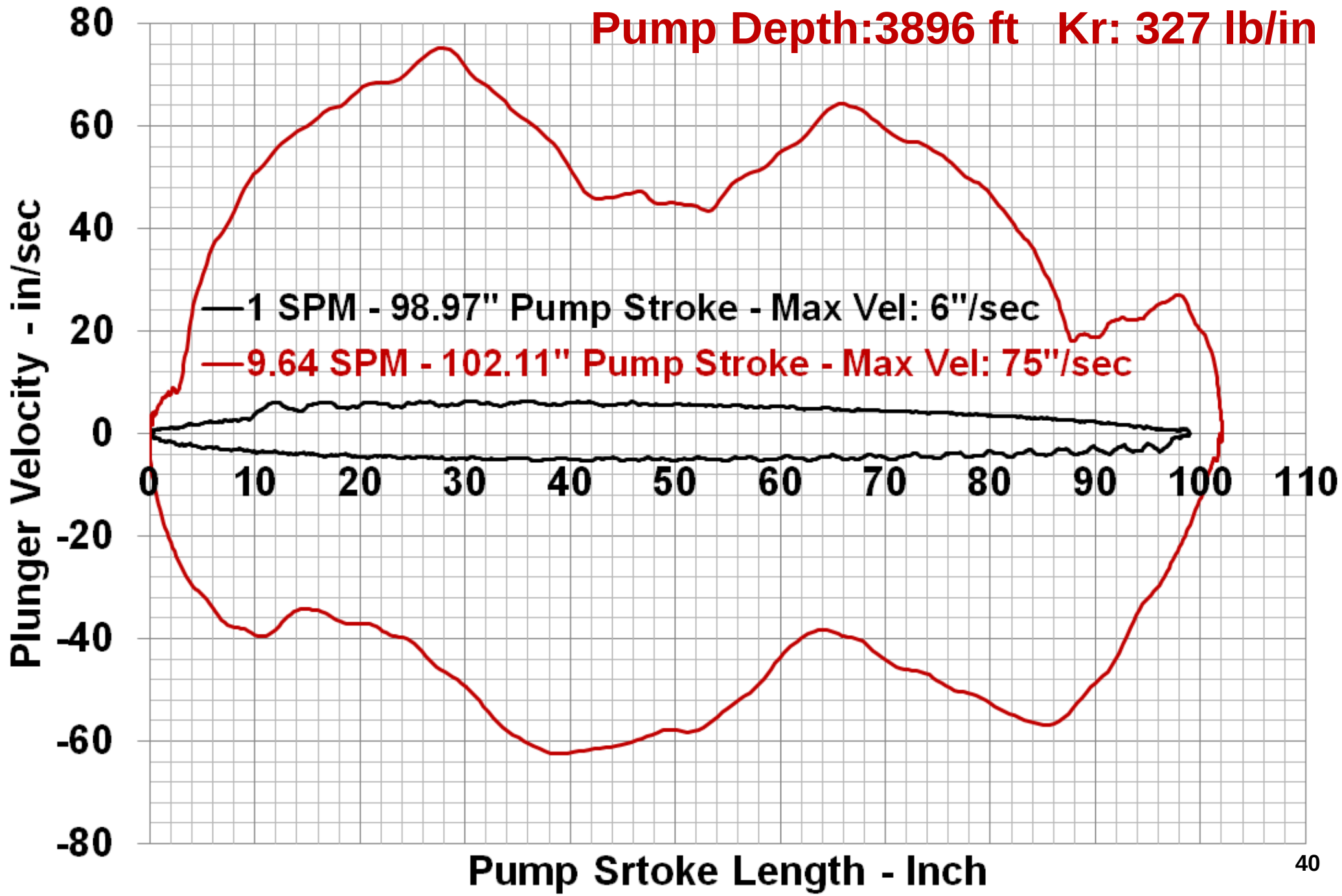
TTU Test Well 1 to 9.6 SPM

08/25/2006 Stroke:105.6” Plunger:1.5” Clearance:0.005 API #: 76 PIP:135



TTU Test Well – Compare Velocity Profile

08/25/2006 Stroke:105.6” Plunger:1.5” Clearance:0.005 API #: 76 PIP:135

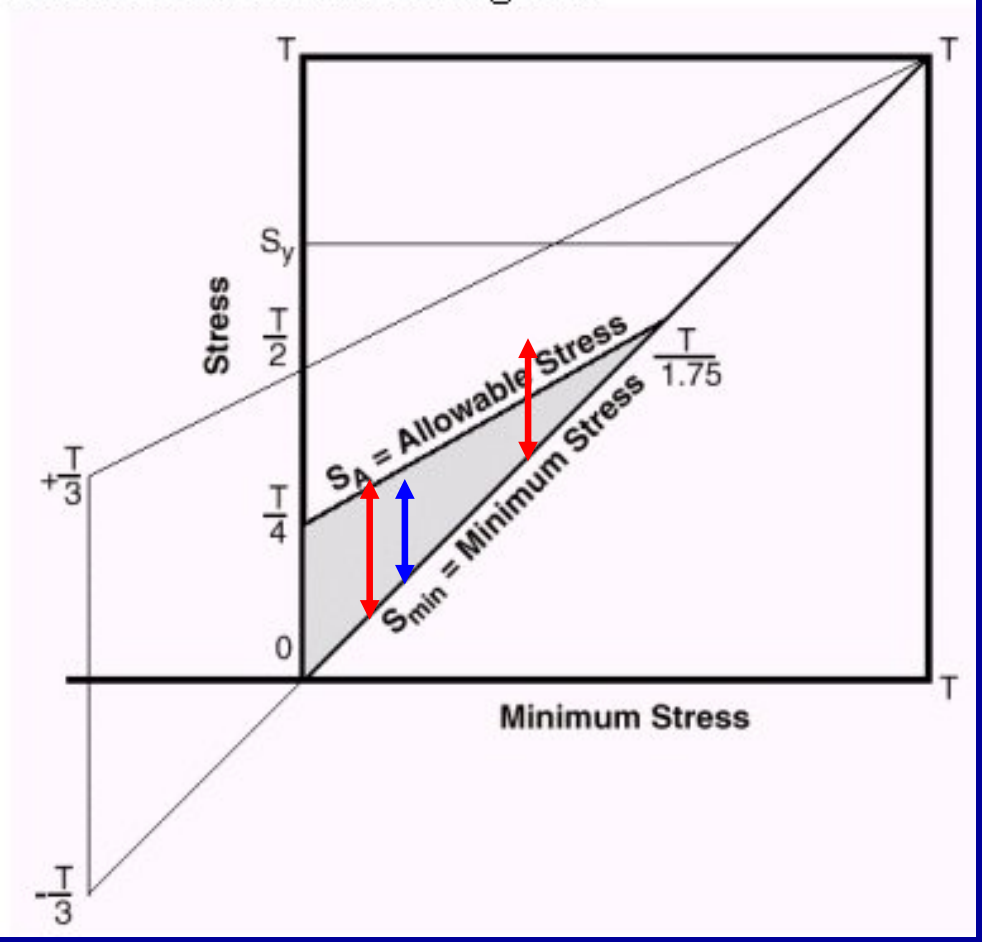


Tapered Rod String Design:

1) Largest diameter rods are located at the top of the string
2) Support the weight of the all the rods connecting the pump to the top rod in each taper. Loads on the top rod in a taper are the highest
3) Load decreases as the suspended rod weight decreases as you move closer to the pump, Supports the pump forces applied at the bottom of the rod string.

- Rod string is designed for a long operational life
- Planned failure mode due to fatigue – <u>10 million cycles</u>
- Wear out the rods
- DO NOT tensile fail due maximum load near the peak tensile strength of the rod.
- Design the string so the unit stresses are equal in the top rod of each of the different-sized sections of the string. Provides good safety margin as far as corrosion pitting is concerned.

Modified Goodman Diagram



Maximum allowable working stresses should not be higher than about 30,000 to 40,000 psi, although some sucker rods, such as the "high tensile strength" rods are rated at 40,000 to 50,000 psi maximum.

Operation of rods in corrosive environments requires that the maximum allowable stress be decreased.

Max. Allowable Stress,
Sa = (0.25T + 0.5625*Smin)*SF
Allowable Stress Range, Sr = Sa - Smin

Stress Limit For New Rods Based On API-Goodman Guide	Service Factor 1.0 T/4	T/1.75	Peak Tensile(T)
New Grade C Rod (Psi)	23,750	54,286	95,000
New Grade K Rod (Psi)	21,250	48,571	85,000
New Grade D Rod (Psi)	28,750	65,714	115,000
New Grade H Rod (Psi)	50,000	50,000	140,000

Use of Sinker Bars

1. Use of sinker bars in rod pumped wells is proven to reduce failures:

   Albert S. Garza and Danny Hernandez, Pioneer Natural Resources USA, Inc. Scott W. Long, Flexbar, Inc.: "PIONEER NATURAL RESOURCES 10 YEAR "BEST PRACTICES" PROGRAM AND DATABASE" , SWPSC, Lubbock, Texas (2007)

2. During a 10 year time period the failure frequency was reduced from 2.73 to 0.42 failures per well per year.
3. One of the best practices was "Installation of an average of 375' of 1.5" Grade-C Sinkerbars to reduce buckling during the downstroke."
4. Since the 1980 this sinker bar design technique used throughout the United States to determine sinker bar length, proven by field experience to reduce tubing failure near pump.

Weight Bars/Sinkerbars

1. During the pumping cycle Upstroke:
   - traveling valve shut
   - rod string will be under tension
   - buoyed rods and fluids loads are lifted.

2. During the pumping cycle Down stroke:
   - traveling valve is opened and the standing valve is shut,
   - rods are suspended in fluid and still under tension.

3. But any upward force applied to the rod string from the plunger/pump assembly
   - Due to fluid flow in the traveling valve, barrel/plunger friction, compressing gas, etc…
   - Results in compressive (negative) loads
   - Causes rod buckling at the bottom of the rod string just above the pump.

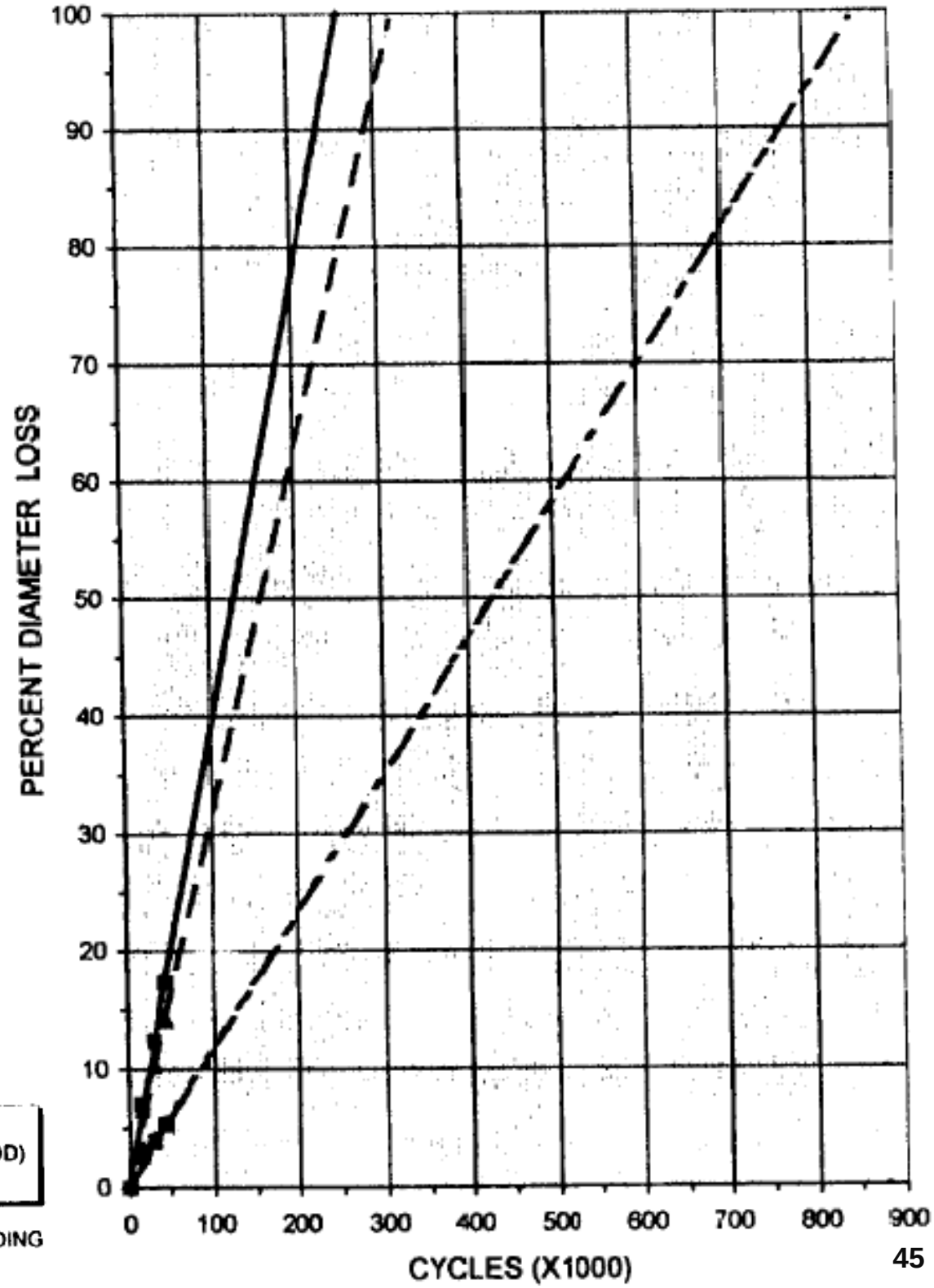
SWPSC 1996

Scott W. Long

Measured Rod String/Tubing Wear and Associated Side Loading

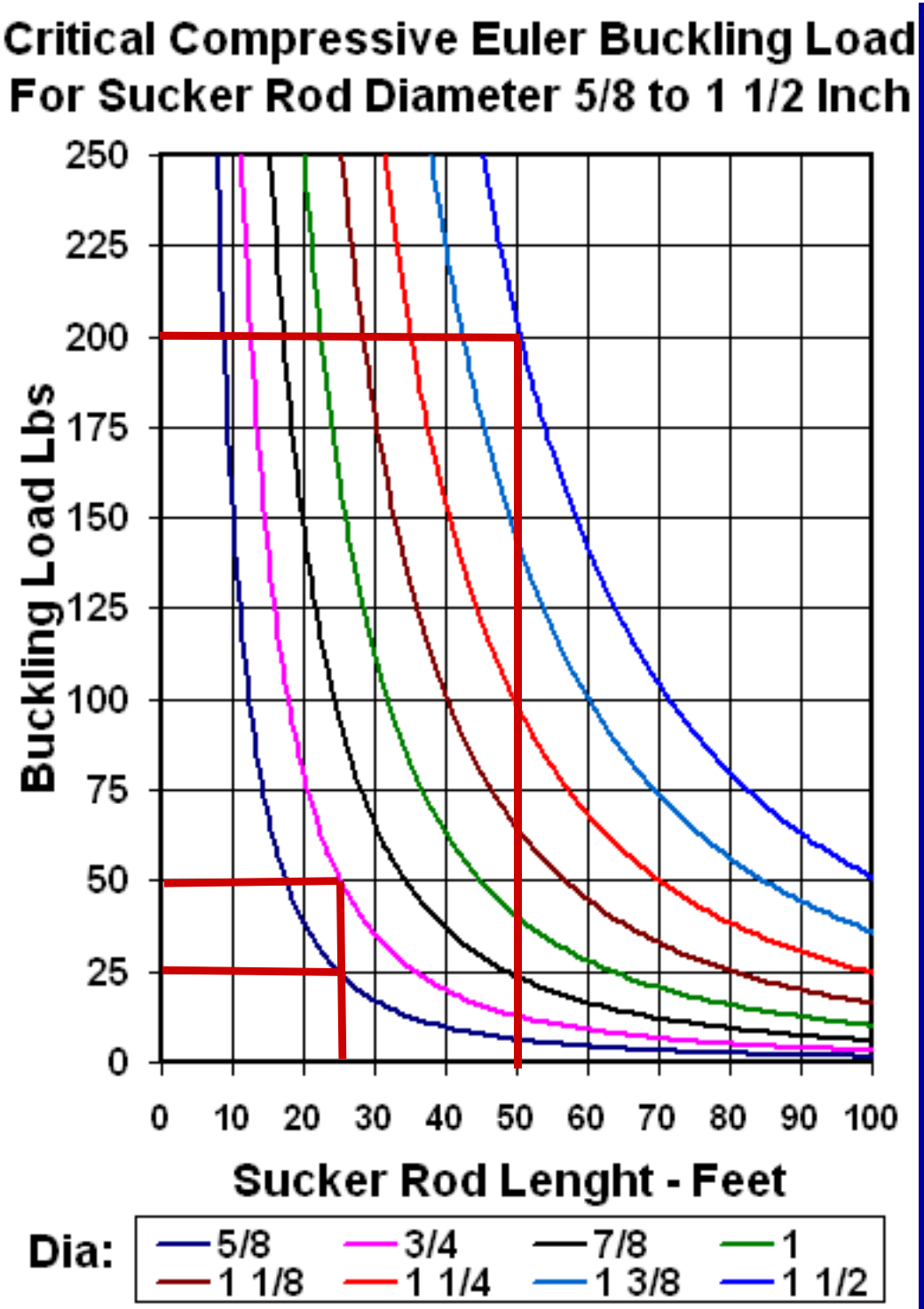
For 100 Lb Side Load

Tubing Wear Rate 3.4 X higher with ¾" rod VS 1.5" Sinker Bars



■ 0.75" ROD ▲ 1.00" ROD ◆ 1.50" SBAR
■ 1.75" SBAR —— Linear (0.75" ROD) — — Linear (1.00" ROD)
- - - Linear (1.50" SBAR) — - Linear (1.75" SBAR)

MEASURED ROD STRING/TUBING WEAR AND ASSOCIATED SIDE LOADING
Scott W. Long, P.E. and Donald W. Bennett, Flexbar, Inc.



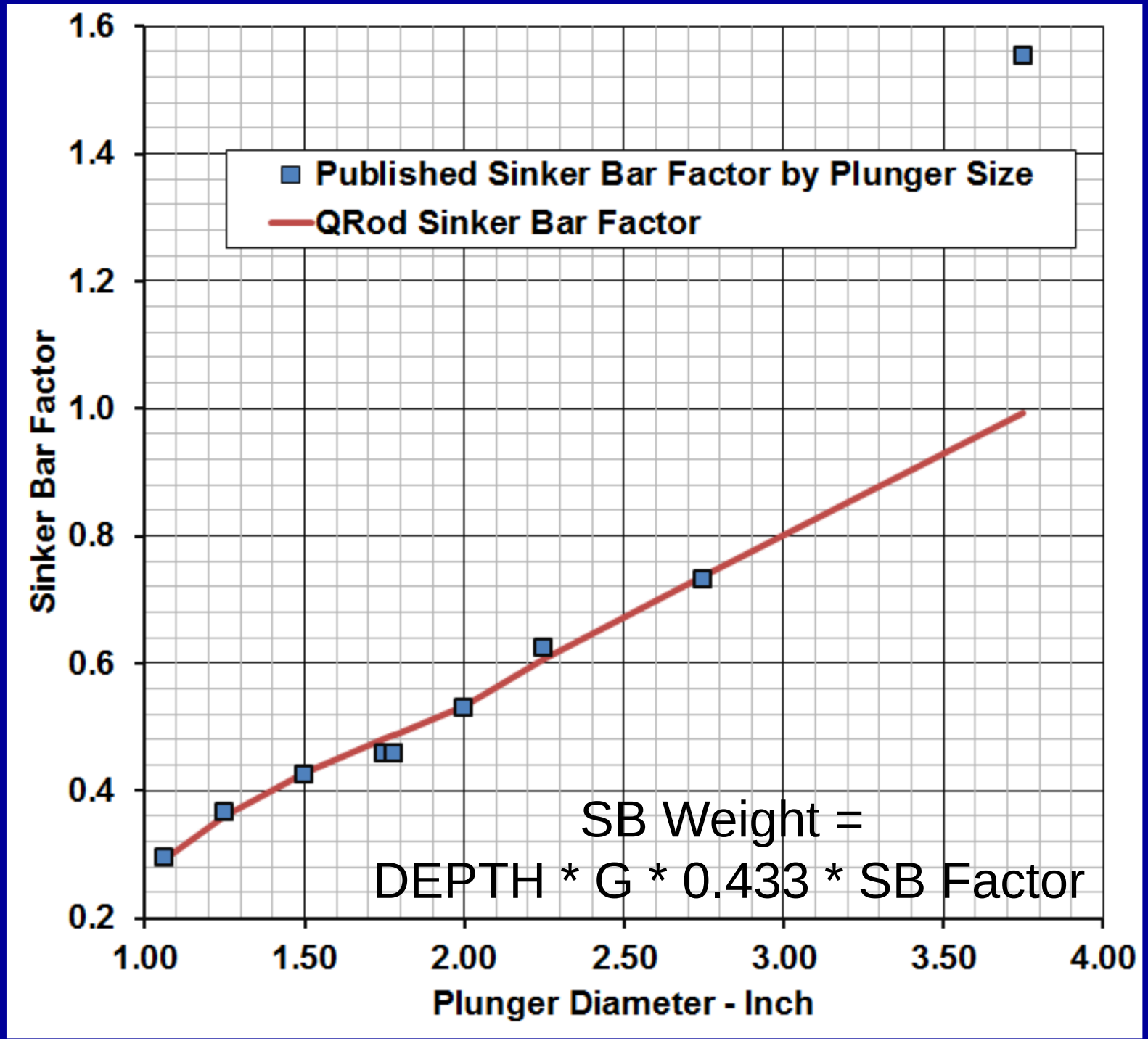
Sinker Bars Reduce Deep Failures Caused by Rod on Tubing Wear

- Rod strings behave as a slender Euler column.
- Buckling occurs under small compressive loading.

Notice:

- 25 Lbs. Buckles > 25 feet of 5/8 Inch Dia. Rod
- 50 Lbs. Buckles > 25 feet of 3/4 Inch Dia. Rod
- 200 Lbs. Buckles > 50 feet of 1 ½ Inch Dia. Rod

Weight Bars/Sinkerbar Factor



Tool: Sinker Bar Calculator

File Tools Help

Title

Design Inputs

Unit	CWConv	
Pump Depth	5,000	ft
Surface Stroke Length	100.00	in
Pump Diameter (D)	2.000	in
Tubing Size	2.875" (6.40 lb/ft) 2.441" ID	

Anchored Tubing

Rods

Steel Rods

Fiberglass and Steel Rods

Rod Number	76
Rod Grade	D

Results

Rate (100% pump volumetric eff.)	174 BBL/D
Rate (95% pump volumetric eff.)	165 BBL/D
Rod Taper	
Top Rod Loading	
Min API Unit Rating	
Min NEMA D Motor Size	
Polished Rod Power	
TVLoad	
SVLoad	

Calculate from S Rate

Stroke Rate (SPM)

Target Rate

Calculate

Default Settings

Total Sinker Bar Weight	1,152.9	lb	Damping Factor		
Fluid Specific Gravity	1.00	Sp.Gr.H2O	Surface Unit Efficie		
Tubing Pressure	80.00		Pump Volumetric Efficiency	95.00	%
Casing Pressure	45.00				

You may enter Pump Intake Pressure direct from Reservoir Pressure and Productivity Index.

Pump Intake Pressure 50.00 psi

Reservoir Pressure 1,000.00 psi

Productivity Index 0.200 STB/D/psi

Echometer Company Phone: (940) 767-4334 E-Mail: info@echometer.com
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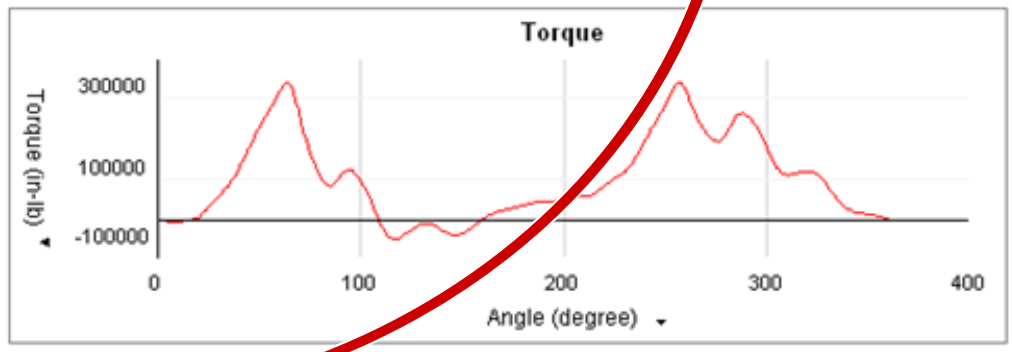
Sinker Bar Calculator

File

Pump Diameter	2.000	in	Sinker Bar Factor	0.5321	
Pump Depth	5,000	ft	Required Weight	1,152.9	lb
Fluid Specific Gravity	1.00	Sp.Gr.H2O	Required Length	220	ft
Sinker Bar Diameter	1.500	in	Recommended Weight	1,180.5	lb
			Recommended Length	225	ft

Calculate | Use Calculation | Cancel



Peak GearBox Torque	340	Kin-lb
Counter Balance Moment	762	Kin-lb
Counter Balance Effect	16,049.7	lb

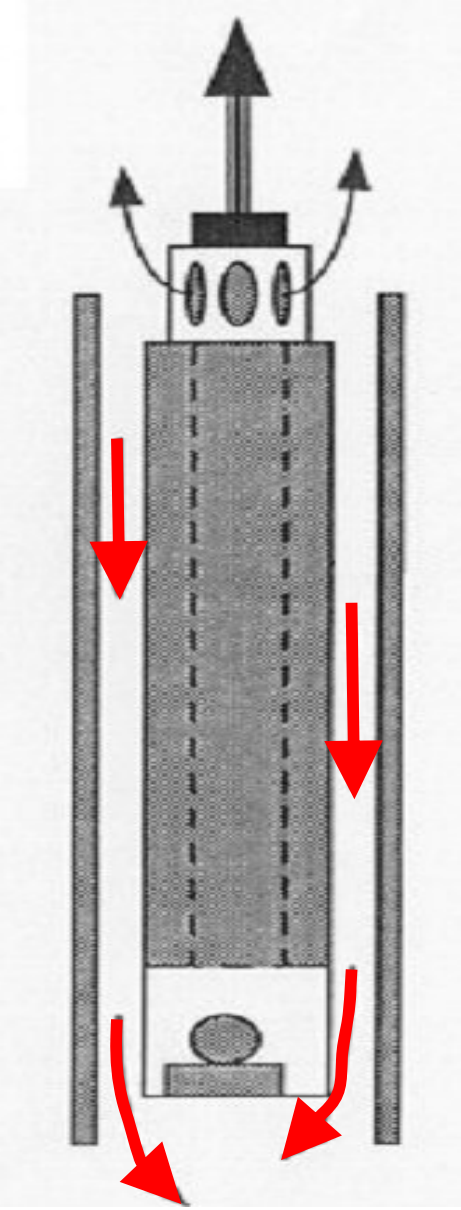
Pump Slippage

1) Fluid that leaks back into pump between the Plunger OD and the Barrel ID
2) Leaks into the pump chamber between the standing valve and traveling valve
3) When traveling ball is on Seat.

Pump Efficiency =
BPD Tank / BPD Pump

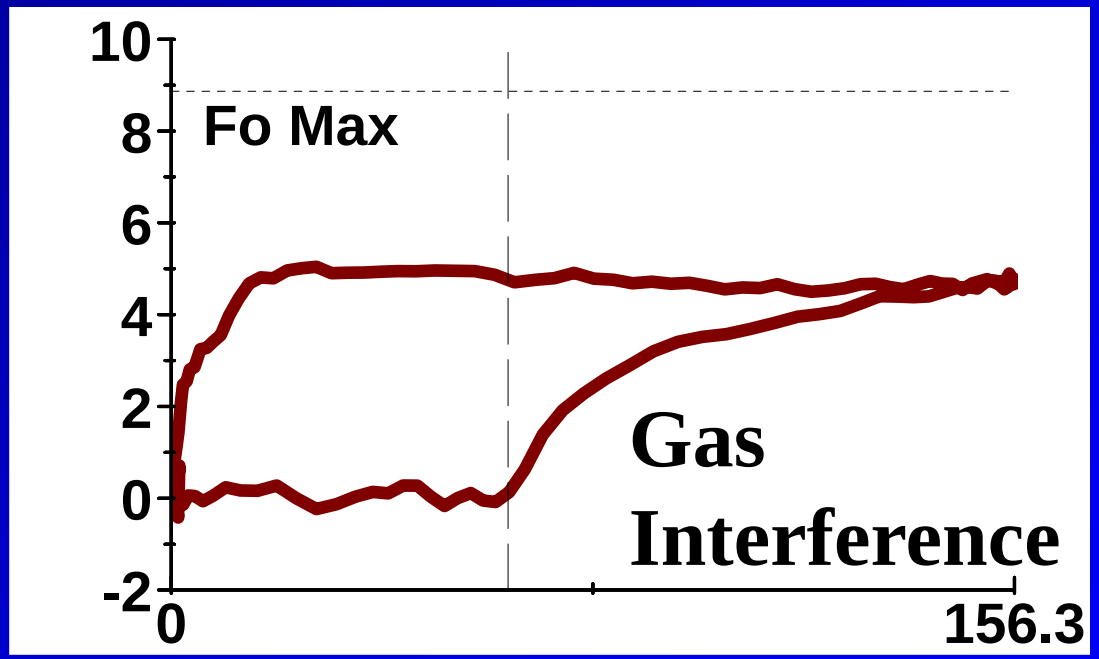
Slippage % =
Slippage BPD / BPD Pump

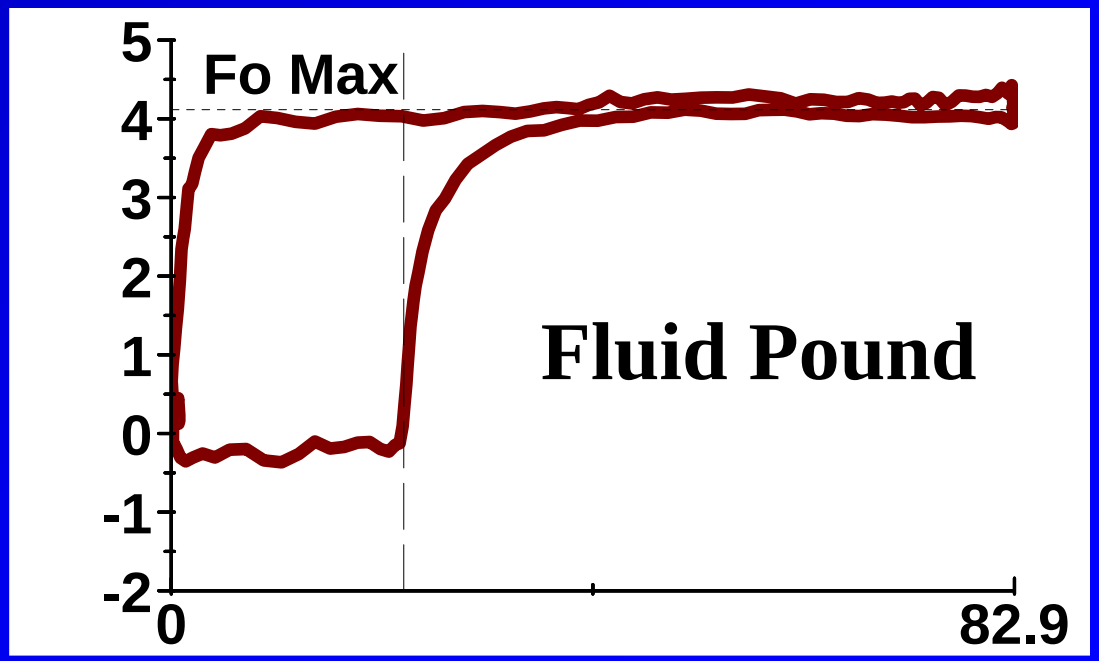
BPD Tank = BPD Pump
- Slippage



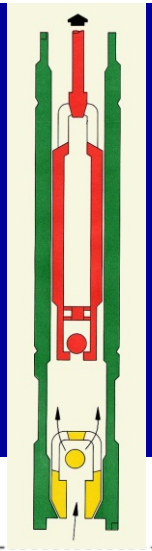
Pump's Effective Displacement Influenced By:

- Pump Slippage
- Incomplete Pump Fillage
  - Gas Interference
  - Fluid Pound
  - Blocked Intake
  - Choked Annulus

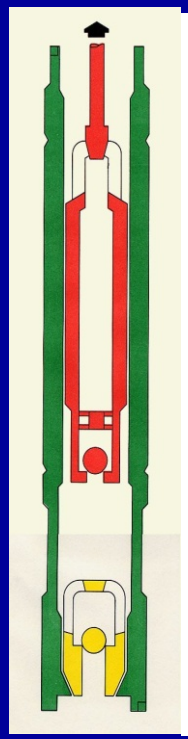


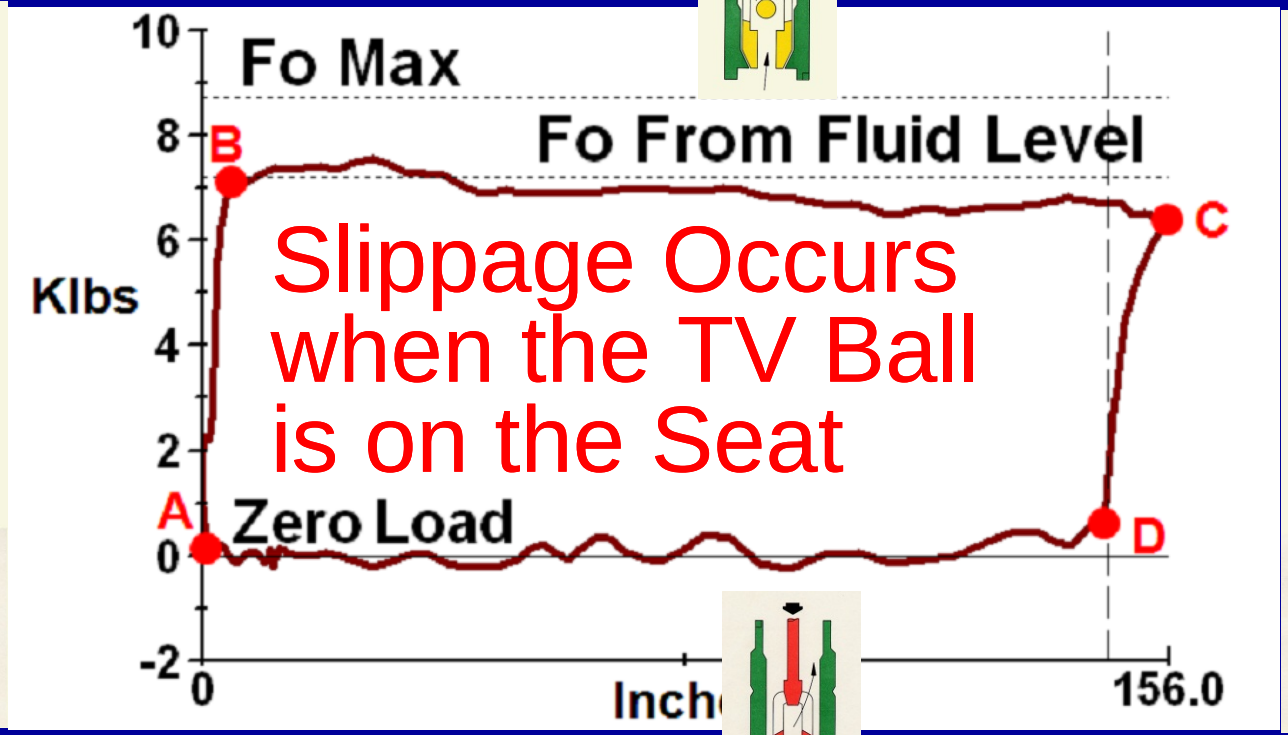


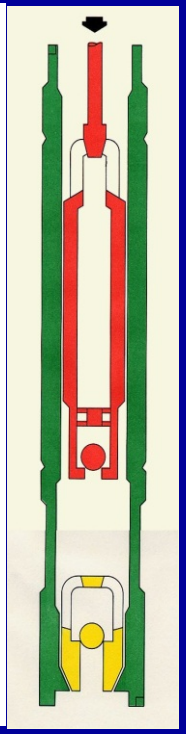
1) <u>Point A to B</u> pressure acting on closed SV gradually transferred from tubing at point A to be fully carried by the Closed TV at point B.

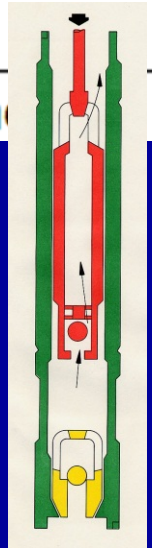


2. <u>Point B to C</u>, plunger carries full differential pressure across Closed TV









4) <u>Point D to A</u>, TV open as fluid in the pump is displaced through the traveling valve on the down stroke

3) <u>Point C to D</u> pressure across closed TV gradually transferred from rods to be fully carried by the Closed SV at point D.

Patterson Pump Slippage Equation

modified ARCO-HF equation to include the effect of SPM on slippage

QRod Tool - "Pump Slippage Calculator"

$$453 \cdot \left[\left(0.14 \cdot SPM \right) + 1 \right] \frac{DPC^{1.52}}{L\mu}$$

EXCEL Spreadsheet Available on PDF Download:
"Pump Slippage Calculator_SPM_PattersonEq.xls"

D = nominal pump diameter, inches
C = diametrical clearance, inches
P = Pressure drop across the plunger, psi
L = length of the plunger, inches
SPM = strokes per minute
μ = <u>viscosity of fluids, cp</u>

Presented at 2007 SWPSC

Progress Report #4 on "Fluid Slippage in Down-Hole Rod-Drawn Oil Well Pumps"

John Patterson – ConocoPhillips Company
Kyle Chambliss – Oxy Permian
Lynn Rowlan – Echometer
Jim Curfew – Oxy Permian

Based on Slippage test, "the following minimum pump clearances are recommended for a 48" Plunger with a "+1 Barrel". These clearances have become widely used in the Permian Basin for well depths up to 8000 feet"

DO NOT DO THIS

- 1.25" pump = -3 to -4 plunger (0.004" to 0.005" total clearance)
- 1.50" pump = -4 to -5 plunger (0.005" to 0.006" total clearance)
- 1.75" pump = -5 to -6 plunger (0.006" to 0.007" total clearance)
- 2.00" pump = -6 to -7 plunger (0.007" to 0.008" total clearance)

Rule-of-Thumb Table

???? Design: Clearance Using Patterson Eq. w/ 90% Pump Efficiency

Inputs to Pump Slippage Calculations

D=Plunger Diameter (inches)	1.5
*P=Pressure Differiential	3617
C=Clearance (inches)	0.006
u=Fluid Viscosity (centipoise)	0.76
Plunger length (inches)	48
Strokes per Minute	8

***Calculating Differential Pressure**

Pump Depth	8000
Tubing Discharge Pressure (Psi)	250
Tubing Fluid Gradient (Psi/Ft)	0.4271
Pump Intake Pressure (Psi)	50
Input your production rate, BPD	274.0
Slippage in BPD	59.9

$$Slippage = [(0.14 \cdot SPM) + 1]453 \frac{DPC^{1.52}}{L\mu}$$

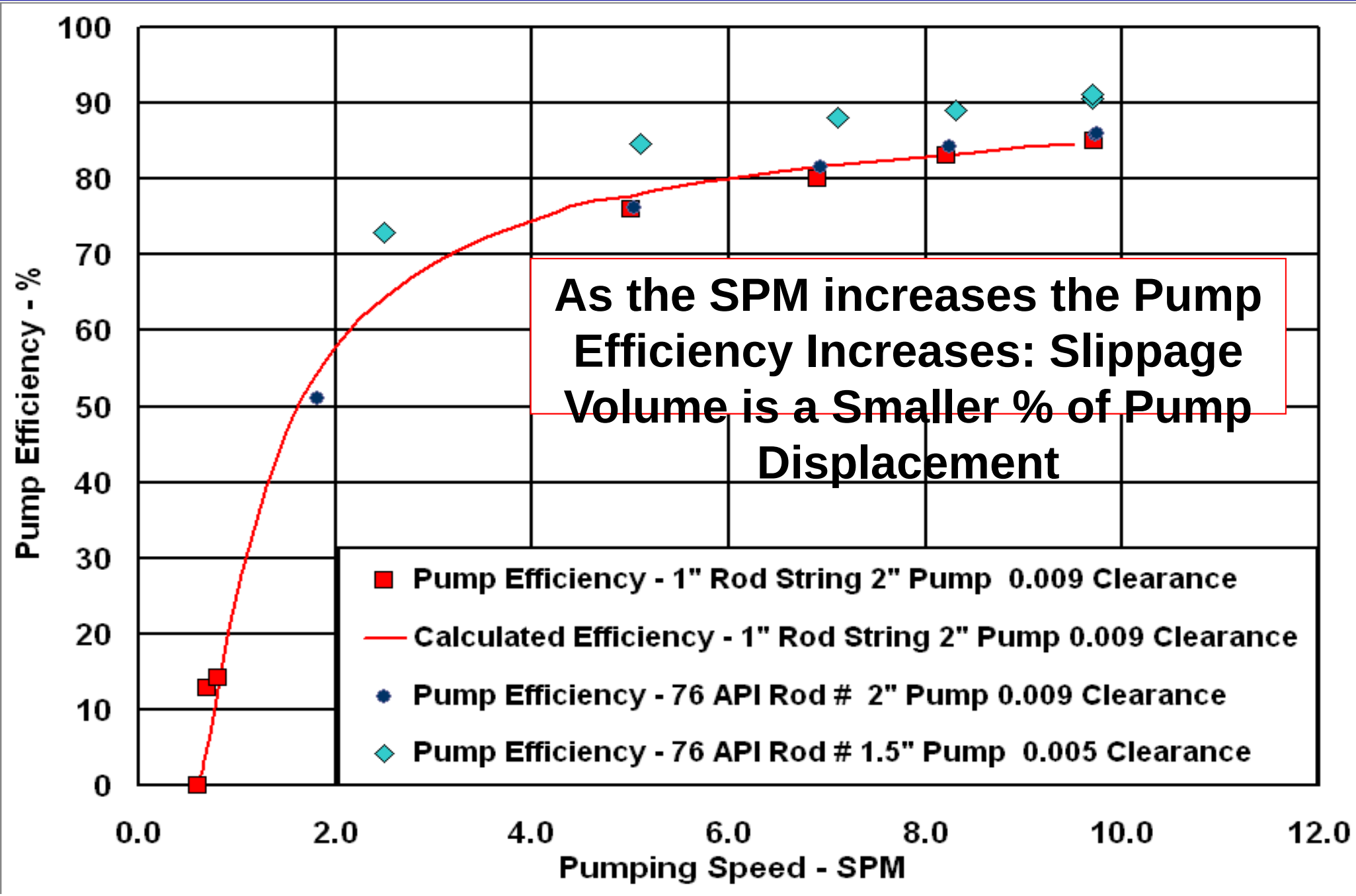
If You Use Recommended Clearances from 2007 Rule-of-Thumb Table

Plunger Size Inch	Total Clearance Inch	Slipage BPD	100" Stroke Pump Disp. BPD	Slippage %	144" Stroke Pump Disp. BPD	Slippage %
1.25	0.005	37.8	131	28.9	208	18.2
1.50	0.006	59.9	143	41.9	274	21.9
1.75	0.007	88.4	172	51.4	324	27.3
2.00	0.008	123.7	200	61.9	349	35.4
2.25	0.009	166.5	211	78.9	401	41.5

86 API Rod String | Anchored Tubing | Red - D Rod Loading > 100%

Pump Speed vs Pump Efficiency

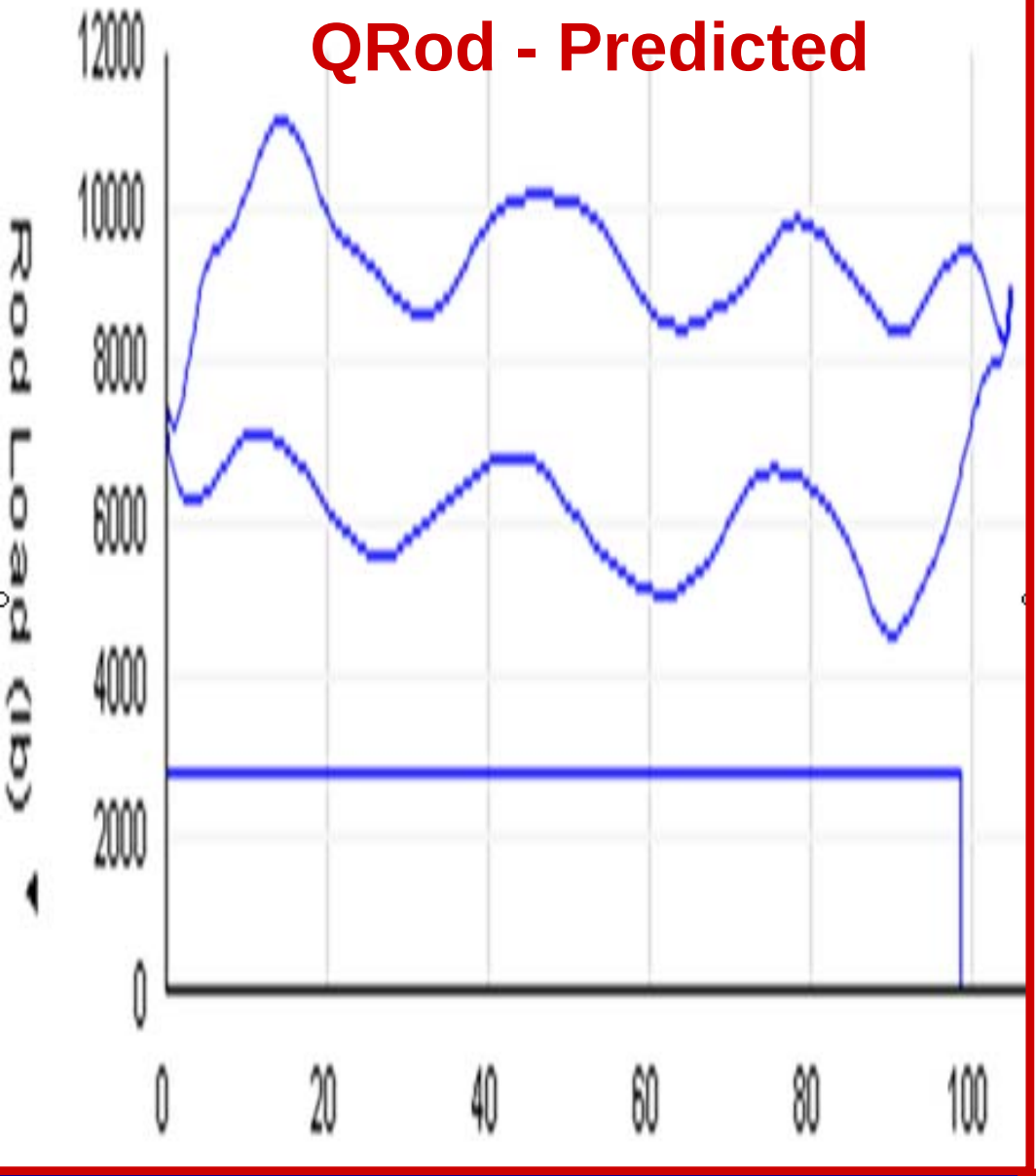
$$PumpEfficiency\% = \frac{SurfaceRate}{PumpDisplacment} \times 100$$

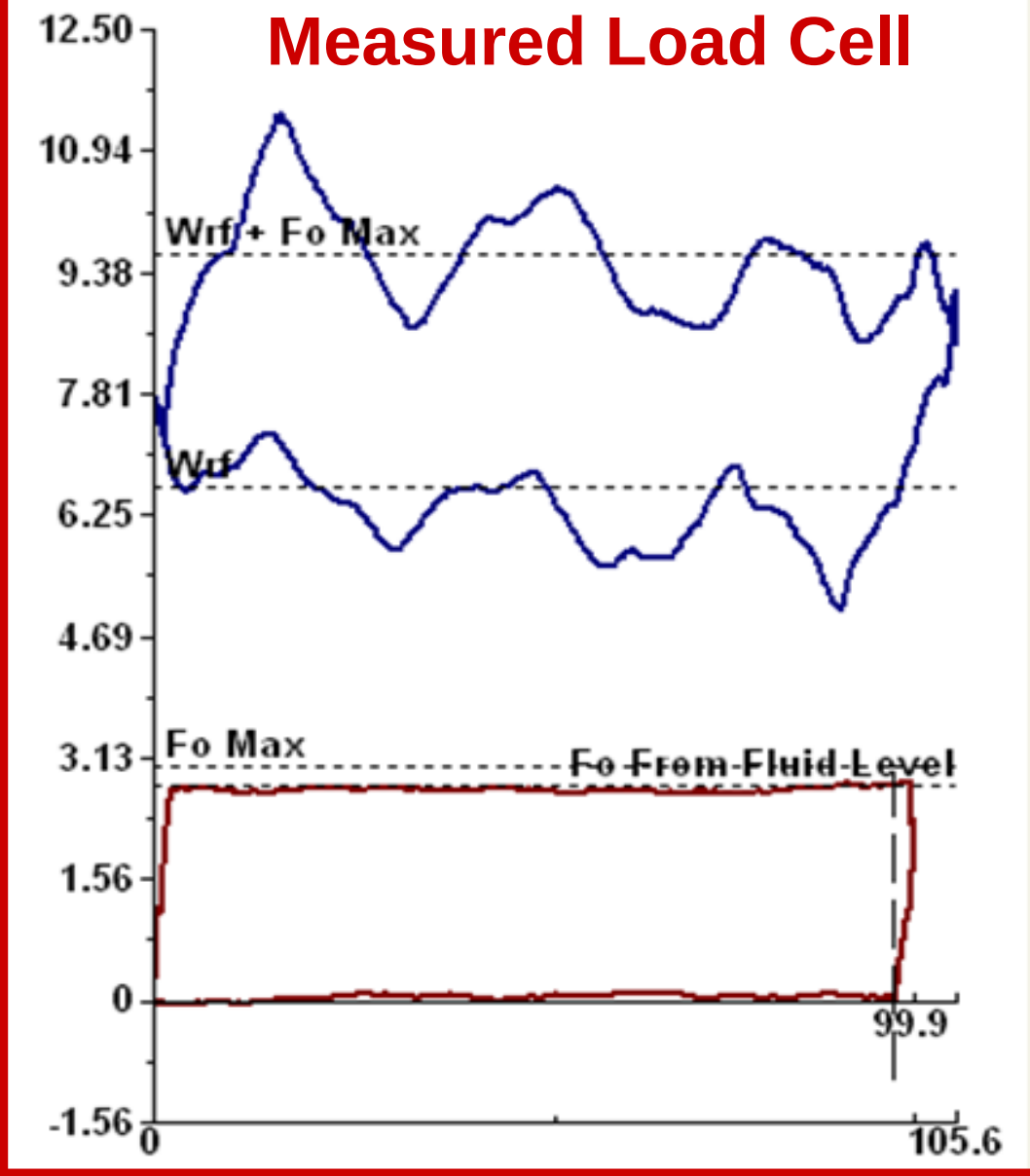


As the SPM increases the Pump Efficiency Increases: Slippage Volume is a Smaller % of Pump Displacement

TTU Slippage Test: Stroke #36 08/25/06 18:24:56

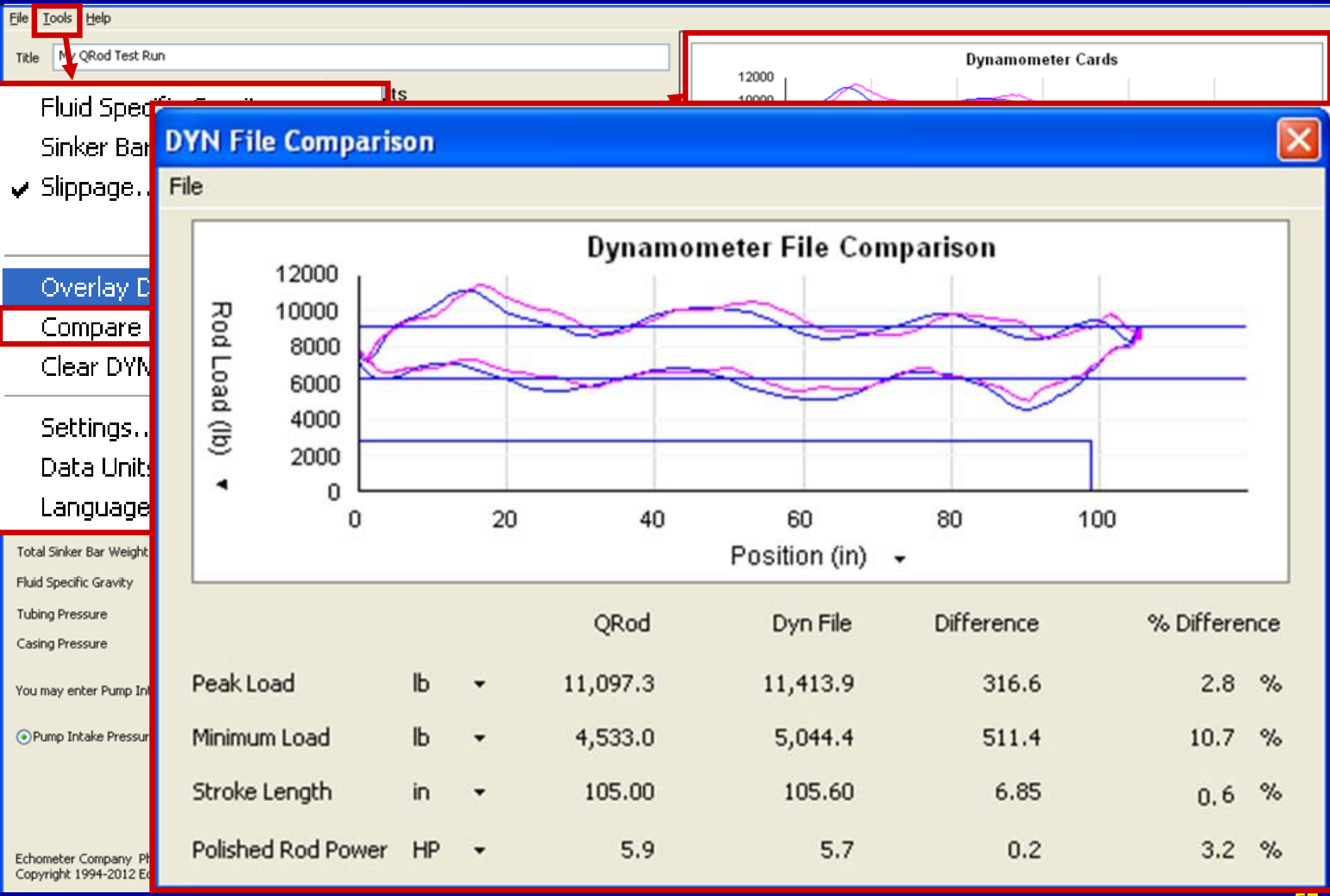
1. 76 Rods – 1.5” Pump – 7.046 SPM – 0.005” Clearance
2. Measured Slippage 21.4 BPD – Pump Efficiency 88.2%





TTU_TestWell.qrd

Tool: Dyn File Overlay and Comparison



Slippage Calculator

File

QRod Inputs

Pump Diameter (D)	1.500	in
Pump Depth	3,896	ft
Tubing Pressure	13.00	psi
Pump Intake	116.80	psi
Stroke Rate (SPM)	7.045	SPM
Pump Displacement	182	BBL/D
Fluid Specific Gravity	1.00	Sp.Gr H2O

User Inputs

Clearance (C)	0.005	in
Fluid Viscosity (μ)	0.76	cP
Plunger Length (L)	48.000	in

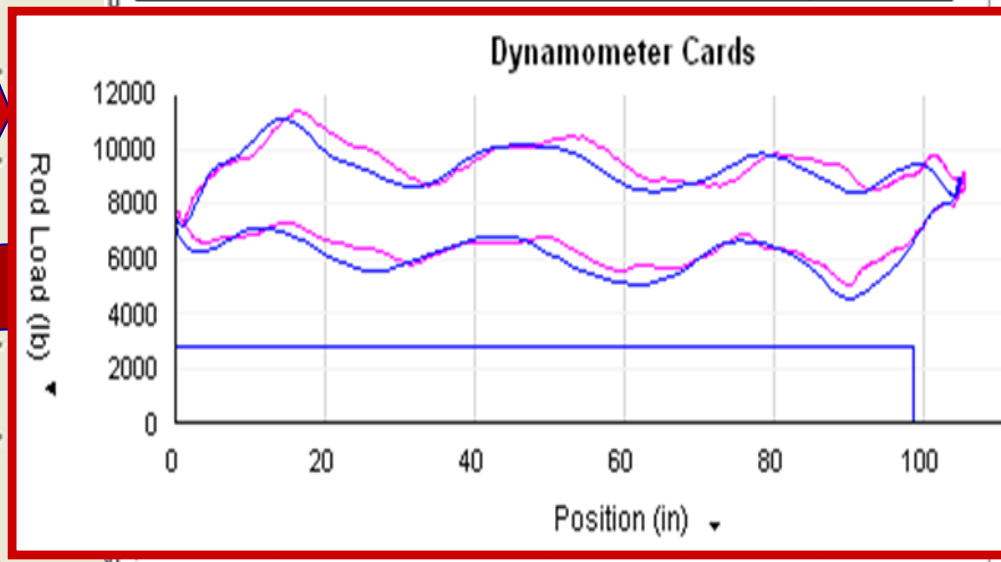
Calcu

Calculate from SPM or Target Rate

Stroke Rate (SPM) << 7.045 >> SPM

Target Rate << 164 >>

Calculate



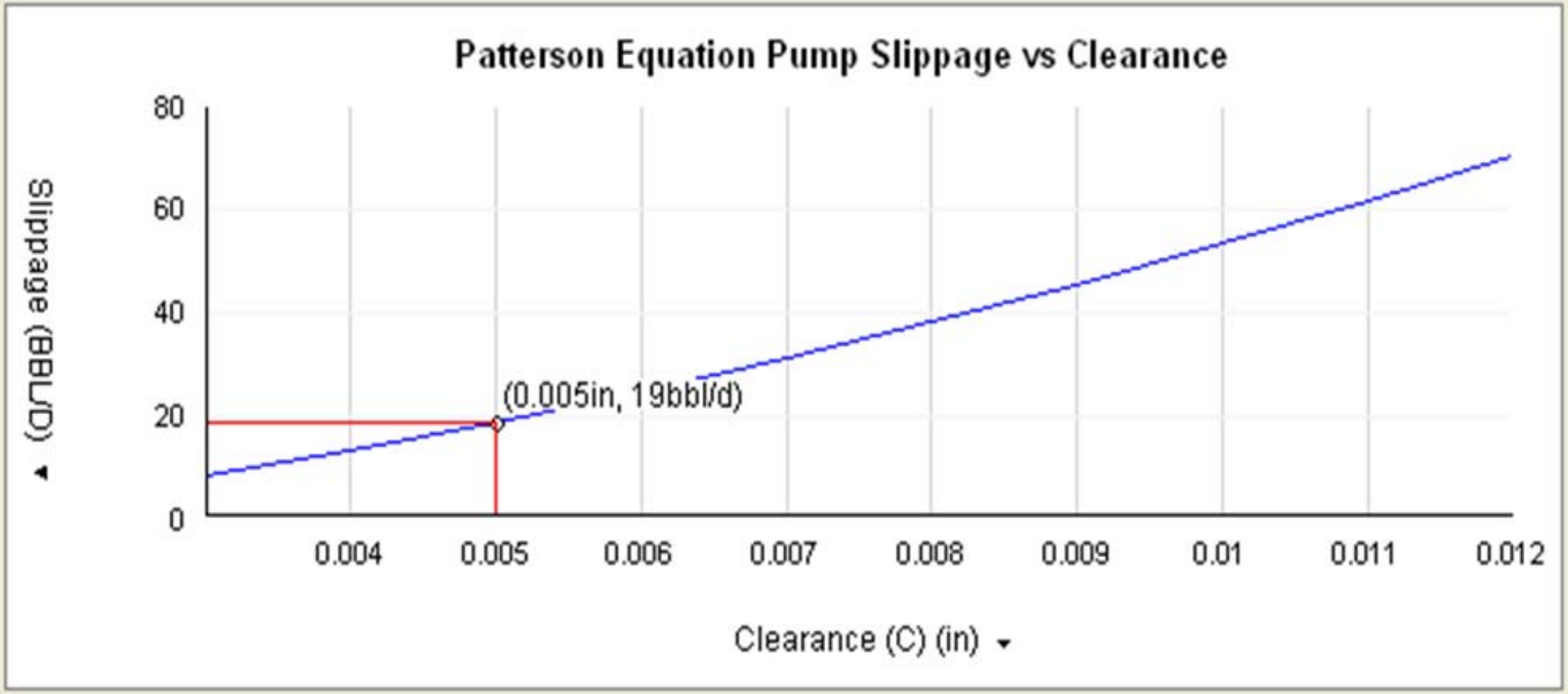
Pump Volumetric Efficiency 89.79 %

Rate (100% pump volumetric eff.)	182 BBL/D
Rate (90% pump volumetric eff.)	164 BBL/D

Counter Balance Effect 10,222.0 lb

Slippage Plot vs Clearance

Slippage	19	BBL/D	Pressure Differential (P)	1,583.05	psi
Pump Volumetric Efficiency	89.79	%	Tubing Fluid Gradient	0.4330	psi/ft



$$Slippage = \left[\left(0.14 \cdot SPM\right) + 1\right] 453 \frac{DPC^{1.52}}{L\mu}$$

Use Calculation | Cancel

159 BPD Measured vs 164 BPD Predicted

File Tools Help

Title: TTU Slippage Test: Stroke #36 08/25/06 18:24:56 Measured Slippage 21.4 BPD – Pump Efficiency 88.2%

Design Inputs

Unit	CWConv	
Pump Depth	3,896	ft
Surface Stroke Length	105.00	in
Pump Diameter (D)	1.500	in

Results

Rate (100% pump volumetric eff.)	182 BBL/D
Rate (90% pump volumetric eff.)	164 BBL/D
Rod Taper	34.0%, 66.0%
Top Rod Loading	55.9%
Min API Unit Rating	228-119-105
Min NEMA D Motor Size	10.4 HP
Polished Rod Power	5.9 HP
TVLoad	9,107 lb
SVLoad	6,310 lb

Rate (100% pump volumetric eff.) 182 BBL/D
Rate (90% pump volumetric eff.) 164 BBL/D

Steel Rods
Fiberglass and Steel Rods

Rod Number 76
Rod Grade D

Calculate from SPM or Target Rate

Stroke Rate (SPM) << 7.045 >> SPM
Target Rate << 164 >>
Calculate

Default Settings

Total Sinker Bar Weight	0.0	lb	Damping Factor	0.07	
Fluid Specific Gravity	1.00	Sp.Gr.H2O	Surface Unit Efficiency	95	%
Tubing Pressure	13.00	psi	Pump Volumetric Efficiency	89.79	%
Casing Pressure	6.00	psi			

You may enter Pump Intake Pressure directly, or calculate it from Reservoir Pressure and Productivity Index.

Pump Intake Pressure 116.80 psi
Reservoir Pressure 1,000.00 psi
Productivity Index 2.000 STB/D/psi

Pump Volumetric Efficiency 89.79 %

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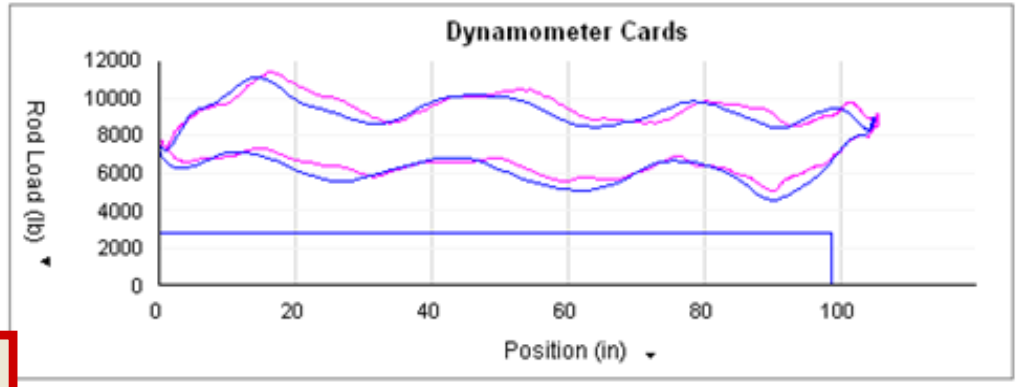
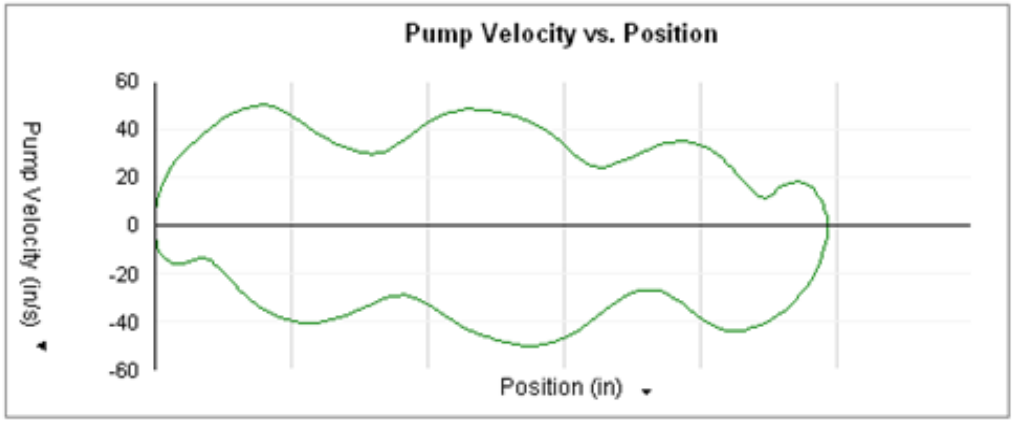
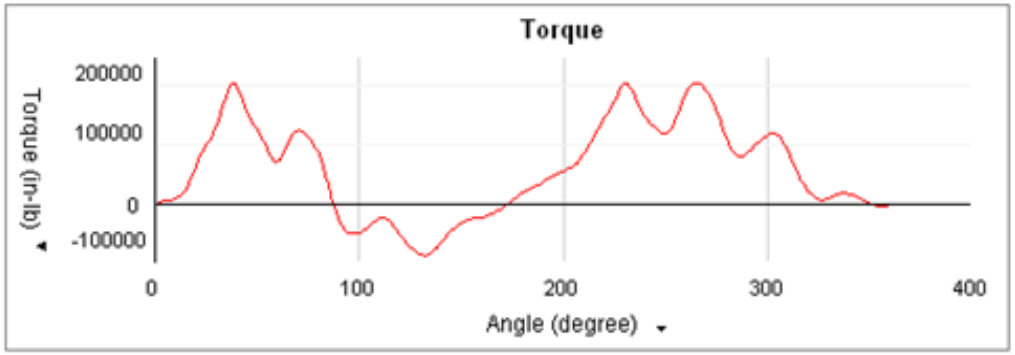


PRL	11,097	psi	MPRL	4,533.0	lb	Fo	2,797.5 lb
Pump Stroke Length	98.75	in	Static Stretch	8.76	in	Overtravel	2.50 in
Fo/Skr	0.083		Kr	319	lb/in	Kt	1147 lb/in





Peak GearBox Torque	204	Kin-lb
Counter Balance Moment	509	Kin-lb
Counter Balance Effect	10,222.0	lb

Recommended Procedure to Select Pump Clearances

1. Use predictive sucker rod design program to calculate pump displacement, assume 100% liquid pump fillage.
2. Input correct well parameters into QRod Tool - “Pump Slippage Calculator”, be sure to adjust water viscosity for the temperature at the pump
3. Examine Plot of “Patterson Equation Pump Slippage vs Clearance” and select pump clearance that gives the desired percentage of pump slippage.

Slippage Calculator

File

QRod Inputs

Pump Diameter (D)	2.250	in
Pump Depth	7,156	ft
Tubing Pressure	250.00	psi
Pump Intake	151.00	psi
Stroke Rate (SPM)	9.52	SPM
Pump Displacement	651	BBL/D
Fluid Specific Gravity	1.00	Sp.Gr.H2O

User Inputs

Clearance (C)	0.009	in
Fluid Viscosity (μ)	0.76	cP
Plunger Length (L)	48.000	in

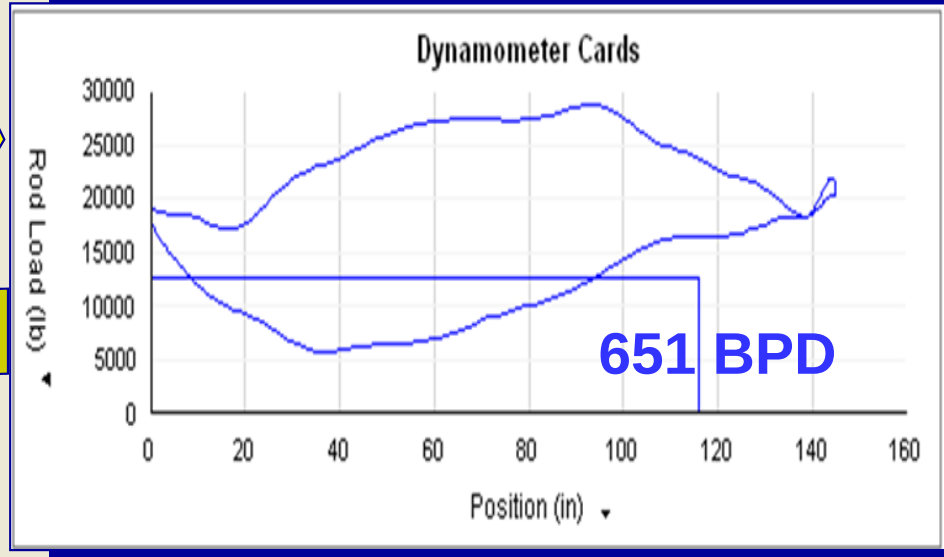
Calculate

Calculate from SPM or Target Rate

Stroke Rate (SPM) << 9.52 >> SPM

Target Rate << 489 >>

Calculate



Pump Volumetric Efficiency 75.12 %

Rate (100% pump volumetric eff.)	651 BBL/D
Rate (75% pump volumetric eff.)	489 BBL/D

SlippageExample.qrd

Slippage Calculator

File

Patterson Slippage 155.5 BPD

QRod Inputs

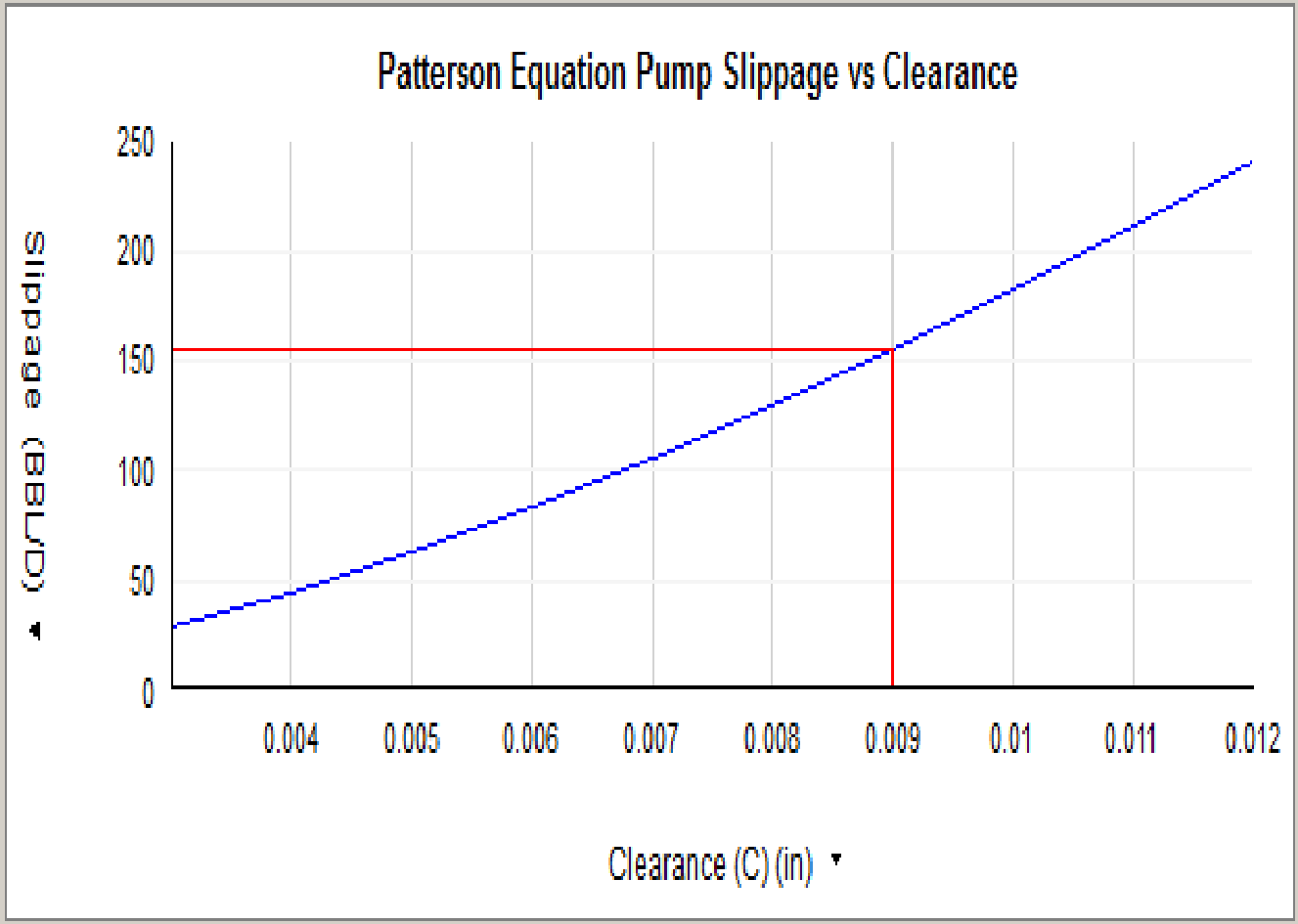
Pump Diameter (D)	2.250	in
Pump Depth	7,156	ft
Tubing Pressure	250.00	psi
Pump Intake Pressure	229.00	psi
Stroke Rate (SPM)	9.47	SPM
Pump Displacement	534.00	BBL/D
Fluid Specific Gravity	0.99	Sp.Gr.H2O

User Inputs

Clearance (C)	0.009	in
Fluid Viscosity (μ)	0.76	cP
Plunger Length (L)	48.000	in

Calculate

Slippage	155.47	BBL/D	Pressure Differential (P)	178.96	psi
Pump Volumetric Efficiency	70.89	%	Tubing Fluid Gradient	0.985701	psi/ft



$$Slippage = \left[(0.14 \cdot SPM) + 1\right] 453 \frac{DPC^{1.52}}{L\mu}$$

Use Calculation

Cancel

651 BPD Pump Displacement

Title

Design Inputs

Unit	CWConv	
Pump Depth	7,156	ft
Surface Stroke Length	145.00	in
Pump Diameter (D)	2.250	in
Tubing Size	2.875" (6.40 lb/ft) 2.441" ID	

☑ Anchored Tubing

Rods

- ○ Steel Rods
- ◉ Fiberglass and Steel Rods

Fiberglass Size	1.250	in
Steel Size	0.875	in
Percent Fibreglass	34	%

Results

Rate (100% pump volumetric eff.)	651 BBL/D
Rate (75% pump volumetric eff.)	489 BBL/D
Rod Taper	34.0%, 66.0%
Top Rod Loading	103.8%
Min API Unit Rating	912-305-145
Min NEMA D Motor Size	61.9 HP
Polished Rod Power	41.3 HP
TVLoad	23,849 lb
SVLoad	11,135 lb
Max Fiberglass Load	24,858 lb
Min Fiberglass Load	3,163 lb
Max Fiberglass Stress	20,585 psi
Min Fiberglass Stess	2,619 psi
Fiberglass Load	93.0%

Calculate from SPM or Target Rate

◉ Stroke Rate (SPM) << 9.52 >> SPM

○ Target Rate << 489 >>

Calculate

Default Settings

Total Sinker Bar Weight	816.0	lb	Damping Factor	0.10	
Fluid Specific Gravity	1.00	Sp.Gr.H2O	Surface Unit Efficiency	95.00	%
Tubing Pressure	250.00	psi	Pump Volumetric Efficiency	75.12	%
Casing Pressure	45.00	psi			

You may enter Pump Intake Pressure directly, or calculate it from Reservoir Pressure and Productivity Index.

◉ Pump Intake Pressure 151.00 psi ○ Reservoir Pressure 1,000.00 psi

Productivity Index 2.000 STB/D/psi

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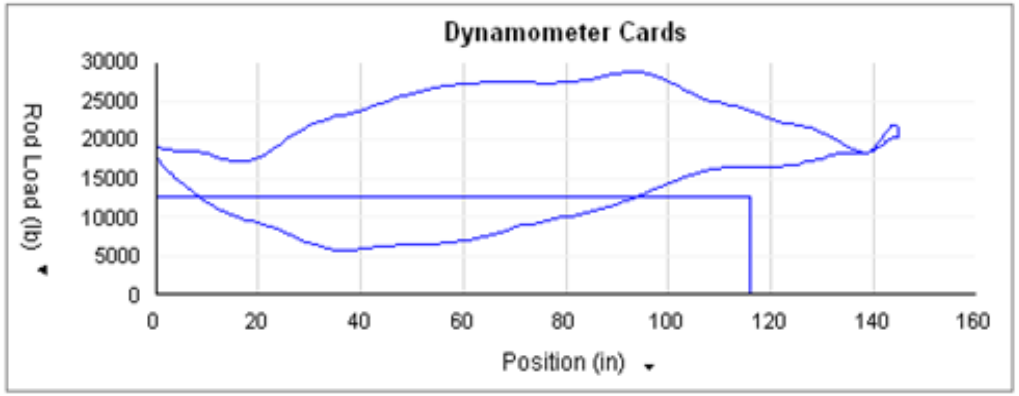
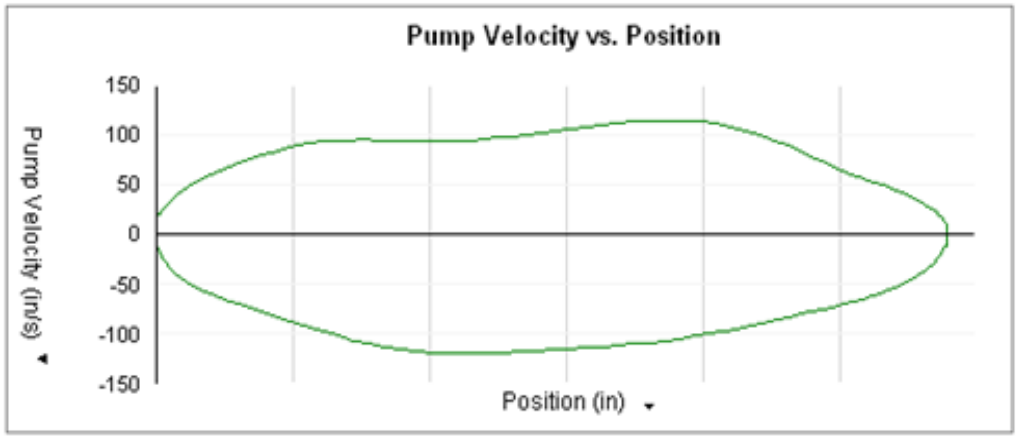
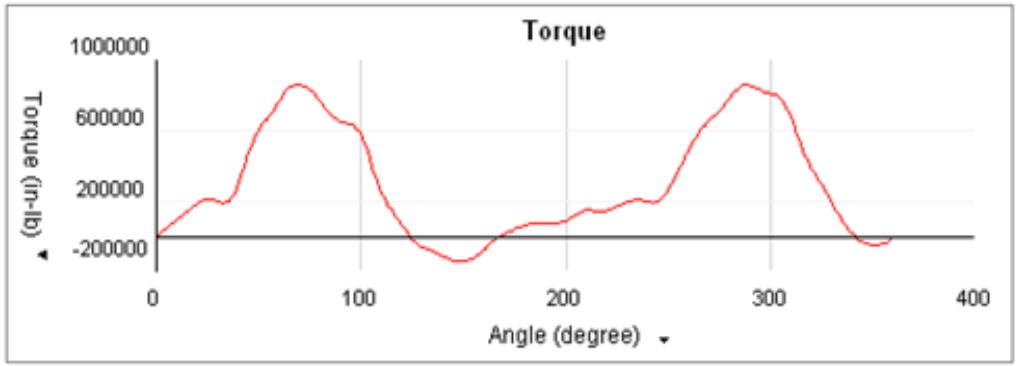


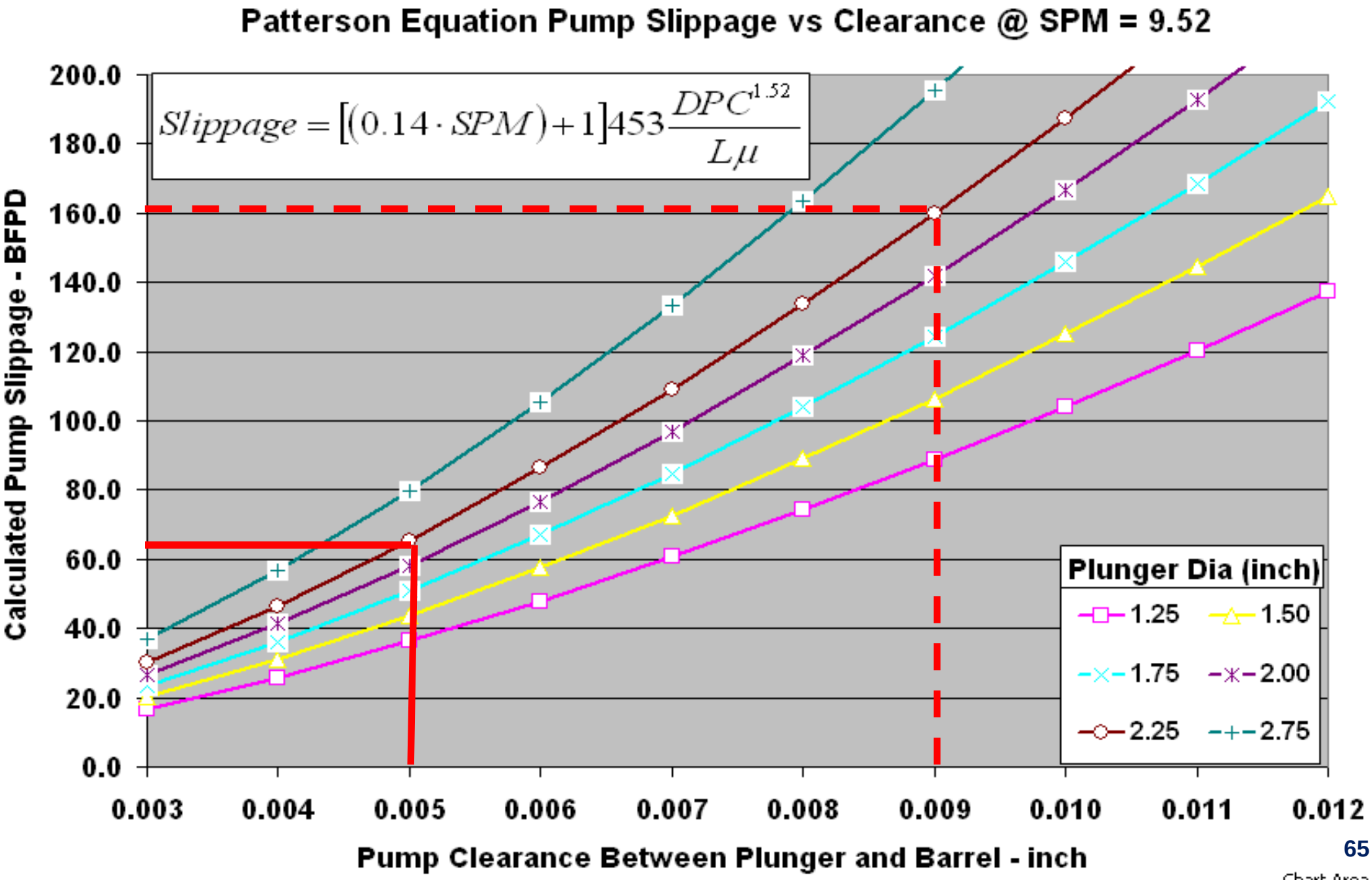
PPRL	28,635	psi	MPRL	5,777.7	lb	Fo	12,713.7 lb
Pump Stroke Length	115.89	in	Static Stretch	81.66	in	Overtravel	52.55 in
Fo/Skr	0.563		Kr	156	lb/in	Kt	625 lb/in



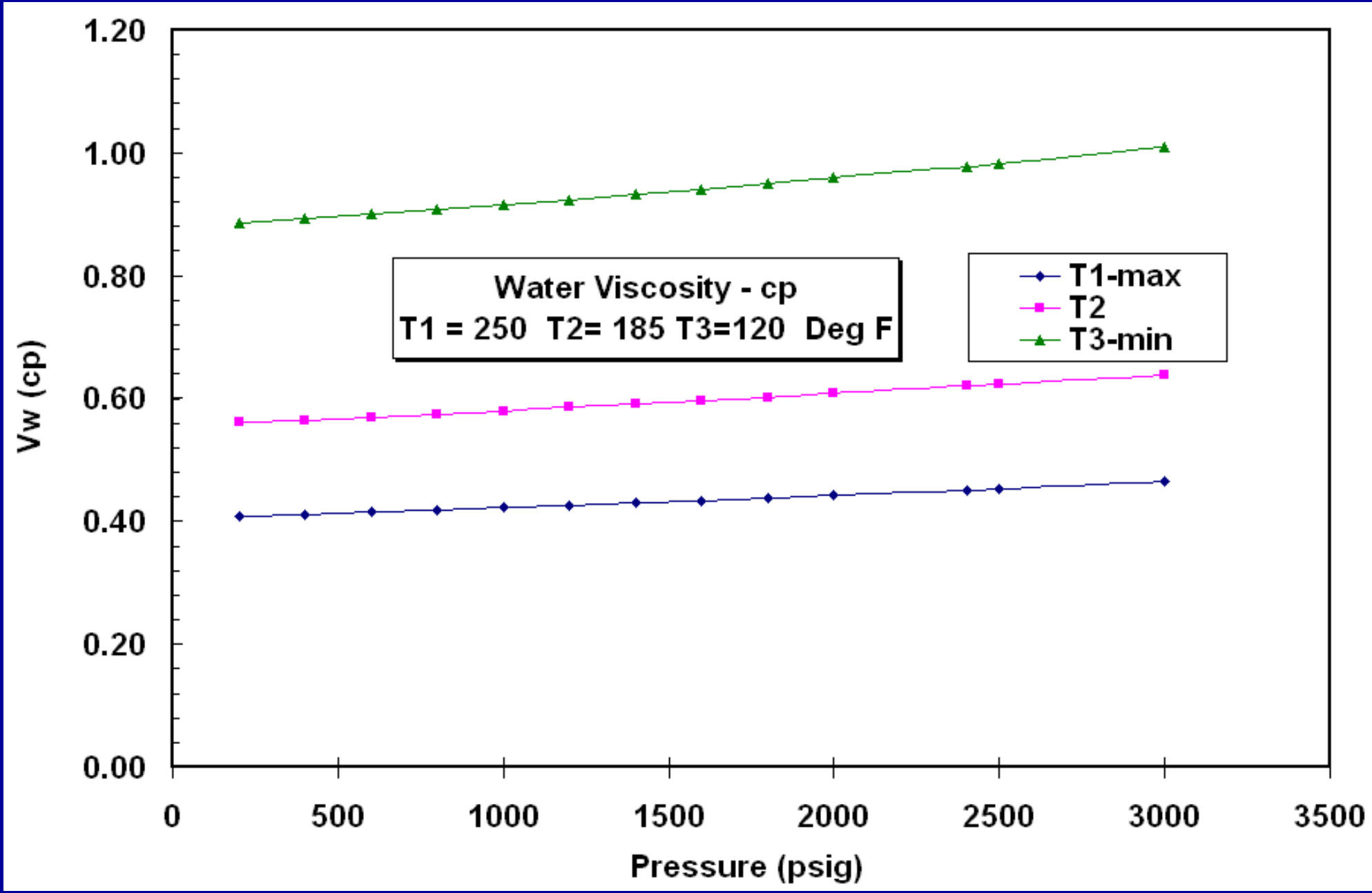


Peak GearBox Torque	851	Kin-lb
Counter Balance Moment	1,525	Kin-lb
Counter Balance Effect	22,157.3	lb

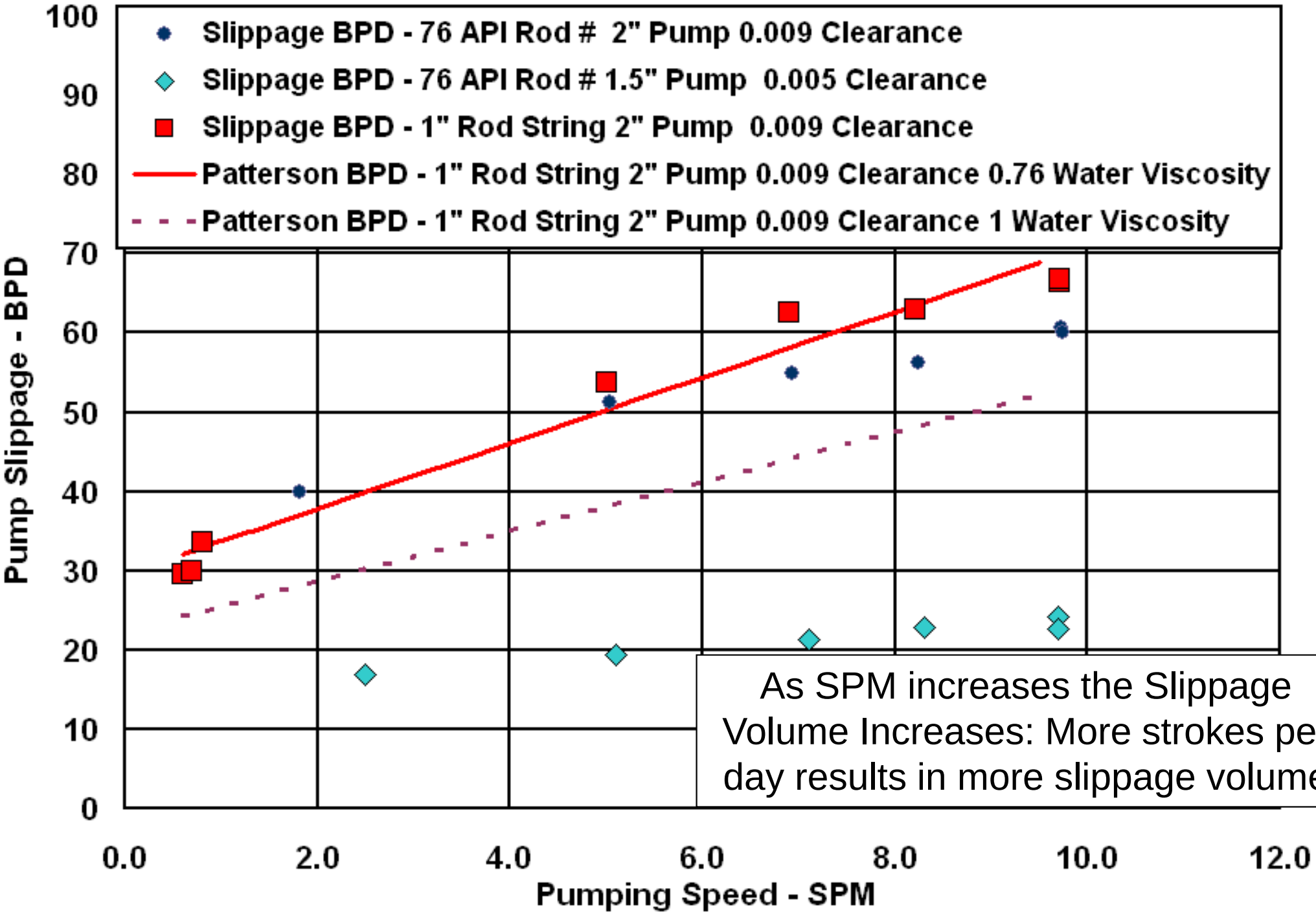
Design Pump Clearance of 0.005” to Achieve 90% Pump Efficiency with 65 BPD Slippage



Water Viscosity - Cp



Viscosity Impact on Slippage Calculation



As SPM increases the Slippage Volume Increases: More strokes per day results in more slippage volume

Slippage Calculator

File

Patterson Slippage 155.5 BPD

QRod Inputs

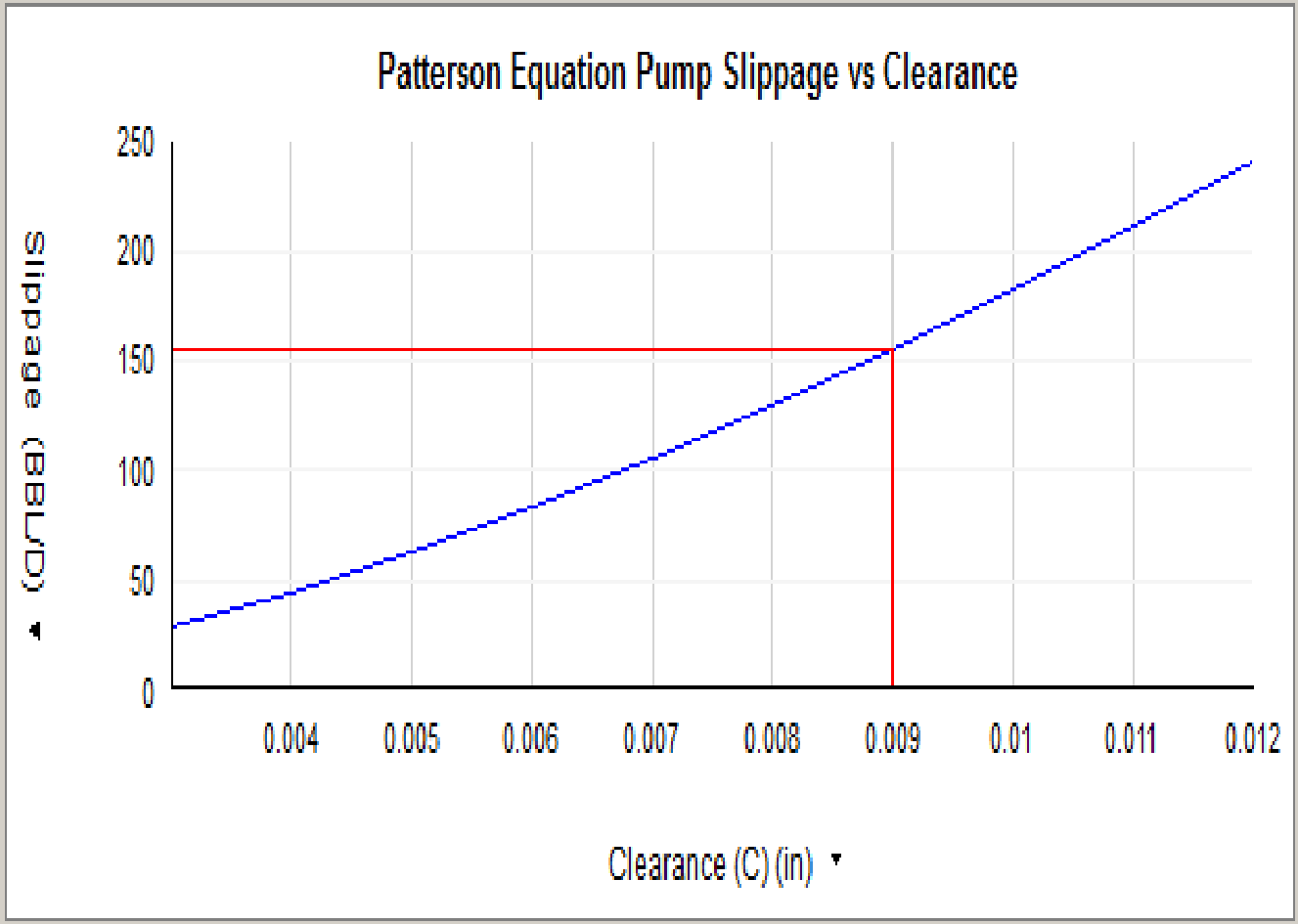
Pump Diameter (D)	2.250	in
Pump Depth	7,156	ft
Tubing Pressure	250.00	psi
Pump Intake Pressure	229.00	psi
Stroke Rate (SPM)	9.47	SPM
Pump Displacement	534.00	BBL/D
Fluid Specific Gravity	0.99	Sp.Gr.H2O

User Inputs

Clearance (C)	0.009	in
Fluid Viscosity (μ)	0.76	cP
Plunger Length (L)	48.000	in

Calculate

Slippage	155.47	BBL/D	Pressure Differential (P)	178.96	psi
Pump Volumetric Efficiency	70.89	%	Tubing Fluid Gradient	0.985701	psi/ft



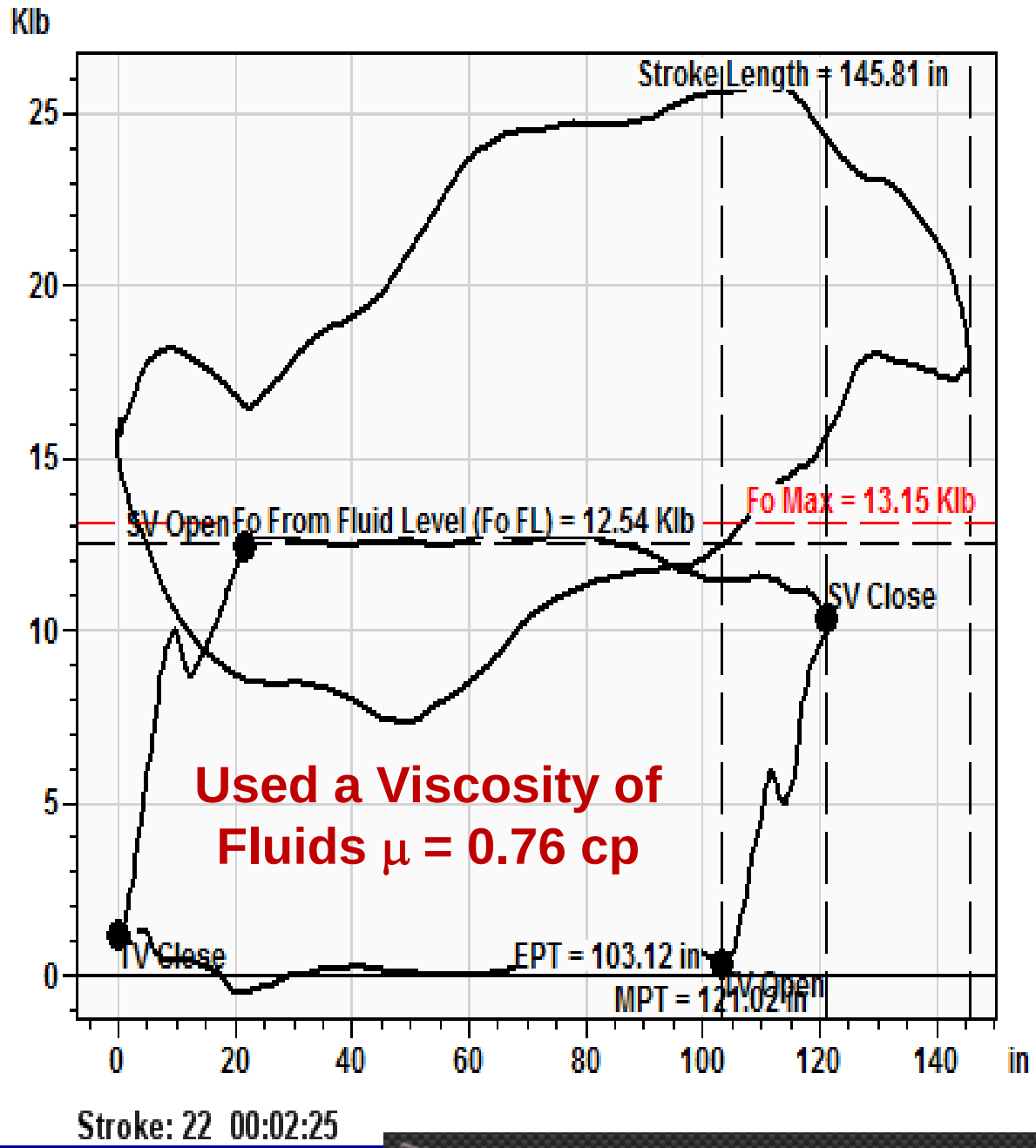
$$Slippage = \left[(0.14 \cdot SPM) + 1\right] 453 \frac{DPC^{1.52}}{L\mu}$$

Use Calculation

Cancel

Actual Field Example of 0.009” Clearance

Why only 402 barrels per day is being produced to the tank, when the effective downhole pump displacement is 577 BPD?



1. New pump w/ no wear or damage
2. Installed 0.009 in. clearance w/ 2.25 inch diameter & 4 foot plunger
3. ***Patterson Eq. Slippage 155 BPD***
4. 576 BPD Full Pump dynamometer card (No correction for slippage or gas in solution).
5. Tested Rates are 106 BOPD & 296 BWPD ~ 26.4% Oil
6. Production is 175 BPD less than the 577 BPD pump displacement.
7. (106+296)/577 = ***70% Pump Eff.***
8. 14 MscfD gas up tubing (245 GOR), at 3307 psi discharge pressure, then water swelled 1.7% due P&T. Oil swelled 6.8% due to P&T and gas in solution. Liquid from P&T and solution gas looses 12 BPD.
9. Patterson Equation appears to calculate slippage fairly accurately.

TAM - Echometer Online : LiquidPumpPumps 2020_6 : Calculate_PlungerClearance

Measured Rate Matches Calculated

Pump

	in	BBL/D
Maximum Plunger Travel	121.02	
Free Gas in Pump at Intake	18.84	105
Effective Plunger Stroke	103.12	577
Free Gas in Pump at Discharge	0.93	5
TV Close Delay	0.00	0
Slippage (Patterson)	27.80	155
Pump Displacement	74.39	416

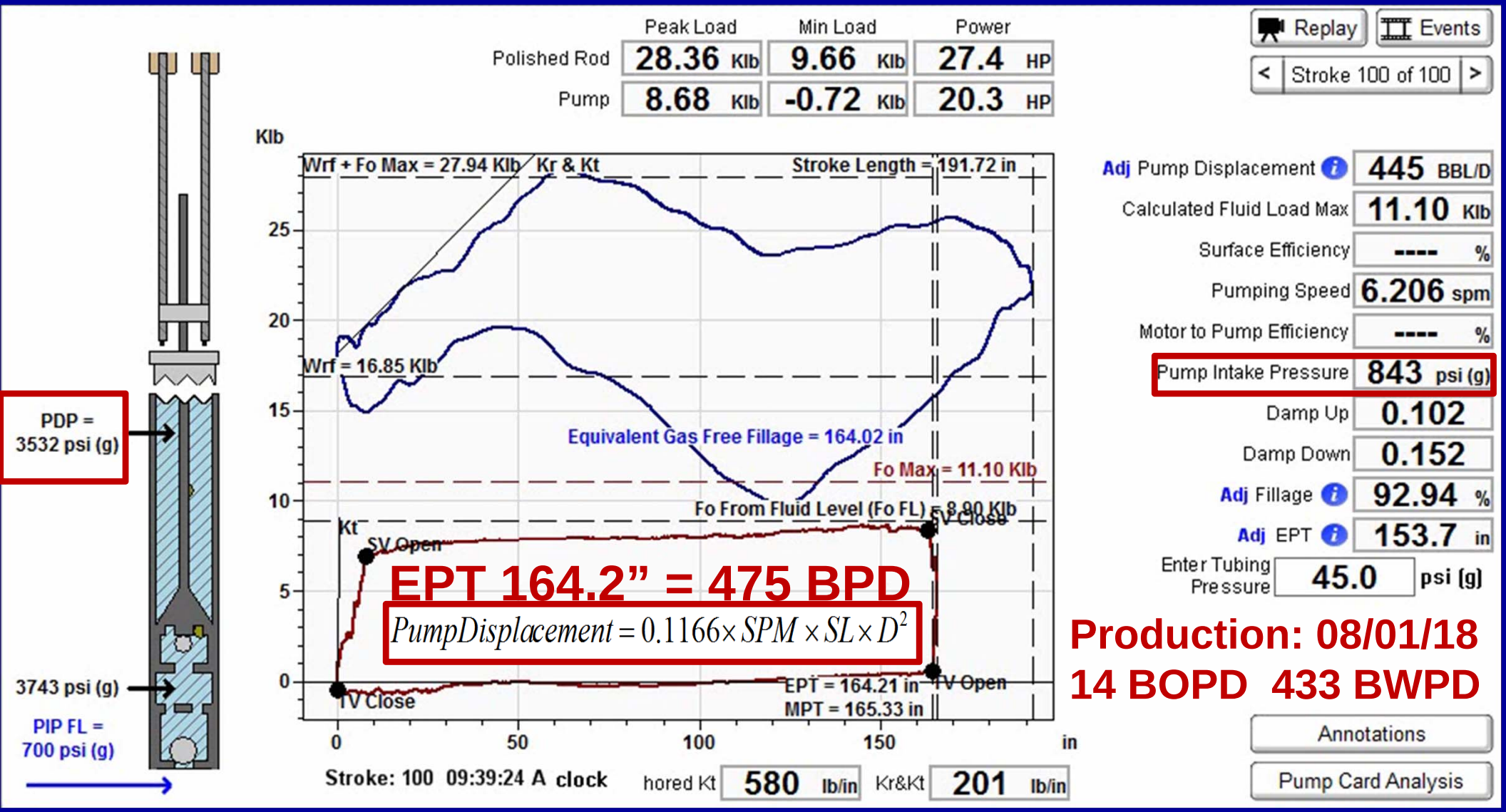
Viscosity of Fluids

$\mu = 0.76$ cp

Liquid

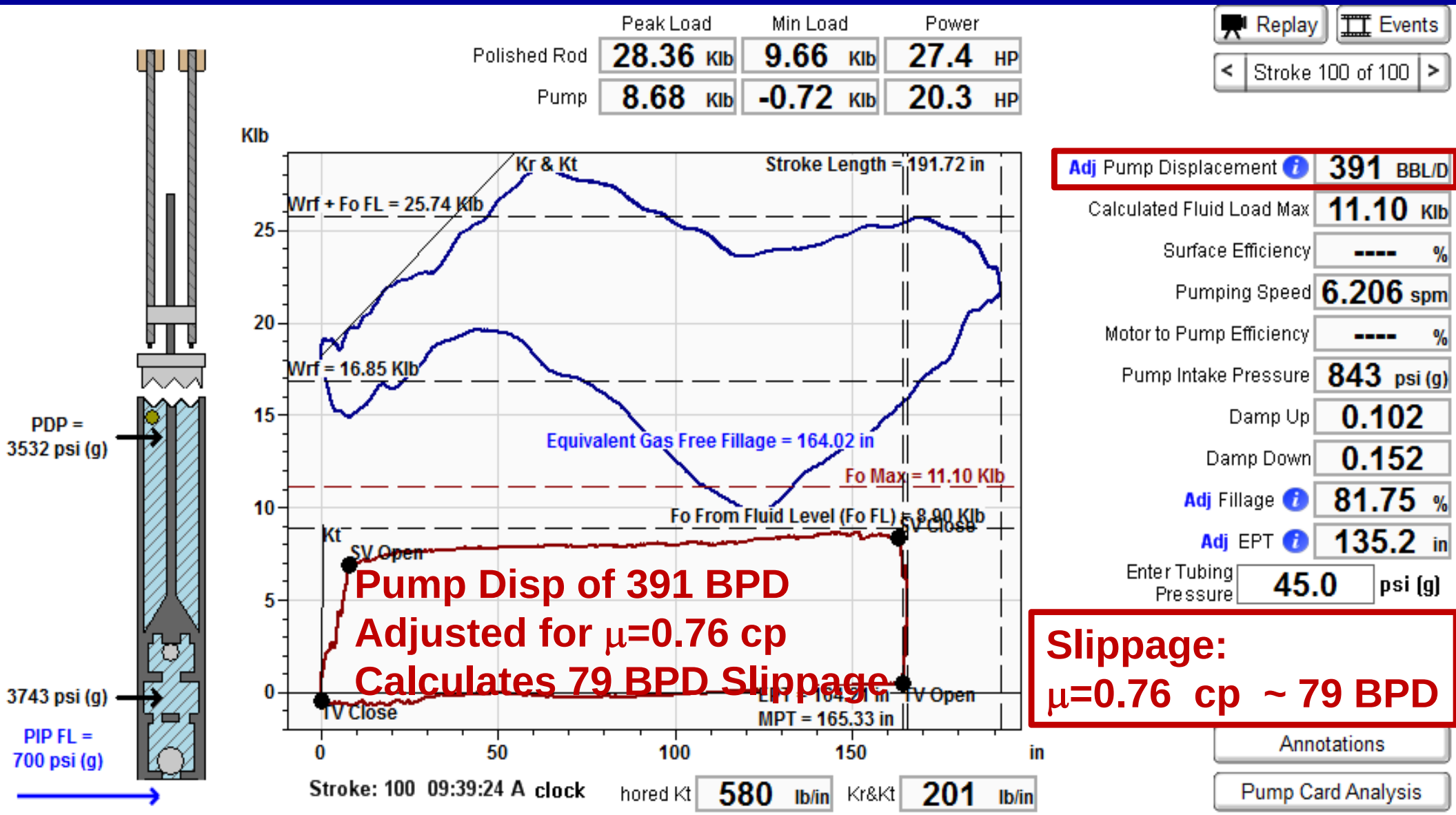
	Pump Discharge BBL/D	(Calc) Surface Stock Tank BBL/D	(Input) Surface Stock Tank BBL/D
Oil	110	103	106
Water	306	301	296
Total Liquid	416	404	402

475 BPD at TV Open on Pump Card but Why 447 BPD Produced into the Tank



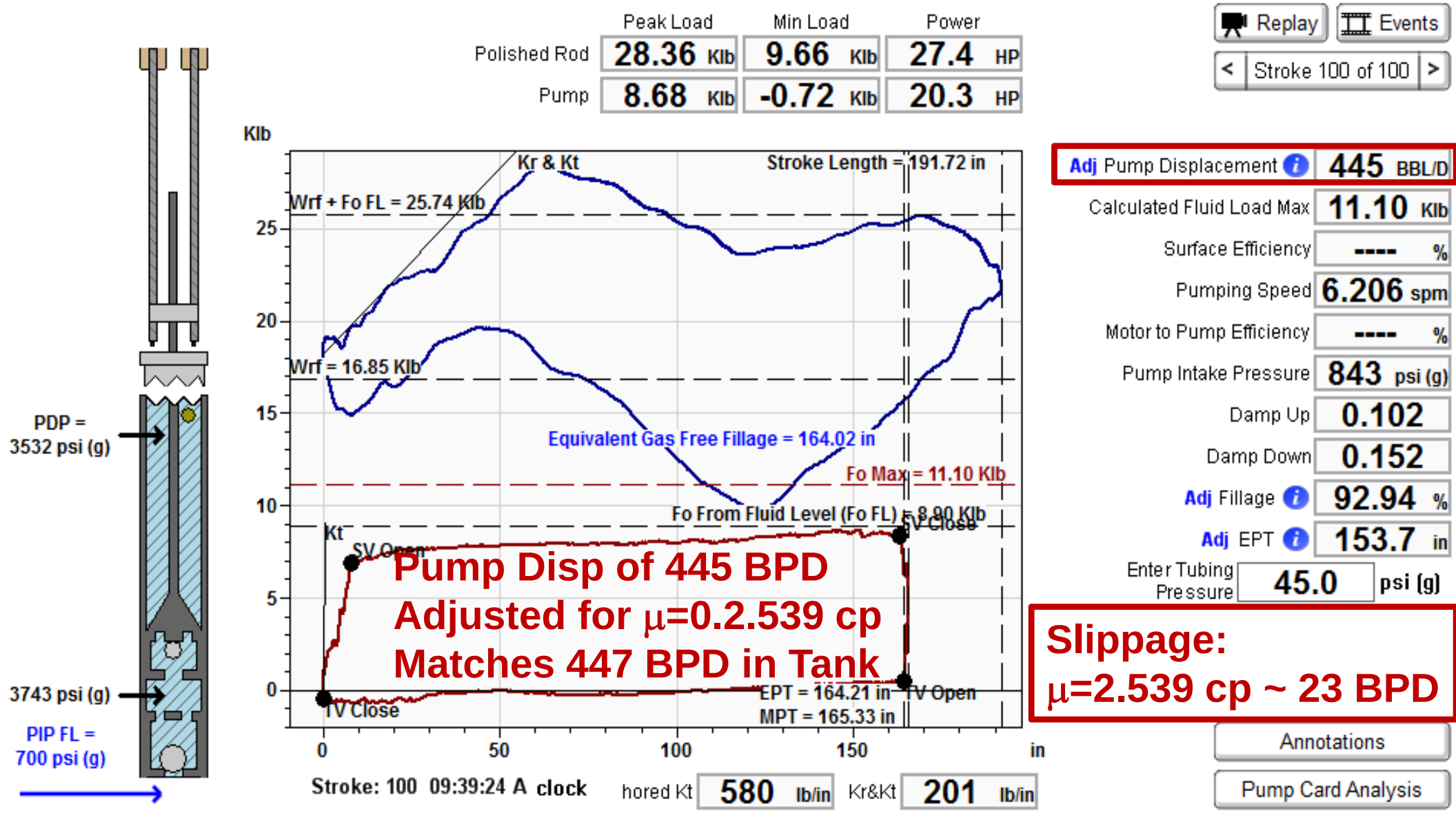
Using Default 0.76 μ Calculates *TOO MUCH* Slippage

For Oil Gravity of <30-32 Degrees Need to Use Oil Viscosity



Using Default 0.76 μ Calculates *TOO MUCH* Slippage

For Oil Gravity of 24.4 Deg Used Oil Viscosity of Fluids μ=2.539 cp



Plunger Length, Diameter, Clearance Important

Pump

Intake Depth	7701.0	ft	Pump Length	26.0	ft
Pump Run Date	1/19/2018		Plunger Length	60.000	in
API Pump Designation			Plunger Diameter	2.000	in
25-200 RXBC 26-5			Plunger Clearance	0.009	in

$$453 \cdot \left[(0.14 \cdot SPM) + 1 \right] \frac{DPC^{1.52}}{L\mu}$$

Viscosity f(P, T, Pb, Oil Wat Gas SG)

What about a mixture viscosity based on %Oil and % Water?

Pressure (psia)	R_s (SCF/BO	B_o (vol/vol)	μ_o (cp)	z_g	B_g (vol/vol)	μ_g (cp)	B_w (vol/vol)	μ_w (cp)	c_w (1/psi)
100	10.3	1.0815	4.440	0.991	0.19049	0.0133	1.0459	0.274	9.07E-07
500	57.8	1.1011	3.610	0.957	0.03678	0.0138	1.0455	0.279	1.08E-06
350	38.5	1.0931	3.906	0.969	0.05323	0.0136	1.0457	0.277	1.04E-06
600	71.3	1.1067	3.427	0.949	0.03040	0.0140	1.0454	0.280	1.17E-06
850	106.9	1.1218	3.024	0.930	0.02104	0.0145	1.0451	0.283	1.30E-06
1100	144.7	1.1381	2.690	0.914	0.01597	0.0150	1.0448	0.286	1.44E-06
1350	184.2	1.1555	2.412	0.900	0.01282	0.0157	1.0444	0.289	1.57E-06
1600	225.3	1.1738	2.180	0.890	0.01069	0.0165	1.0440	0.293	1.70E-06
1850	267.7	1.1930	1.984	0.882	0.00917	0.0173	1.0435	0.296	1.83E-06
2100	311.2	1.2131	1.818	0.878	0.00804	0.0182	1.0430	0.300	1.96E-06
2326	351.5	1.2319	1.688	0.877	0.00725	0.0191	1.0426	0.303	2.10E-06
2626	351.5	1.2300	1.736	0.880	0.00644	0.0203	1.0419	0.308	2.26E-06
2926	351.5	1.2282	1.791	0.886	0.00582	0.0215	1.0412	0.312	2.42E-06
3226	351.5	1.2263	1.852	0.896	0.00534	0.0228	1.0405	0.317	2.61E-06
3626	351.5	1.2239	1.941	0.914					

PIP 843

P Avg 2187

PDP 3582

EXCEL Spreadsheet Available in PDF

Use Oil Only Viscosity at Average of PDP to PIP at Pump Temp at Oil Pb

Production

Oil	Water	Total Fluid	Oil Cut	Water Cut
13.5	433	446.5	0.0302	0.9698

PIP	<========== Viscosity ==========>		
Psia	Oil	Water	Total Fluid
843	3.16279 ?	0.28311 ?	0.37018 ?

Discharge	<========== Viscosity ==========>		
Psia	Oil	Water	Total Fluid
3532	1.91612 ?	0.32094 ?	0.36917 ?

Average	2.53945207	0.36967549 ?

Note: Use Oil Viscosity when oil gravity is less than 30-32 Degree API
Use Total Fluid when oil gravity is greater than 30-32 Degree API
Use 0.76 cp water only oil gravity is greater than 30-32 Degree API

EXCEL Spreadsheet Available on PDF

Measured Rate Matches Calculated

Pump

	in	BBL/D
Maximum Plunger Travel	165.33	
Free Gas in Pump at Intake	1.32	4
Effective Plunger Stroke	164.21	475
Free Gas in Pump at Discharge	0.20	1
TV Close Delay	0.00	0
Slippage (Patterson)	8.02	23
Pump Displacement	155.99	451

Liquid

Viscosity of Fluids μ=2.539 cp

	Pump Discharge BBL/D	(Calc) Surface Stock Tank BBL/D	(Input) Surface Stock Tank BBL/D
Oil	14	12	14
Water	438	432	433
Total Liquid	451	445	447

- [x] Adjust Free Gas in Pump at Intake for Tubing Stretch
  - (•) Kt Anchored
  - ( ) Kt Unanchored
- [x] Adjust Pump Displacement for Gas in Pump
- [x] Adjust Pump Displacement for TV NOT closing at bottom of stroke
- [x] Adjust Pump Displacement for Slippage
- [x] Adjust Pump Displaced Liquid to Surface Stock Tank Conditions

How to Use

- Troubleshoot when Adj Pump Displacement does not match what's produced into tank.
- Determine Pump Wear and Wear Rate as Equipment Operates in the Well
- Design Pump Clearance for New Installation to Match Inflow from Well
- As Pump Wears Increase SPM to Maintain Full Pump and Obtain Long Run Life
- Know Expected Performance of Every Well

Abrasive Solids Impact Pump Life

Note that the pin is smaller diameter than the plunger

Problems:

- Grooving of the plunger due to solids
- Plungers stuck in pump barrel

Actions:

1. **<u>Increase clearance</u>**
2. Use a “Radial Grooved” Plungers
3. Prevent or reduce the amount of solids entering the pump.

The “problem” with increasing the clearance between barrel & plunger?

Must Design for Increased Pump Slippage ! !

Determine Fluid Viscosity for Slippage Eq.

Use Default 0.76 cp water viscosity for a "good" guess.

- Use Oil Only Viscosity when oil gravity is less than 30-32 Degree API
- Use Total Fluid (based on %Oil and %Water) when oil gravity is greater than 30-32 Degree API
- For Pressure use Average of (PIP + PDP)
- Use Temperature at Pump Depth
- Must Know Plunger Length, Diameter, Clearance
- Should Know Oil, Water, and Gas Gravities
- Use Bubble Point Pressure to determine Gas in Solution

Guidelines

- THE Representative Dynamometer Card should be Selected for Analysis, if You are Matching Calculated Production to Reported Production
- More Input Data is Required to make Calculation Work and Additional Data is Sometimes Difficult to Find Out
- Differences between Liquid in the Tank and Pump Displacement from EPT, NOW easier to explain.
- Default 0.76 cp water viscosity is a “good” guess.
- Better Match of Calculated Production to Measured:
  - Use Oil Only μ when oil gravity is less than 30-32 Degree API
  - Use Total Fluid (based on %Oil and %Water) when oil gravity is greater than 30-32 Degree API

Observation

- **Pumping Rate affects Slippage. As Pump Speed Increases:**
  - **Pump Efficiency Increases: Slippage Volume is a Smaller Fraction of Pump Displacement**
  - **Slippage Increases: More strokes per day results in more slippage volume**

Pump Diametrical Clearance Impact System Efficiency

1. Both Theoretical and Patterson Slippage Equation predicts slippage vs. pumping speed, SPM, Pump diameters and Clearances (other parameters)
2. Patterson Equation modified the ARCO-HF equation to include the effect of SPM on slippage.
3. Data shows increase in power cost per barrel due to slippage.
4. Increased Pump Clearance Reduce the System Efficiency (Significantly at slower pumping speeds)
5. More power must be input to the sucker rod pumping system to re-pump the portion of the pump's displacement lost to slippage.
6. Some Slippage Required for Proper pump lubrication.
7. Clearances can allow sand and other particles need to pass between the barrel and plunger

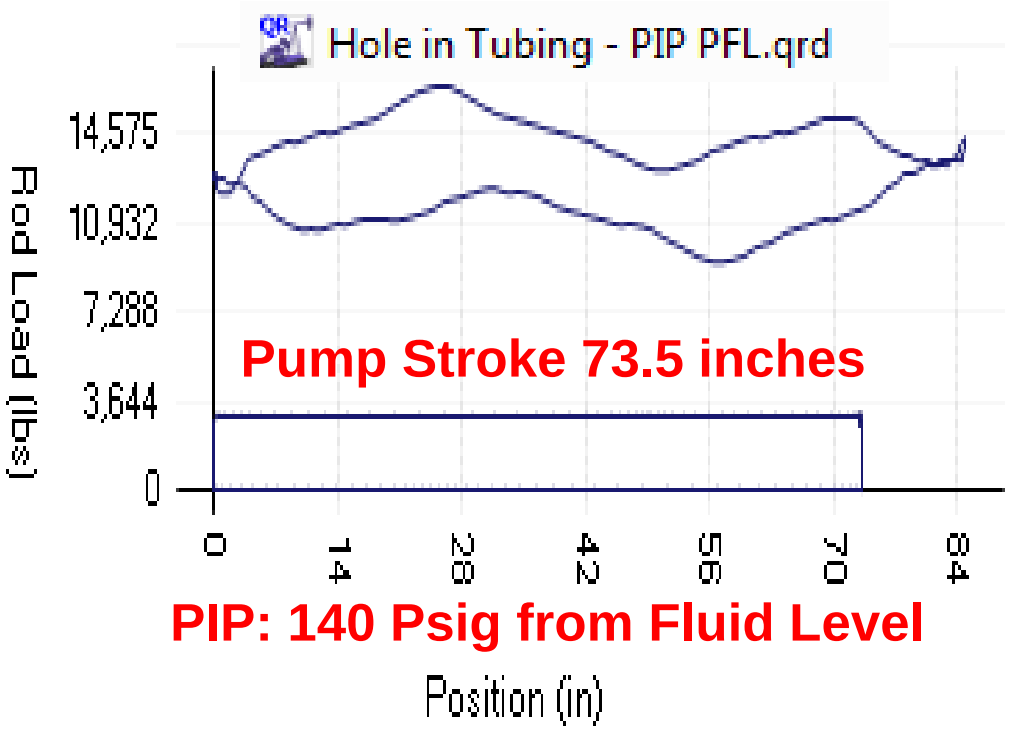
Pump Slippage Summary

1. Patterson Equation should be used to Design Pump Clearances – ***Better than Rule-of-Thumb***
2. Pump Slippage is a Function of SPM, pump efficiency dramatically decreases at slow pumping speed when pump clearances are large.
3. Production from a leaky Pump can be increased by increasing SPM
4. Slippage may be excessive for large clearance pumps when pumping from deeper depths
5. Viscosity of water must be corrected for temperature
6. Proper technique to specify plunger/barrel clearance is to predict the gross downhole pump displacement without slippage, then specify plunger/barrel clearance having a calculated pump slippage volume less than or equal to 5-10% of the gross pump displacement.

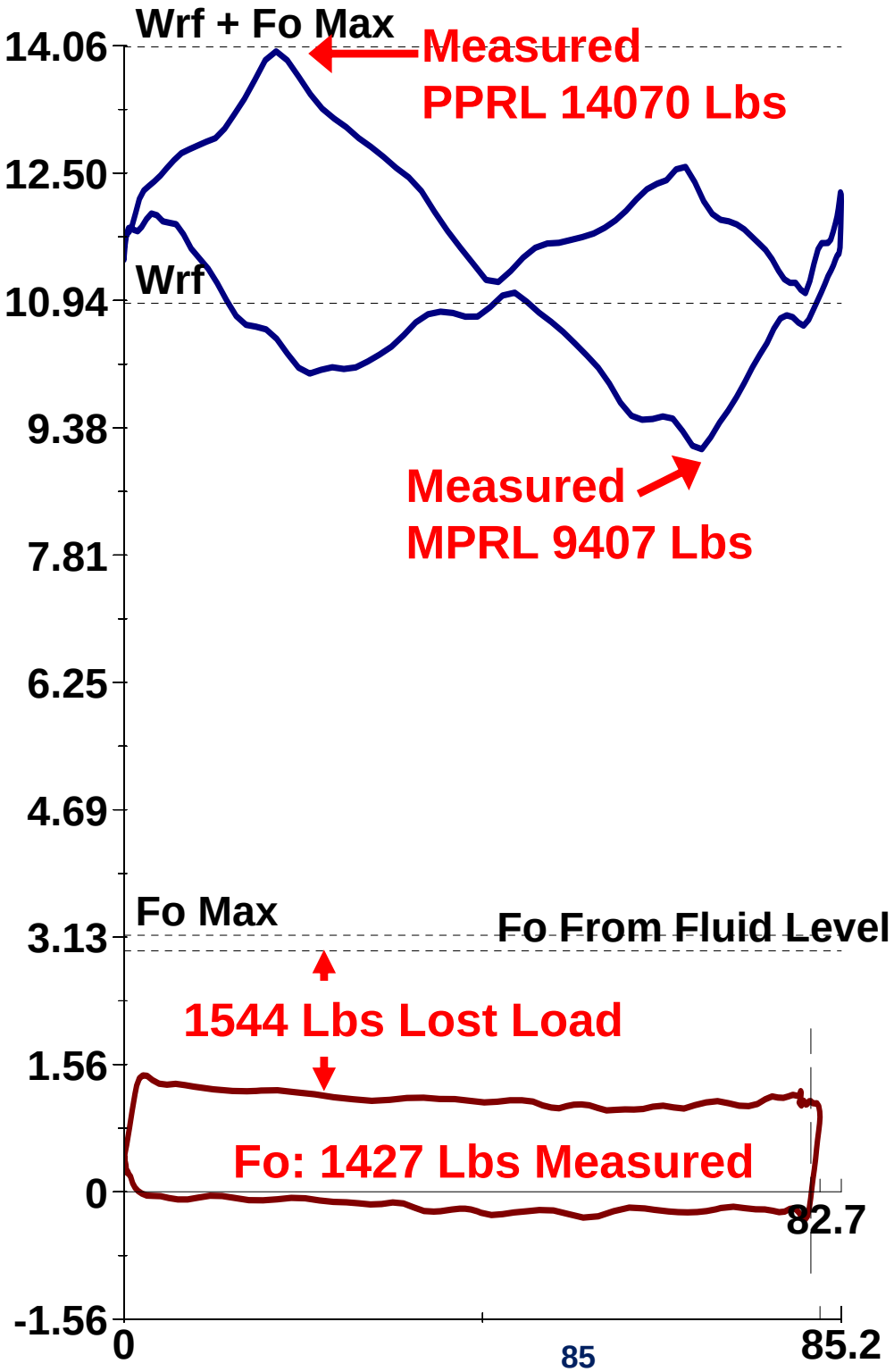
Hole in Tubing

Hole in Tubing detected, because Net Lift shown by the pump card Fo is much less that Fo required by fluid level and full pump card's valves are OK .

QRod Predicted



PPRL 16,563 lbs	MPRL 9,354 lbs	Fo 2,971 lbs
Pump Stroke 73.5 in	Static Stretch 16.8 in	Overtravel 5.1 in
Fo/Skr 0.197	Kr 177 lb/in	Kt 461 lb/in

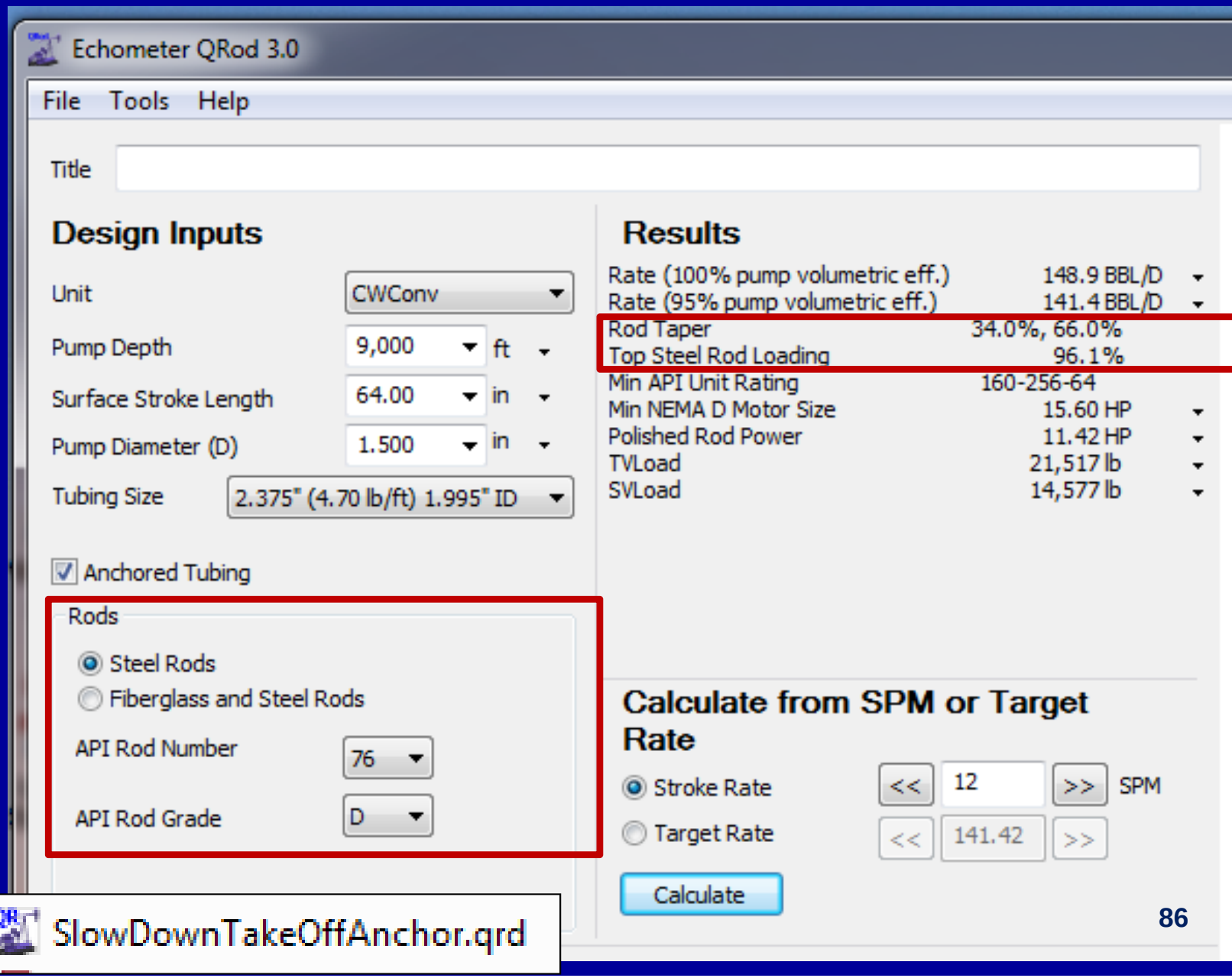


Design a pumping system to pump 33 BPD from a depth of 9000 ft with a 1.5” Plunger ~ 140 BPD?

API RP11L method determines percentage of each rod size and depends on the pump diameter; resulting in a balanced design with approximately equal stresses at the top of each rod section.

76 - 2 taper rod string 34.0% of 7/8 inch and 66.0% of ¾ inch rods.

Loading on the top rod is 96.1% of the allowable for grade “D” rods and calculated using the modified Goodman diagram method.



Echometer QRod 3.0

File Tools Help

Title

Design Inputs

Unit	CWConv	
Pump Depth	9,000	ft
Surface Stroke Length	64.00	in
Pump Diameter (D)	1.500	in
Tubing Size	2.375" (4.70 lb/ft) 1.995" ID	

☑ Anchored Tubing

Rods

◉ Steel Rods

○ Fiberglass and Steel Rods

API Rod Number 76

API Rod Grade D

Results

Rate (100% pump volumetric eff.)	148.9 BBL/D
Rate (95% pump volumetric eff.)	141.4 BBL/D
Rod Taper	34.0%, 66.0%
Top Steel Rod Loading	96.1%
Min API Unit Rating	160-256-64
Min NEMA D Motor Size	15.60 HP
Polished Rod Power	11.42 HP
TVLoad	21,517 lb
SVLoad	14,577 lb

Calculate from SPM or Target Rate

◉ Stroke Rate << 12 >> SPM

○ Target Rate << 141.42 >>

Calculate

Default Settings

Total Sinker Bar Weight	0.0	lb	Damping Factor	0.10	
Fluid Specific Gravity	1.00	Sp.Gr.H2O	Surface Unit Efficiency	95.00	%
Tubing Pressure	80.00	psi	Pump Volumetric Efficiency	95.00	%
Casing Pressure	45.00	psi			

You may enter Pump Intake Pressure directly, or calculate it from Reservoir Pressure and Productivity Index.

◉ Pump Intake Pressure 50.00 psi

○ Reservoir Pressure 1,000.00 psi

Productivity Index 0.200 STB/D/psi

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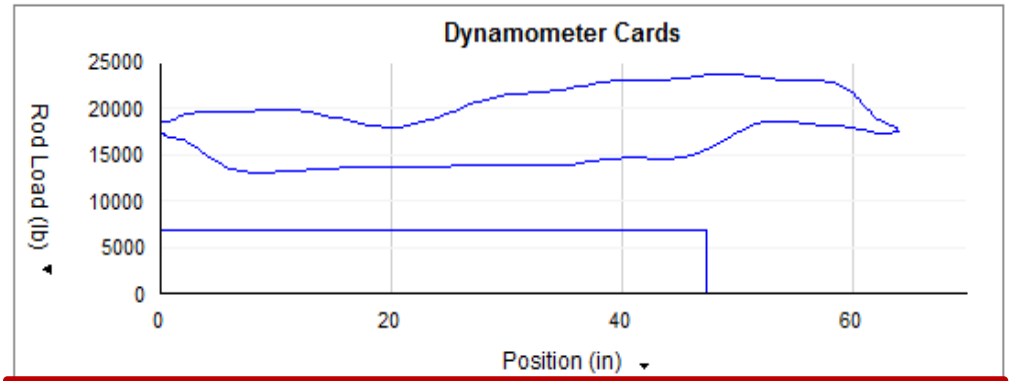
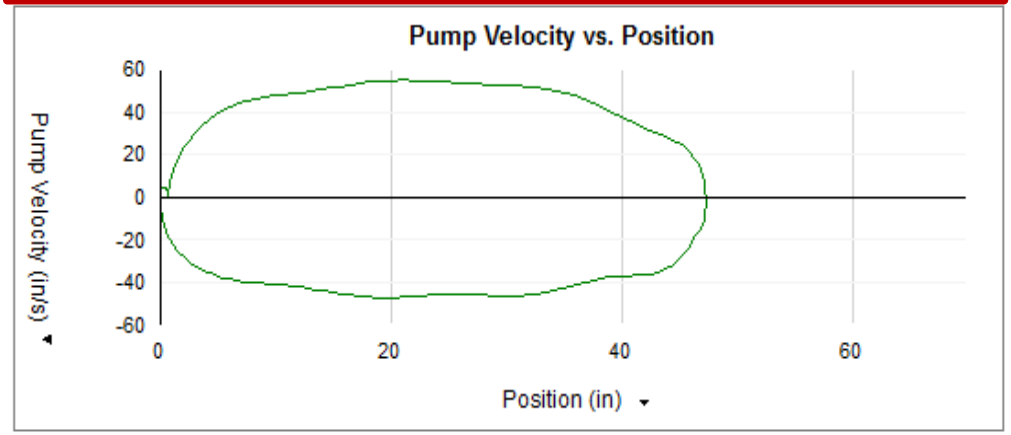
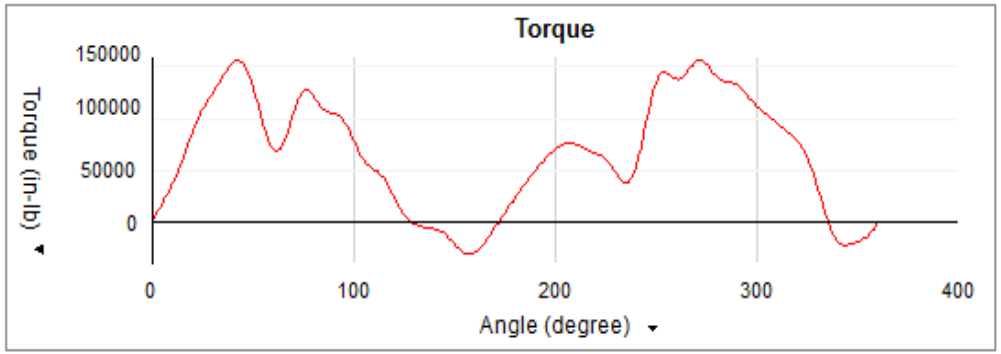


PPRL	23,719.9 lb	MPRL	13,130.4 lb	Fo	6,939.6 lb
Pump Stroke Length	47.30 in	Static Stretch	50.20 in	Overtravel	33.50 in
Fo/Skr	0.784	Kr	138 lb/in	Kt	357 lb/in





Peak GearBox Torque	156	Kin-lb
Counter Balance Moment	637	Kin-lb
Counter Balance Effect	18,255.1	lb

Echometer QRod 3.0

File Tools Help

Title

Design Inputs

Unit	CWConv	
Pump Depth	9,000	ft
Surface Stroke Length	64.00	in
Pump Diameter (D)	1.500	in
Tubing Size	2.375" (4.70 lb/ft) 1.995" ID	

Anchored Tubing

Rods

- Steel Rods
- Fiberglass and Steel Rods

API Rod Number: 76

API Rod Grade: D

Results

Rate (100% pump volumetric eff.)	0.11 BBL/D
Rate (95% pump volumetric eff.)	0.11 BBL/D
Rod Taper	34.0%, 66.0%
Top Steel Rod Loading	79.2%
Min API Unit Rating	57-213-64
Min NEMA D Motor Size	6.22 HP
Polished Rod Power	0.571 HP
TVLoad	21,517 lb
SVLoad	14,577 lb

Calculate from SPM or Target Rate

Stroke Rate << 9.8 >> SPM

Target Rate << 0.11 >>

Calculate

Default Settings

Total Sinker Bar Weight	0.0	lb	Damping Factor	0.10	
Fluid Specific Gravity	1.00	Sp.Gr.H2O	Surface Unit Efficiency	95.00	%
Tubing Pressure	80.00	psi	Pump Volumetric Efficiency	95.00	%
Casing Pressure	45.00	psi			

You may enter Pump Intake Pressure directly, or calculate it from Reservoir Pressure and Productivity Index.

Pump Intake Pressure 50.00 psi

Reservoir Pressure 1,000.00 psi

Productivity Index 0.200 STB/D/psi

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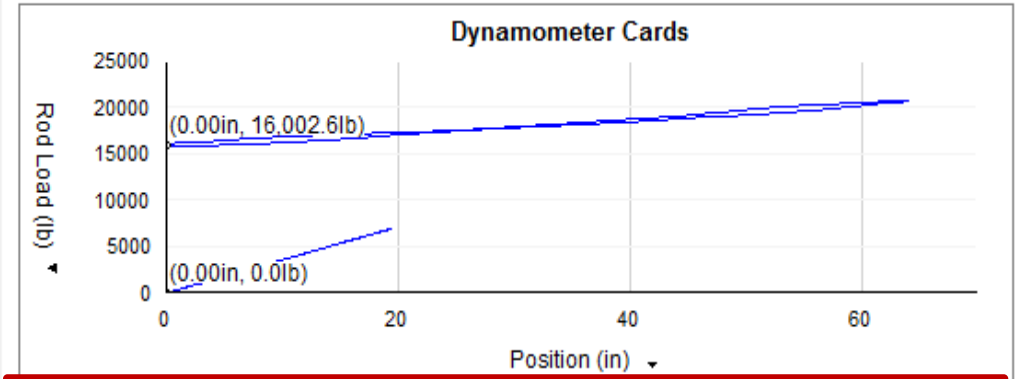
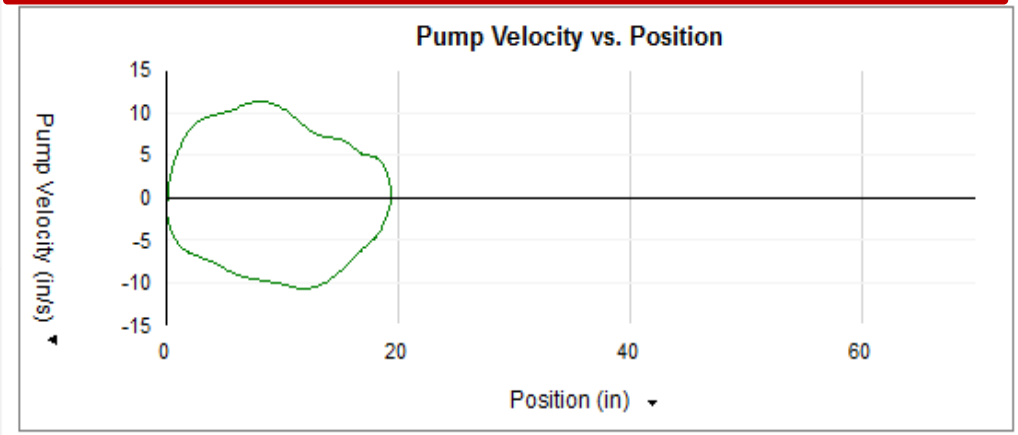
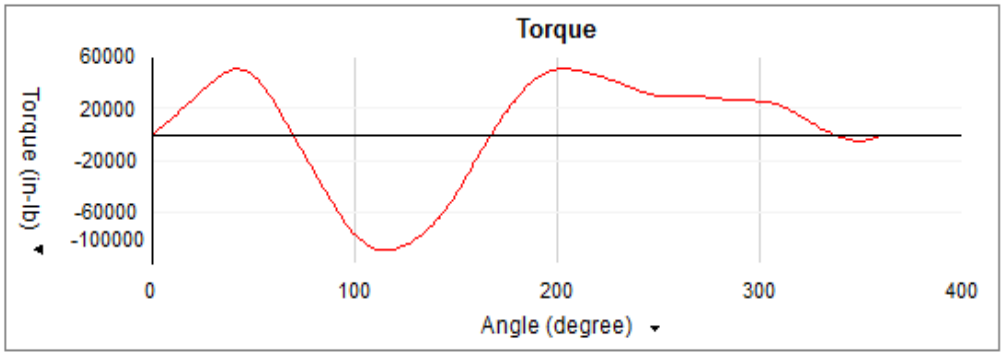


PPRL	20,745.6 lb	MPRL	15,842.5 lb	Fo	6,939.6 lb
Pump Stroke Length	0.04 in	Static Stretch	50.20 in	Overtravel	5.65 in
Fo/Skr	0.784	Kr	138 lb/in	Kt	357 lb/in





Peak GearBox Torque	50	Kin-lb
Counter Balance Moment	660	Kin-lb
Counter Balance Effect	18,255.1	lb

Beam Pumping Gas Wells

1. Rods: Use 5/8” Diameter - Reduce Rod Load
2. Pump: >1.065” Diameter w/ 0.005 Clearance - Reduce Fluid Load
3. Unit: Large Structure, Small Gear Box, Short stroke
4. Motor: Usually 5 Hp or Less
5. Set Intake Below Perfs or Use Good Down Hole Gas Separator
6. Control Run Time to Limit Incomplete Pump Fillage

C-80-133- 64 Unit, 8.3 SPM, 1” Pump, 5/8” Rod String, 5 Hp Motor Lifting 33 BPD from a depth of 9000 ft

File Tools Help

Title: My QRod Test Run

Design Inputs

Unit	CWConv	
Pump Depth	9,000	ft
Surface Stroke Length	64	in
Pump Diameter	1.000	in
Tubing Size	2.375" (4.7 lb/ft) 1.995" ID	

☐ Anchored Tubing

Rods

- ◉ Steel Rods
- ○ Fiberglass and Steel Rods

Rod Number	55
Rod Grade	D

Results

Rate (100% Pump eff.)	34	bbl/day
Rate (95 % Pump eff.)	33	bbl/day
Rod Taper, %	100.0	
Top Rod Loading	94.8	%
Min API Unit Rating	80-133-64	
Min NEMA D Motor Size	4.9	hp
Polished Rod Power	2.7	hp
TVLoad	12,100	lbs
SVLoad	9,000	lbs

Calculate from SPM or Target Rate

◉ Stroke Rate << 8.3 >> SPM

○ Target Rate << 33 >> bbl/day

Calculate

Default Settings

Total Sinker Bar Weight	0	lbs	Damping Factor	0.1	
Fluid Specific Gravity	1	H_2O = 1	Unit Efficiency	95	%
Tubing Pressure	80	psi	Pump Efficiency	95	%
Casing Pressure	45	psi			

You may enter Pump Intake Pressure directly, or calculate it from Reservoir Pressure and Productivity Index.

◉ Pump Intake Pressure 50

○ Reservoir Pressure 1000 psi

Productivity Index 2.000 bbl/day/psi

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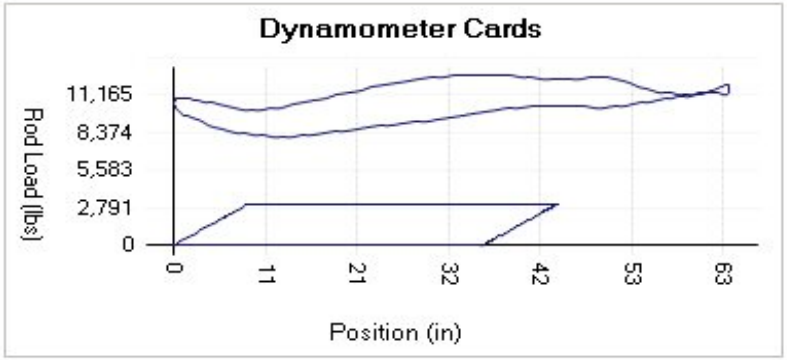
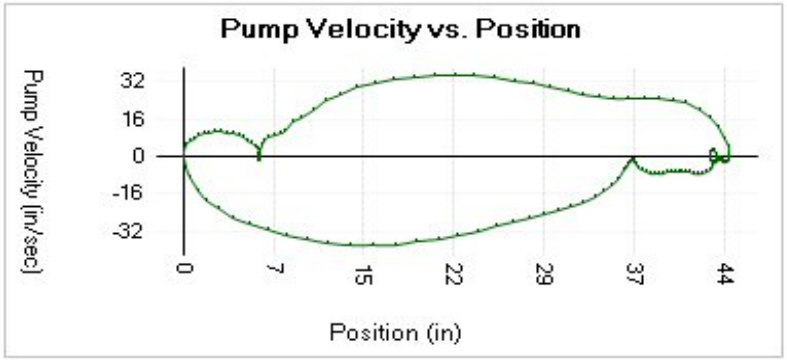
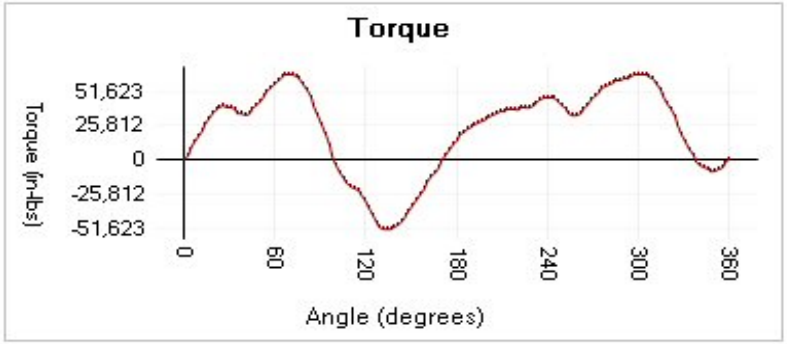


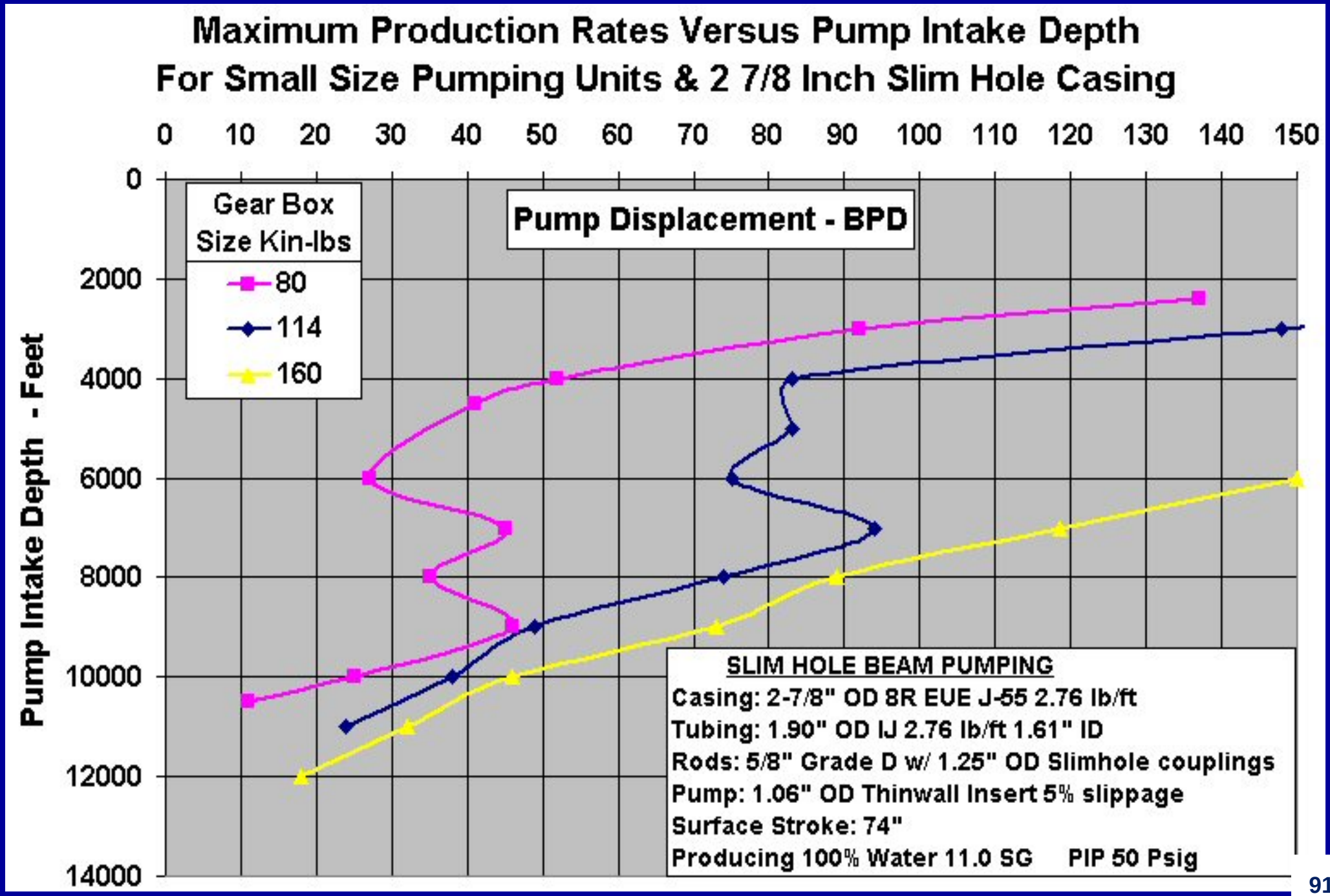
PPRL 12,700 lbs	MPRL 8,100 lbs	Fo 3,100 lbs
Pump Stroke 35.7 in	Static Stretch 35.5 in	Overtravel 15.8 in
Fo/Skr 0.552	Kr 87 lb/in	Kt 357 lb/in





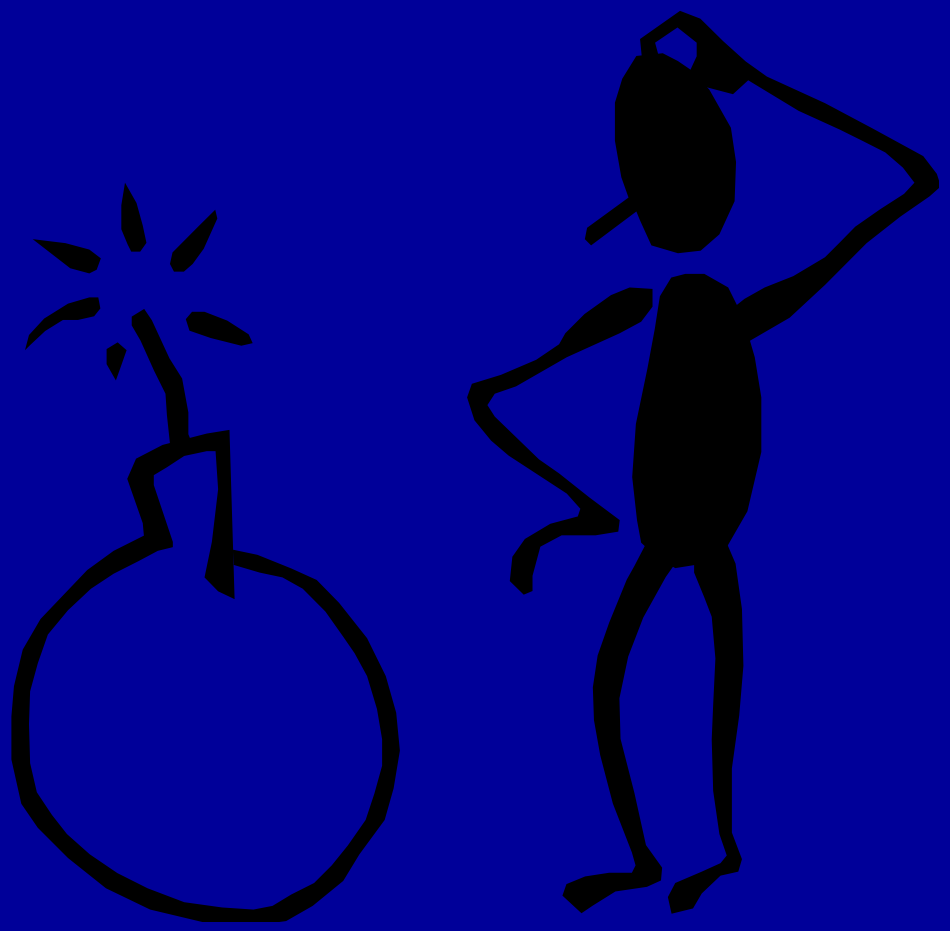
Peak Gear Box Torque	65	Kin-lbs
Counter Balance Moment	380	Kin-lbs
Counter Balance Effect	12,500	lbs

Beam Pumping Gas Wells



QRod - Most Widely Used Program for the Design and Predicted Performance of Sucker Rod Beam Pumping Installations.

- Allows Either English or Spanish Display of Input/output
- Any System of Units
- Helps the beam pumping system designer implement state of the art design technology without getting buried with details
- Wave equation solution to accurately predict the surface dynamometer loads, gearbox torque and pump capacity, with a minimum amount of input
- Immediately Evaluate Effect of Changing Tubing Anchor, Stroke Length, SPM, Pump Diameter
- Slippage Calculator from pump clearances ties the pump efficiency to the predicted pump displacement.
- Sinker Bar length calculator determines the sinker bar length as pump diameter or pump depth changes,
- Results can be shown in any system of units.
- Dynamometer measured surface DYN files can be imported and plotted on top of the predicted surface dynamometer card.

Download: www.echometer.com\software\index.html

Questions ?