8th Annual Sucker Rod Pumping Workshop

Renaissance Hotel

Oklahoma City, Oklahoma

September 25 - 28, 2012

USE OF THE PUMP SLIPPAGE EQUATION TO DESIGN PUMP CLEARANCES

Lynn Rowlan & James N. McCoy

ECHOMETER

James F Lea

PLTECH Production and Artificial Lift Service to the Petroleum Industry

Data Collected at TTU Test Well

Data Acquisition Devices

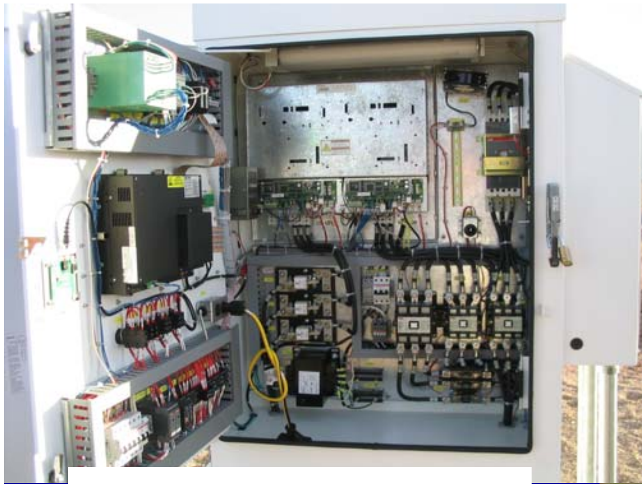


ABB VSD Controller

MicroMotion Mass

Flow Meter F-100

Lufkin SAM Controller ION System Power Measurement System

Wood Group Smart Guard™ RTU package

(3) Echometer Well Analyzers

Patterson Slippage Equation

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

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

Available:
QRod Tool - “Pump Slippage Calculator”

Impact of Pump Clearance and Pumping Speed on Pump Slippage

1. 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

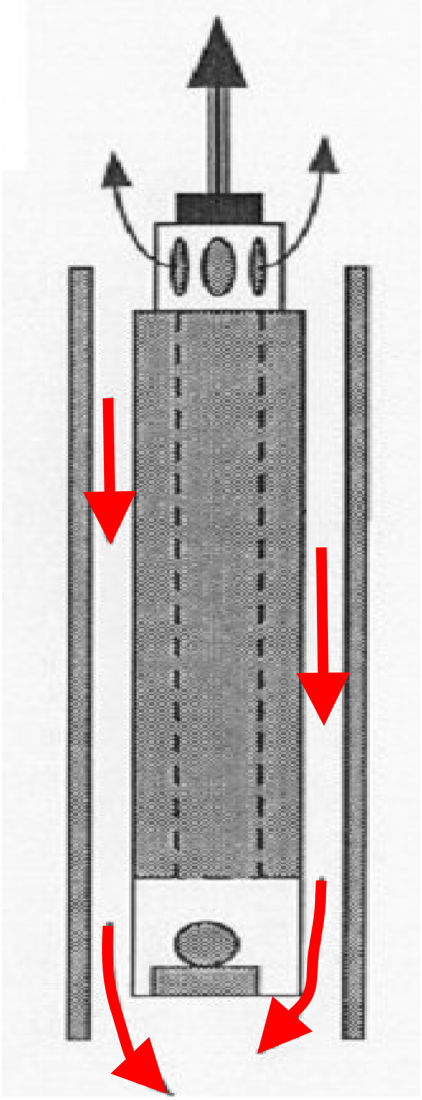
Pump Slippage

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.

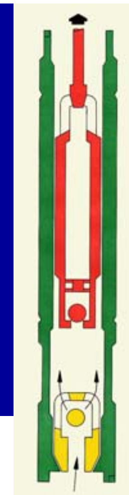
Pump Efficiency =
BPD Tank / BPD Pump

Slippage % =
Slippage BPD / BPD Pump

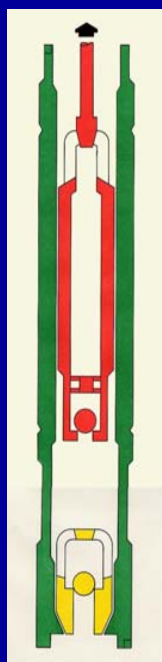
BPD Tank = BPD Pump - Slippage

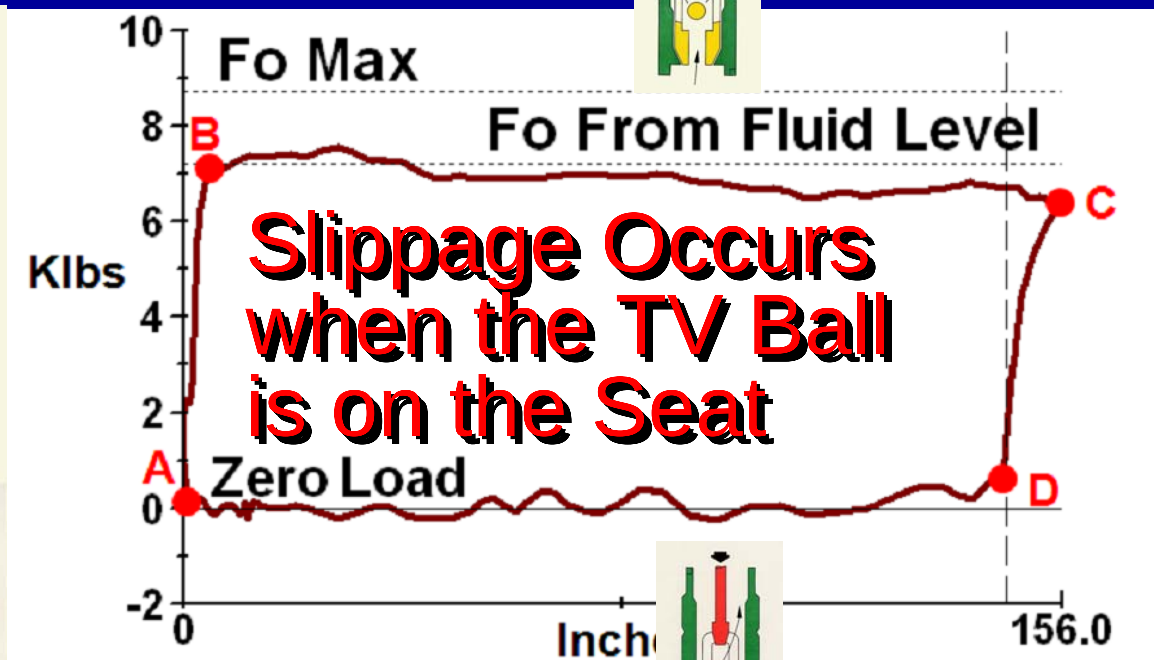


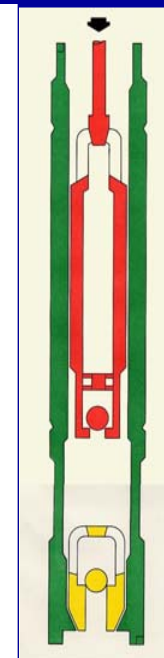
1) **<u>Point A to B</u> pressure acting on closed SV gradually transferred from tubing at point A to be fully carried by the Closed TV at point B.**



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.**

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 Differential	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

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

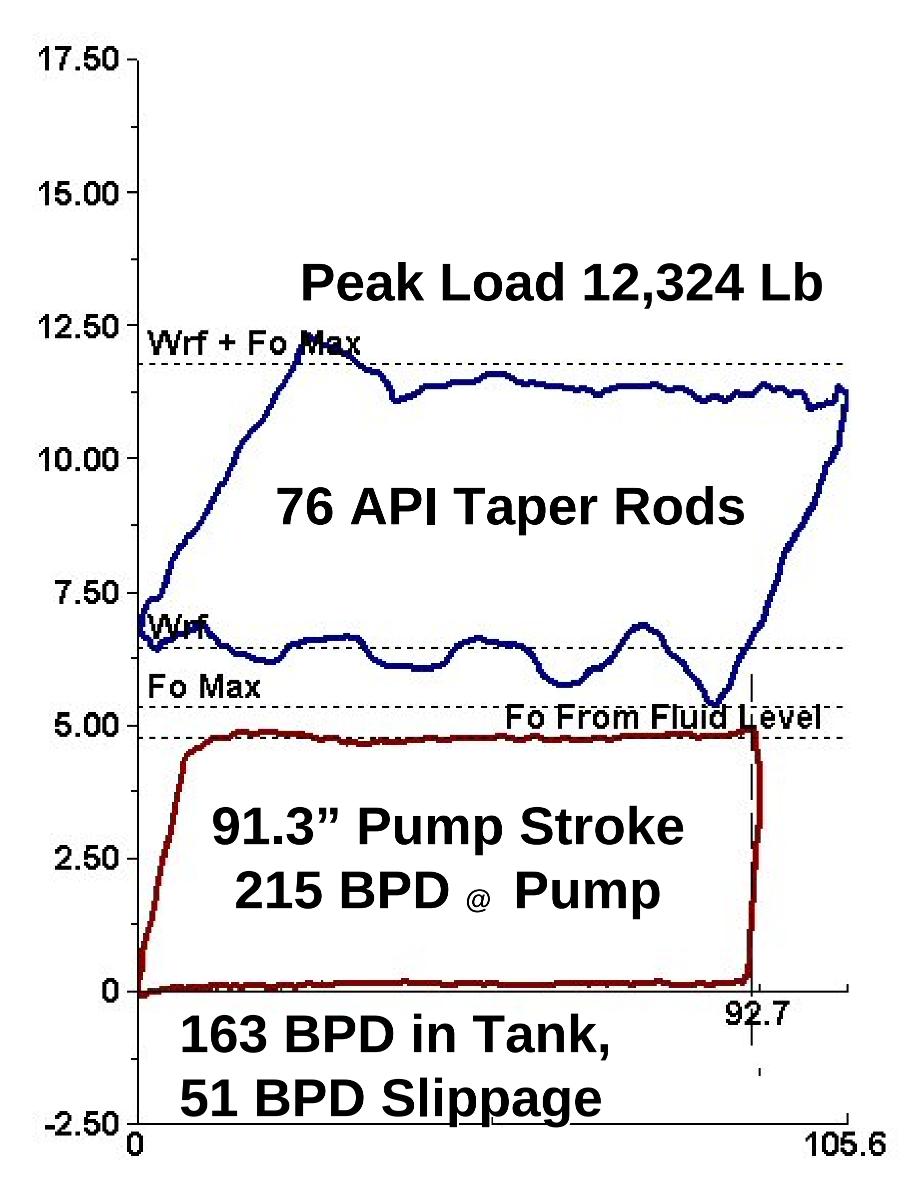
If You Use Recommended Clearances from 2007 Rule-of-Thumb Table

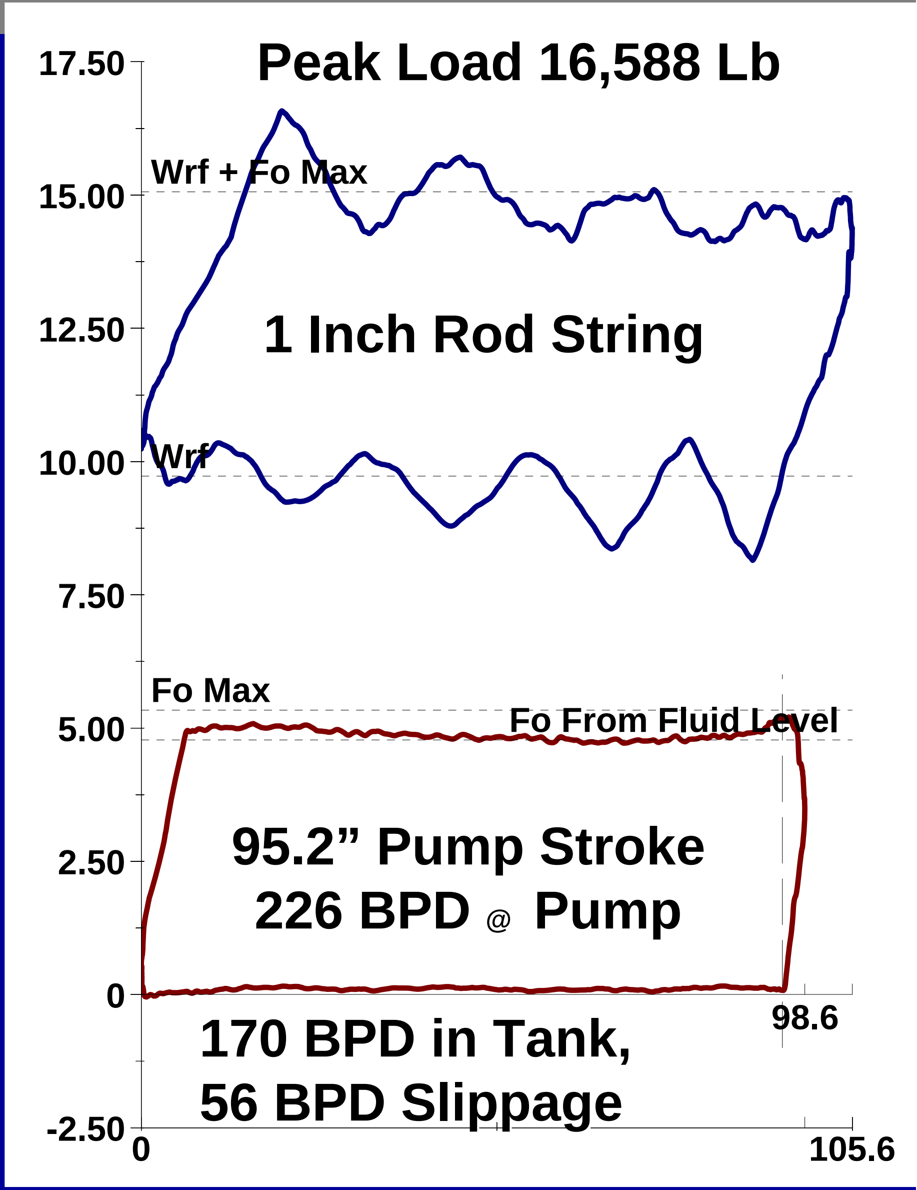
Plunger Size Inch	Total Clearance Inch	Slipage BPD	100" Stroke Pump Disp. BPD	Slippage %	144" Stroke Pump Disp. BPD	Slippage %
1.25	0.005	37.8	131	28.9	208	18.2
1.50	0.006	59.9	143	41.9	274	21.9
1.75	0.007	88.4	172	51.4	324	27.3
2.00	0.008	123.7	200	61.9	349	35.4
2.25	0.009	166.5	211	78.9	401	41.5

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

Dynamometer Cards – 5.01 SPM

2” Plunger, 0.009” Clearance, 12” Sheave, 31.5 HZ



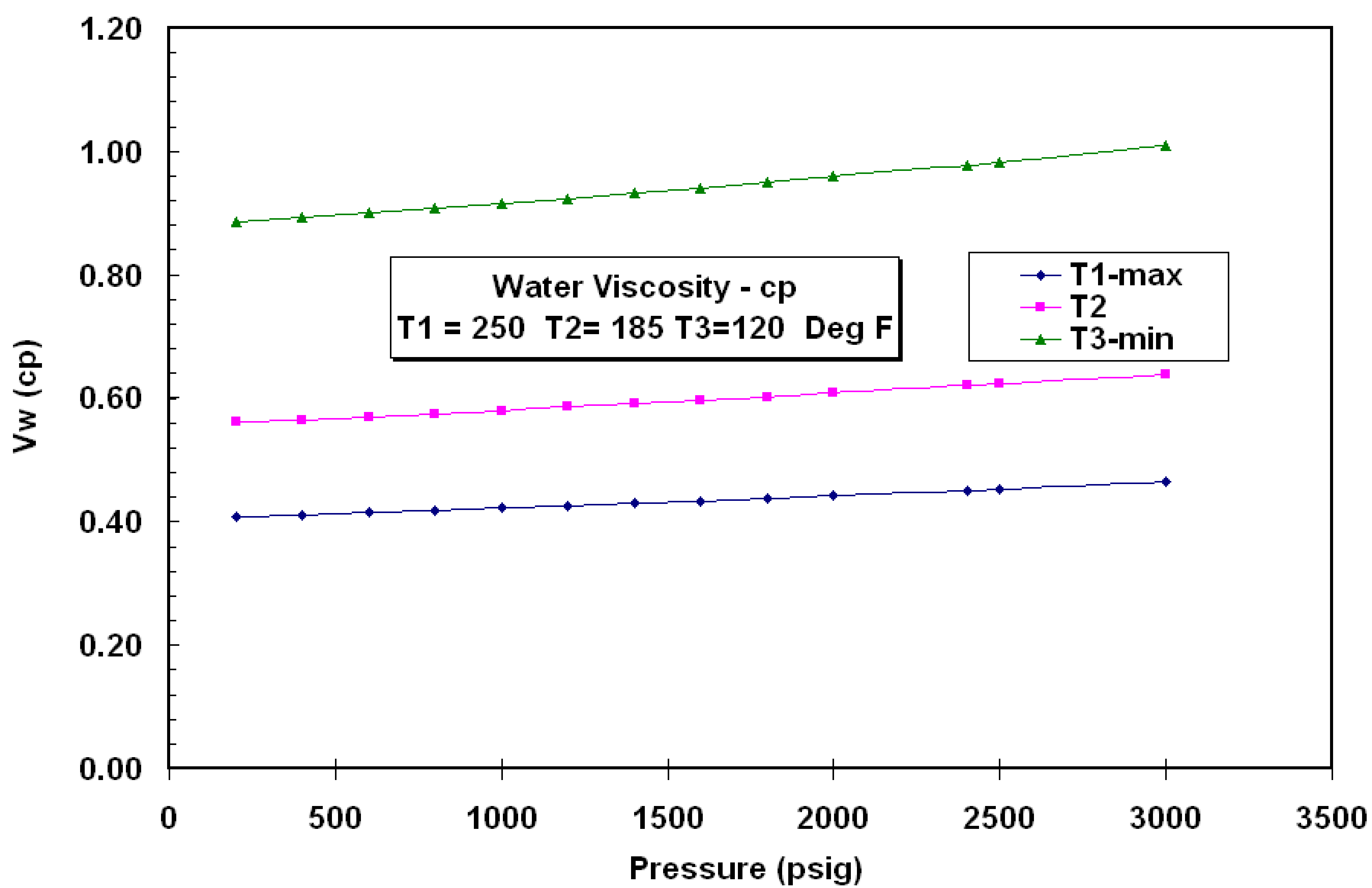


Test #	Date	API Rod String #	Stroke Length (in)	Pump Speed (spm)	Echometer Inferred Production (bpd)	Surface Production (bpd)	Echometer Slippage (bpd)	Pump Efficincy (%)
1-01	7/8/05	76 [1]	105.6	9.73	427.7	367.1	60.6	85.8
1-02	7/8/05	76 [1]	105.6	9.74	428.1	368.0	60.1	86.0
1-03	7/8/05	76 [1]	105.6	8.25	357.5	301.3	56.2	84.3
1-04	7/8/05	76 [1]	105.6	6.93	297.4	242.4	55.0	81.5
1-05	7/8/05	76 [1]	105.6	5.03	214.7	163.5	51.2	76.1
1-06	7/8/05	76 [1]	105.6	1.82	81.5	41.6	39.9	51.1
2-03	7/28/05	88	105.6	0.60	29.6	0.0	29.6	0.0
2-02	7/28/05	88	105.6	0.70	34.4	4.4	30.0	12.8
2-01	7/28/05	88	105.6	0.80	39.2	5.6	33.6	14.2
2-09	7/28/05	88	105.6	5.01	224.0	170.2	53.8	76.0
2-08	7/28/05	88	105.6	6.90	313.4	250.9	62.5	80.1
2-07	7/28/05	88	105.6	8.22	371.6	308.6	63.0	83.0
2-06	7/28/05	88	105.6	9.71	444.6	378.2	66.4	85.1
2-05	7/28/05	88	105.6	9.72	444.6	377.9	66.7	85.0
6-05	8/25/06	76 [5]	105.6	9.7	254.2	230.1	24.1	90.5
6-06	8/25/06	76 [5]	105.6	9.7	254.7	232.1	22.6	91.1
6-07	8/25/06	76 [5]	105.6	8.3	207.9	185.1	22.9	89.0
6-08	8/25/06	76 [5]	105.6	7.1	180.4	159.1	21.4	88.2
6-09	8/25/06	76 [5]	105.6	5.1	127.0	107.6	19.4	84.7
6-10	8/25/06	76 [5]	105.6	2.5	62.5	45.5	16.9	72.9

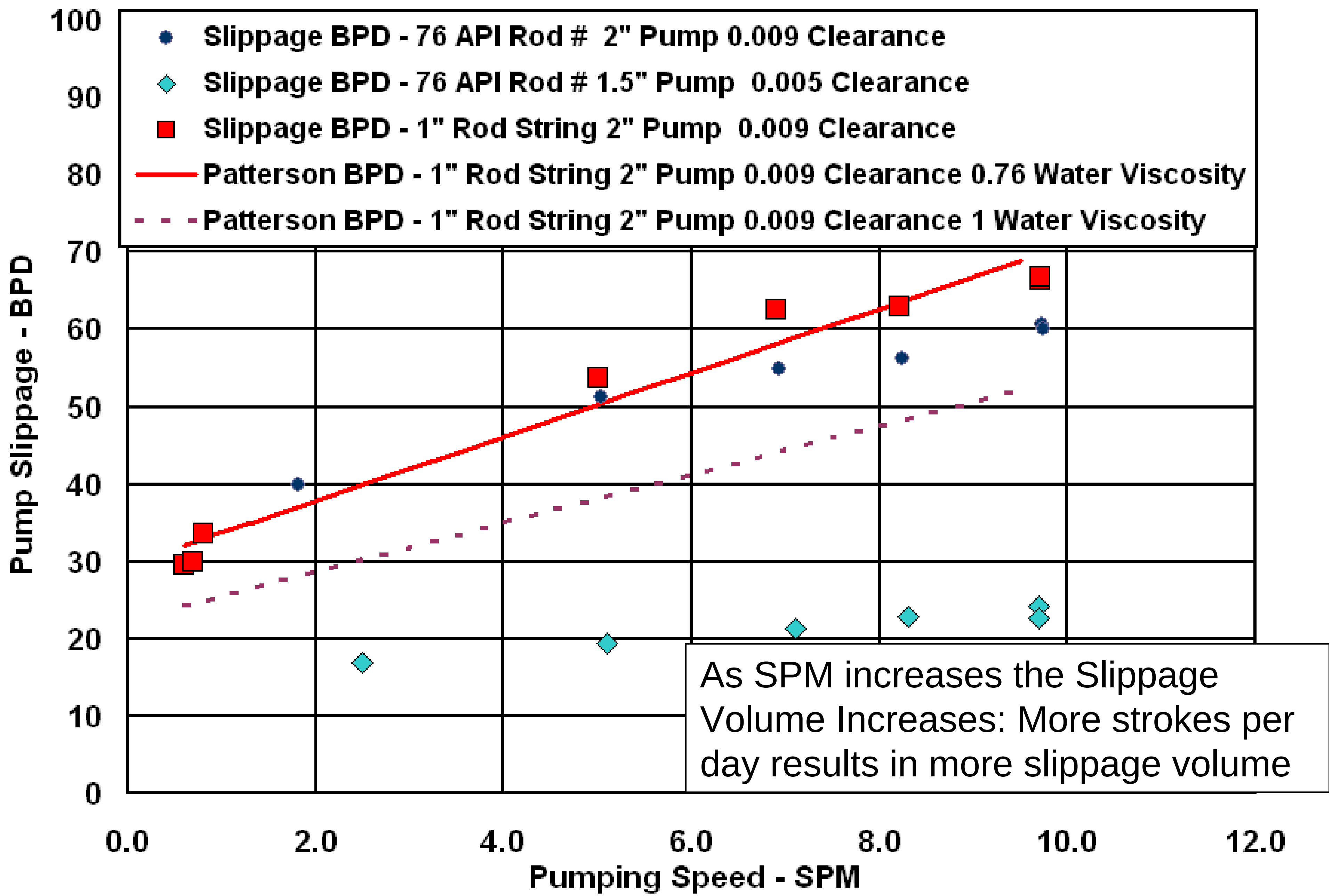
A 2.00 in pump with a 0.009 in clearance and 4 ft plunger was used for tests 1 thru 5

A 1.50 in pump with a 0.005 in clearance and 4 ft plunger was used for test 6

Water Viscosity - Cp

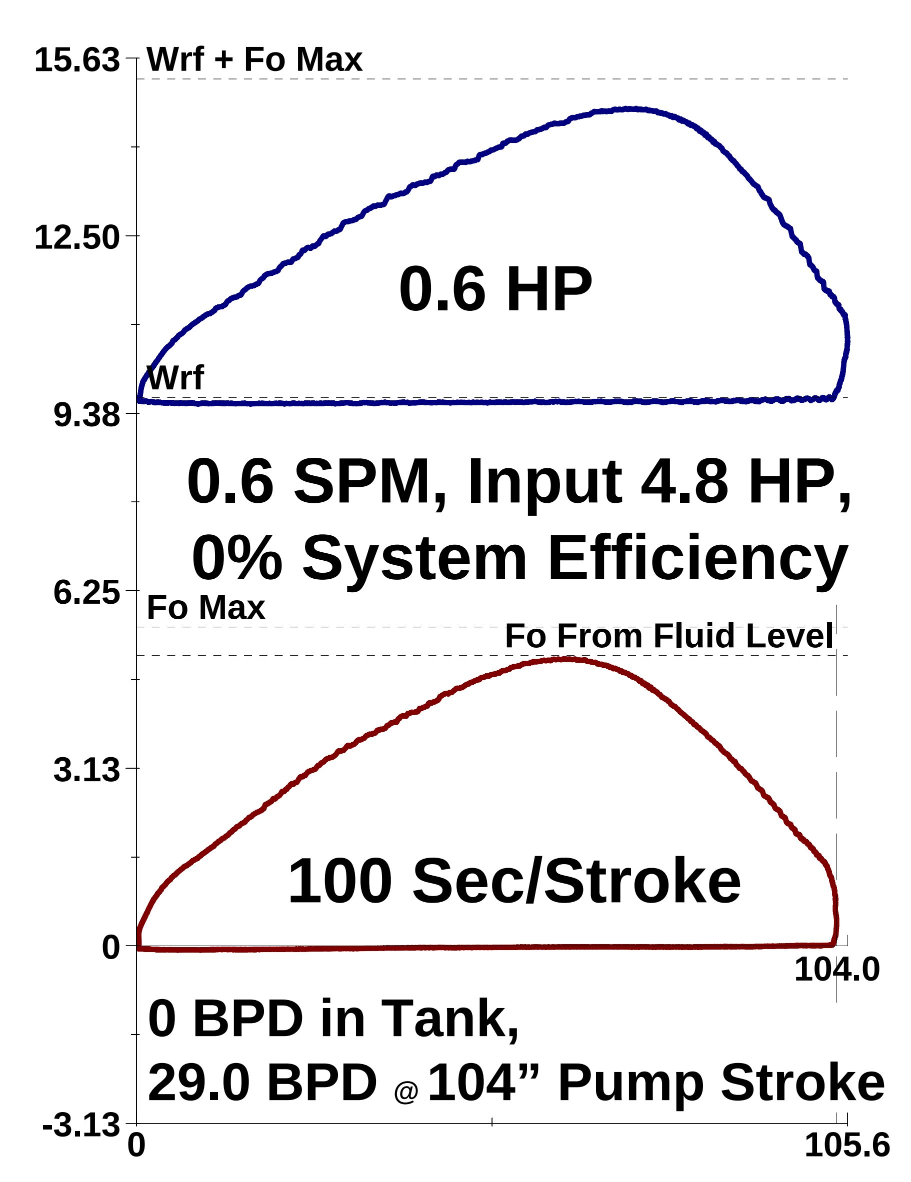


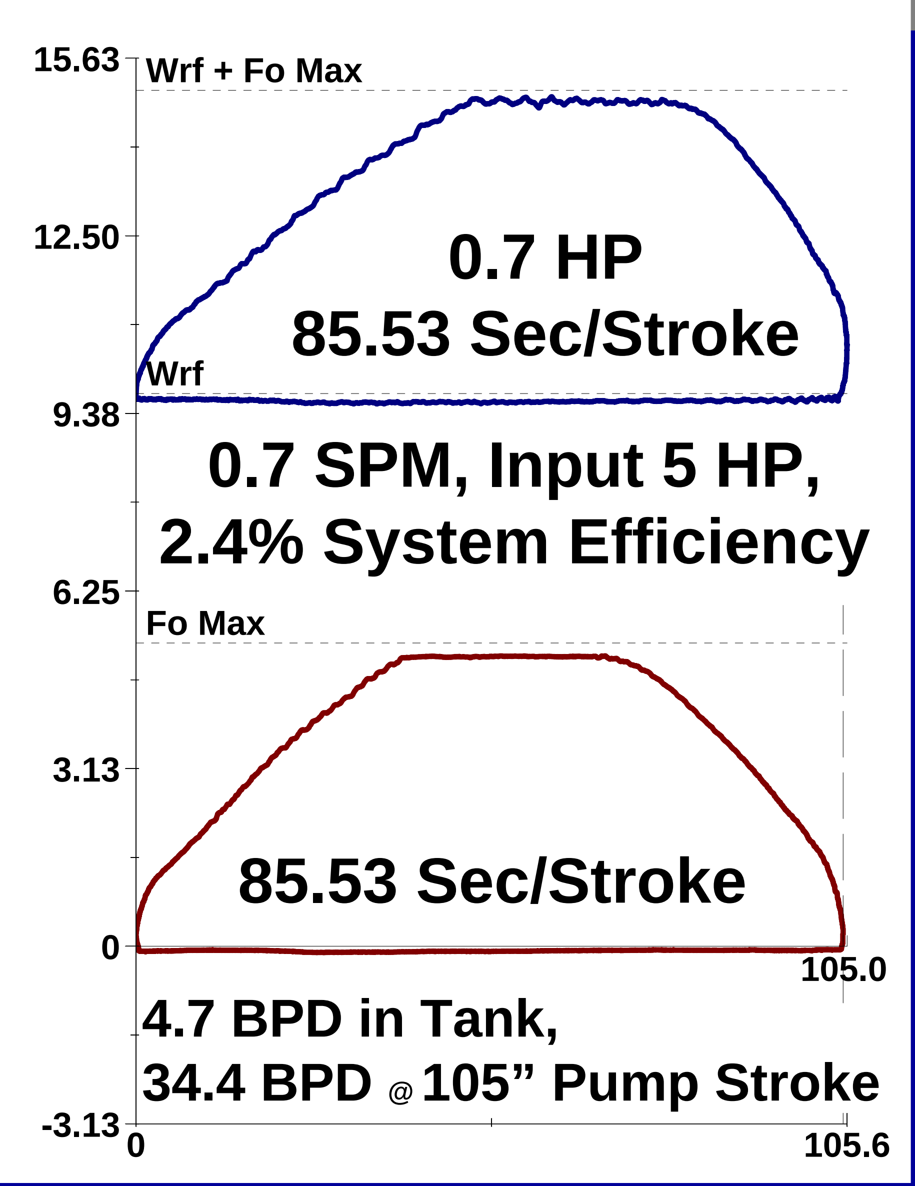
Viscosity Impact on Slippage Calculation



VSD Slows SPM Until Slippage=Displacement

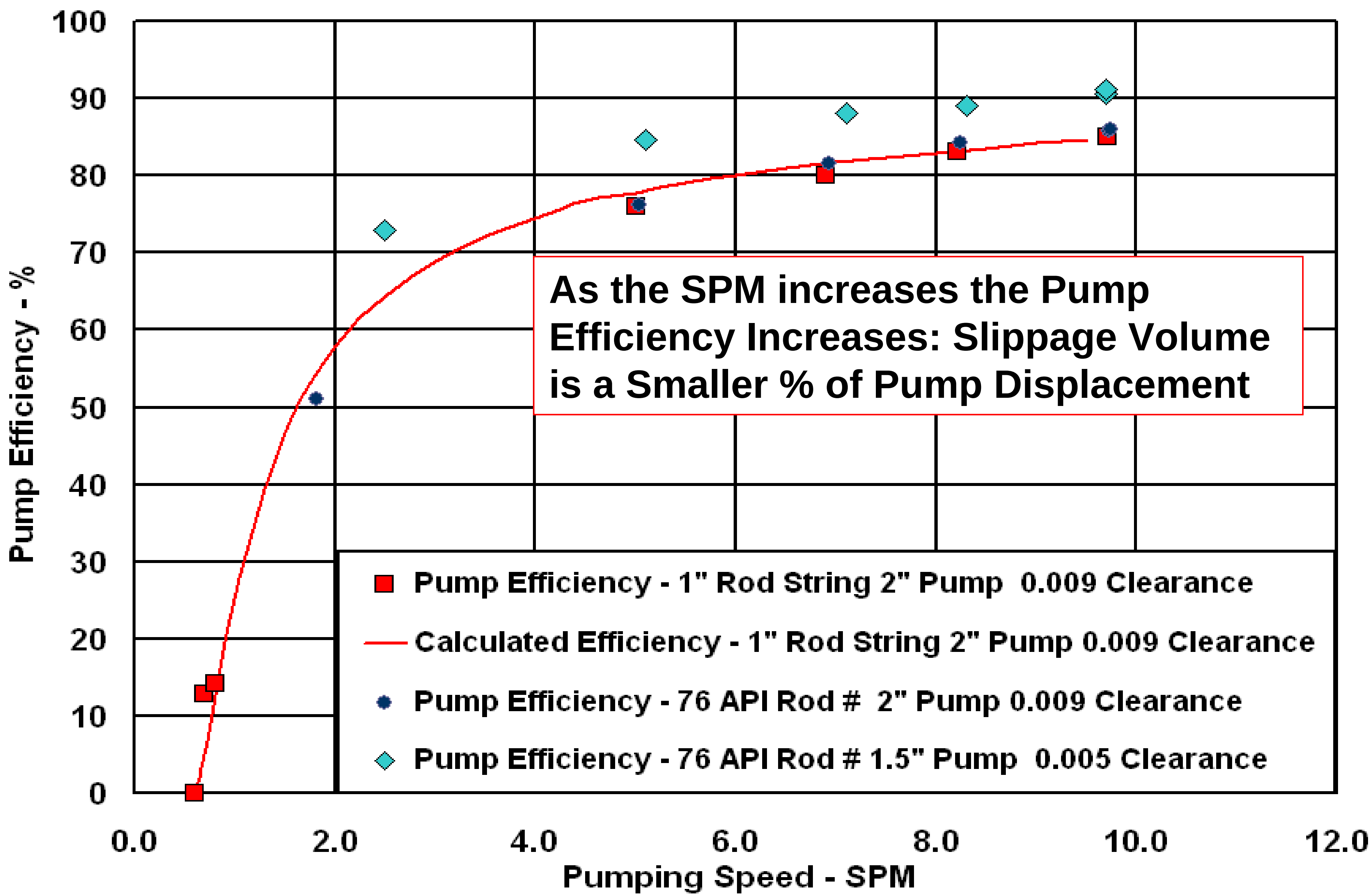
2” Plunger, 1” Rod String, 0.009” Clearance, 12” Sheave





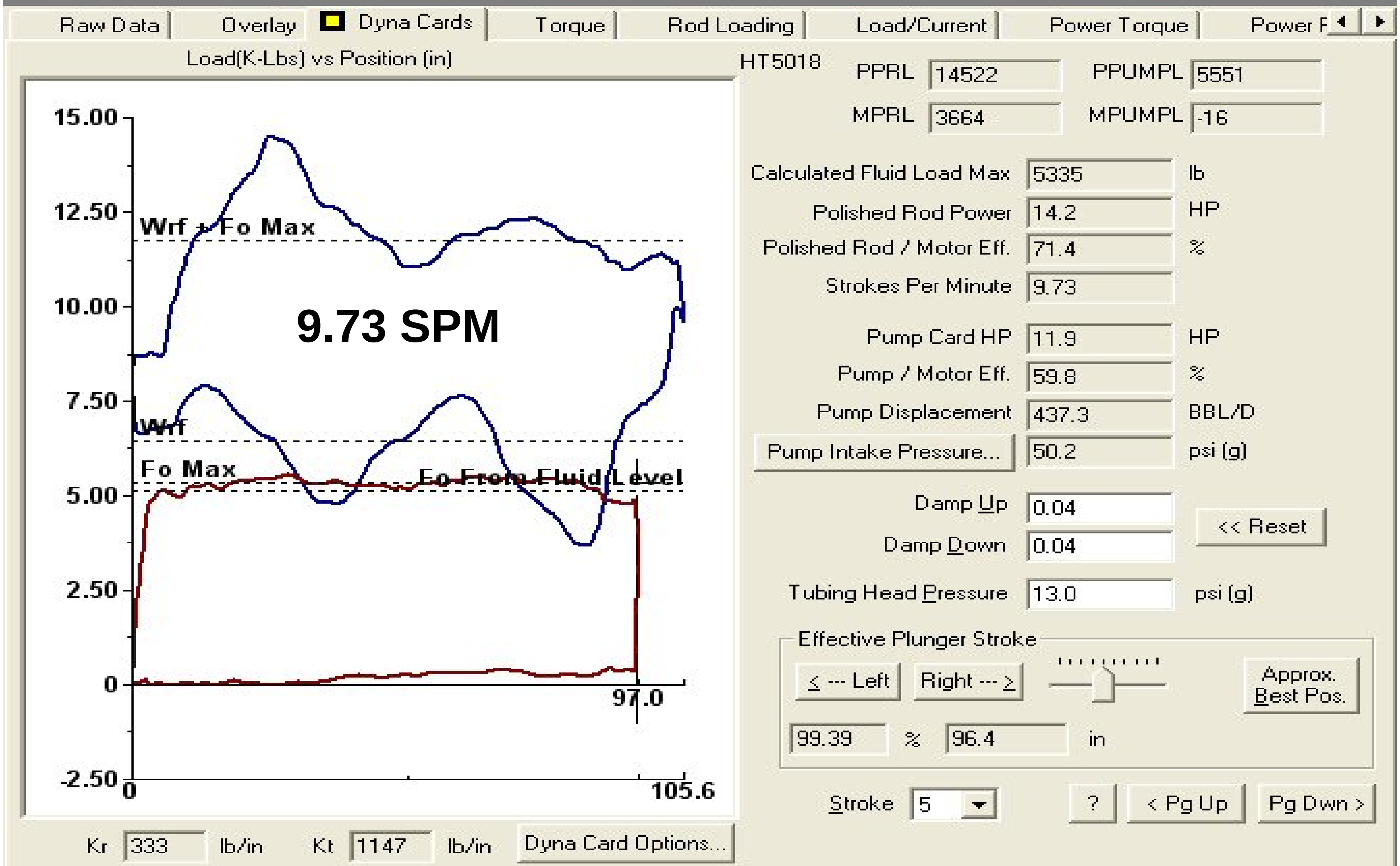
Pump Speed vs Pump Efficiency

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



Dynamometer Data @ 4 SPMs

2” Plunger, 76 Rod String, 0.009” Clearance



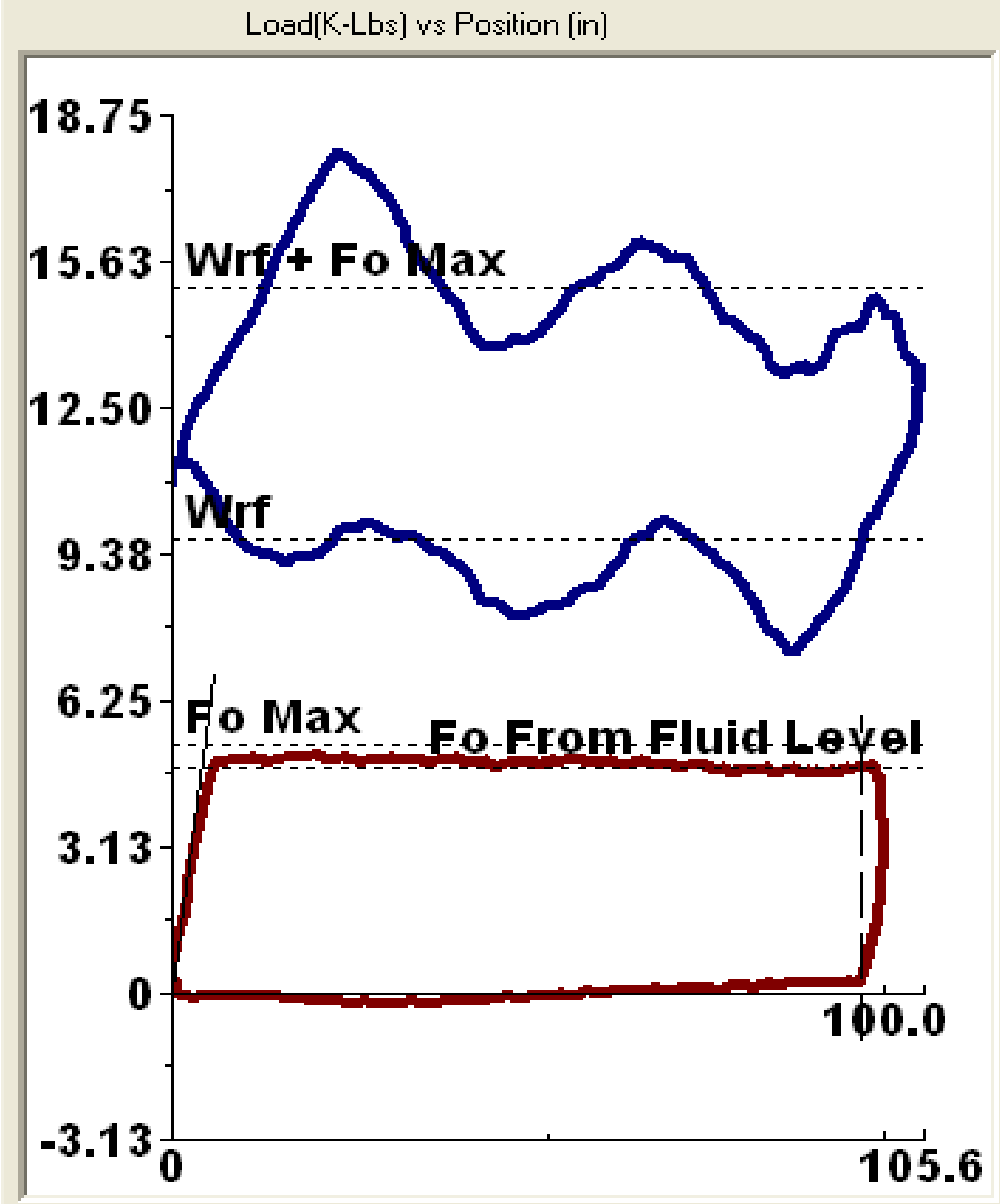
Summary of Test

Card Selected	SPM	Effective Plunger Travel In	Effective Plunger Travel BPD	Water Production Rate (BPD)	Patterson Slippage BPD	Pump Efficiency
2 - Sheave:6 Card #15	5.08	93.9	222.5	181.5	41.0	81.6%
1 - Sheave 8.5 Card #5	6.99	94.3	307.6	260.0	47.6	84.5%
1 - Sheave 10 Card #5	8.22	94.2	361.1	309.3	51.8	85.7%
2 - Sheave 12 Card #5	9.73	96.4	437.5	380.5	57.0	87.0%

Card Selected	SPM	Motor Input HP	Polished Rod HP	Power Cost $/BBL Lifted	System Effic %	Pump Effic %
2 - Sheave:6 Card #15	5.08	11.3	6.6	0.143	44.7	81.6%
1 - Sheave 8.5 Card #5	6.99	14.9	9.5	0.132	50.2	84.5%
1 - Sheave 10 Card #5	8.22	17.4	11.4	0.130	51.6	85.7%
2 - Sheave 12 Card #5	9.73	21.0	14.3	0.127	52.3	87.0%

Example Slippage Calculation

Use Well Parameters to Calculate Table of Slippage and Efficiency Values



1) Range of SPM from 6.22 to 10.72 in 0.5 SPM steps
2) Use Patterson Slippage equation to calculate slippage BPD
3) Use predictive program QRod to calculate pump displacement, BPD, assuming 100% liquid fillage
4) Calculated Slippage % equal to the ratio of Slippage divided by Pump Displacement
5) Calculated Pump Efficiency % equal to the ratio of Production divided by Pump Displacement

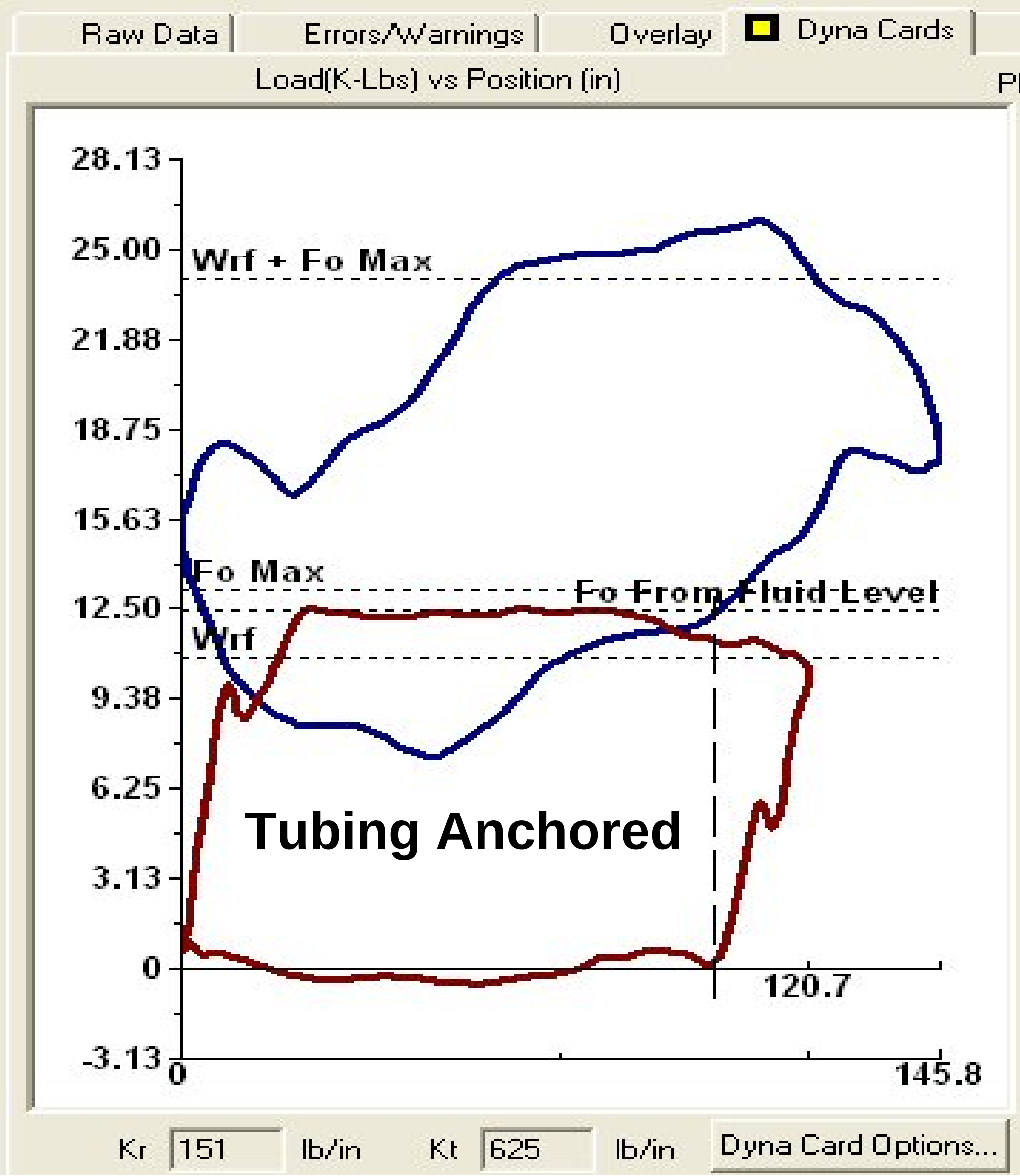
Example Slippage for 2 Plunger Sizes

1. Slippage % less (pump leaks less) as SPM is increased
2. Increasing the pumping speed of a leaky worn pump will increase pump efficiency and increase liquid produced.
3. Increasing the pumping speed from 6.22 SPM by 4.5 SPM to 10.72 SPM reduces pump slippage by only 5-6%
4. Higher pumping speed may increase failures, so temporary oil production make not pay off any damage if failure occurs

Anchored Tubing - 105.6 Inch Stroke - 1 Inch Rods - Clearance - 0.009								
	Plunger Diameter - Inches							
	1.50	1.50	1.50	1.50	2.00	2.00	2.00	2.00
SPM	Calc Pump BPD	Slippage BPD	Slippage %	Pump Eff %	Calc Pump BPD	Slippage BPD	Slippage %	Pump Eff %
6.22	165.0	42.0	25.4	74.6	283.0	56.0	19.8	80.2
6.72	180.0	43.5	24.2	75.8	309.0	58.0	18.8	81.2
7.22	195.0	45.1	23.1	76.9	331.0	60.1	18.2	81.8
7.72	208.0	46.7	22.4	77.6	352.0	62.2	17.7	82.3
8.22	220.0	48.2	21.9	78.1	378.0	64.3	17.0	83.0
8.72	235.0	49.8	21.2	78.8	407.0	66.4	16.3	83.7
9.22	252.0	51.4	20.4	79.6	436.0	68.5	15.7	84.3
9.72	269.0	53.0	19.7	80.3	462.0	70.6	15.3	84.7
10.22	283.0	54.5	19.3	80.7	483.0	72.7	15.1	84.9
10.72	295.0	56.1	19.0	81.0	495.0	74.8	15.1	84.9

Actual Field Example with 0.009 Pump

Why only 402 barrels per day is being produced to the tank, when the effective downhole pump displacement is 576 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 160 BPD***
4. 576 BPD Full Pump dynamometer card (No correction for slippage or gas in solution).
5. Tested Rates are 106 BOPD & 296 BWPD
6. Production is 174 BPD less than the 576 BPD pump displacement.
7. (106+296)/576 = ***70% Pump Eff.***
8. 26 MscfD gas up tubing (245 GOR), at 3155 psi discharge pressure, then oil swelled 4.4% due to gas in solution. 4.4% of 106 = 5 BPD.
9. Patterson Equation appears to calculate slippage fairly accurately.

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

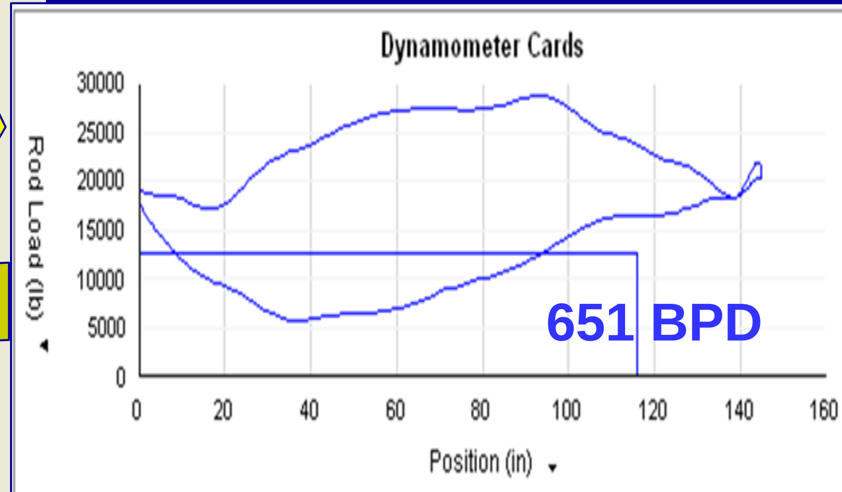
Calculate

Calculate from SPM or Target Rate

Stroke Rate (SPM) << 9.52 >> SPM

Target Rate << 489 >>

Calculate

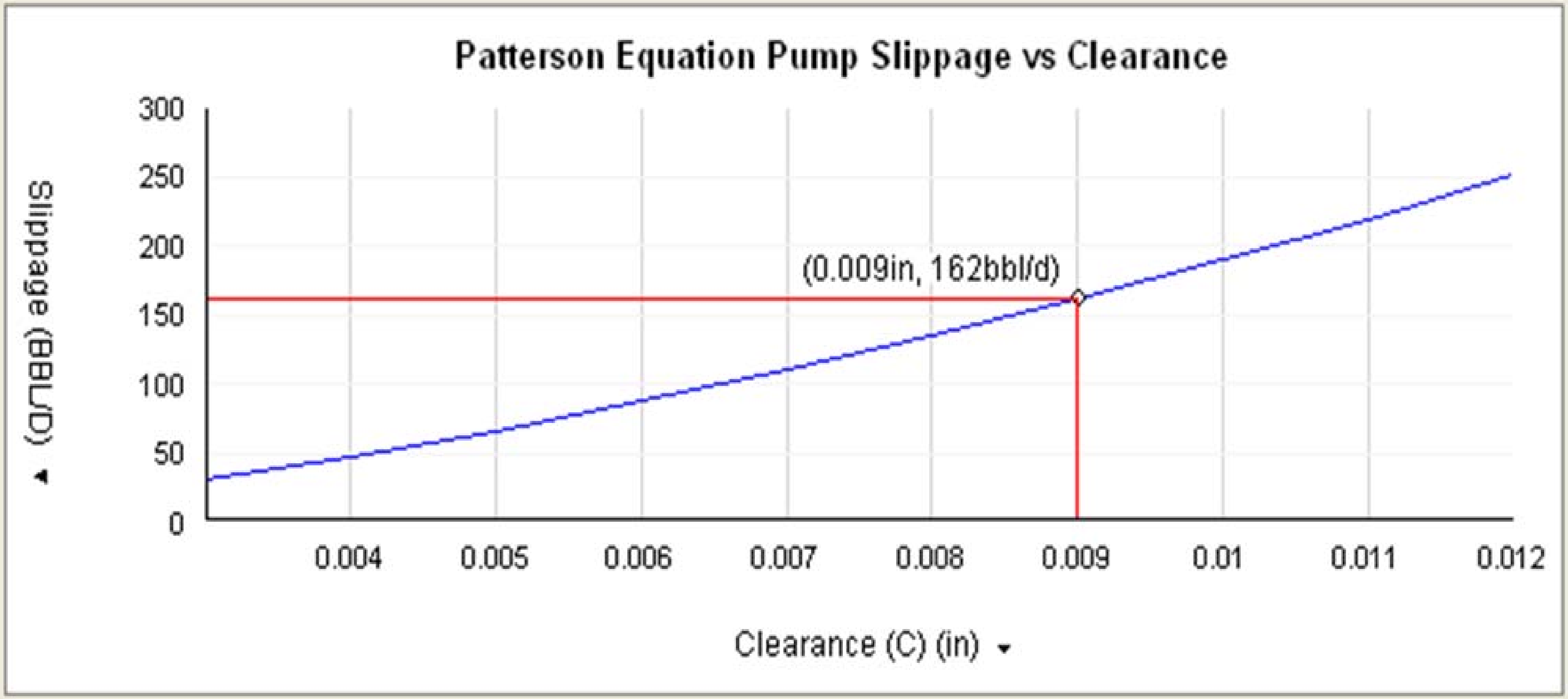


Pump Volumetric Efficiency 75.12 %

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

Slippage Plot vs Clearance

Slippage	162	BBL/D	Pressure Differential (P)	3,197.55	psi
Pump Volumetric Efficiency	75.12	%	Tubing Fluid Gradient	0.4330	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 >>

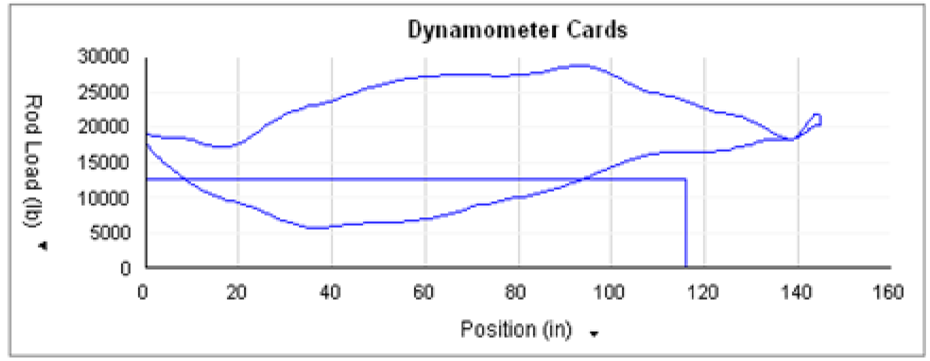
Calculate

Default Settings

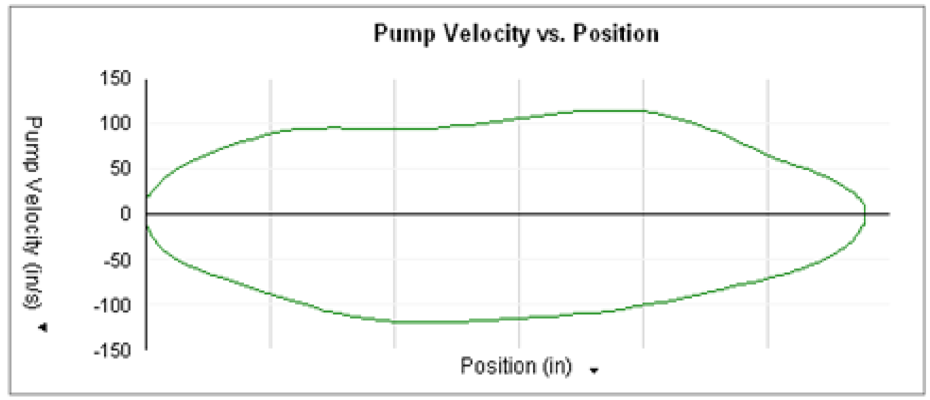
Total Sinker Bar Weight	816.0	lb	Damping Factor	0.10	
Fluid Specific Gravity	1.00	Sp.Gr.H2O	Surface Unit Efficiency	95.00	%
Tubing Pressure	250.00	psi	Pump Volumetric Efficiency	75.12	%
Casing Pressure	45.00	psi			

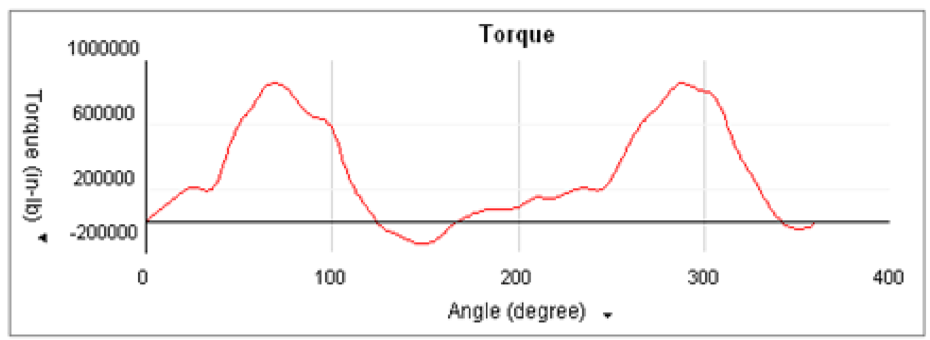
You may enter Pump Intake Pressure directly, or calculate it from Reservoir Pressure and Productivity Index.

Pump Intake Pressure	151.00	psi	Reservoir Pressure	1,000.00	psi
			Productivity Index	2.000	STB/D/psi



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

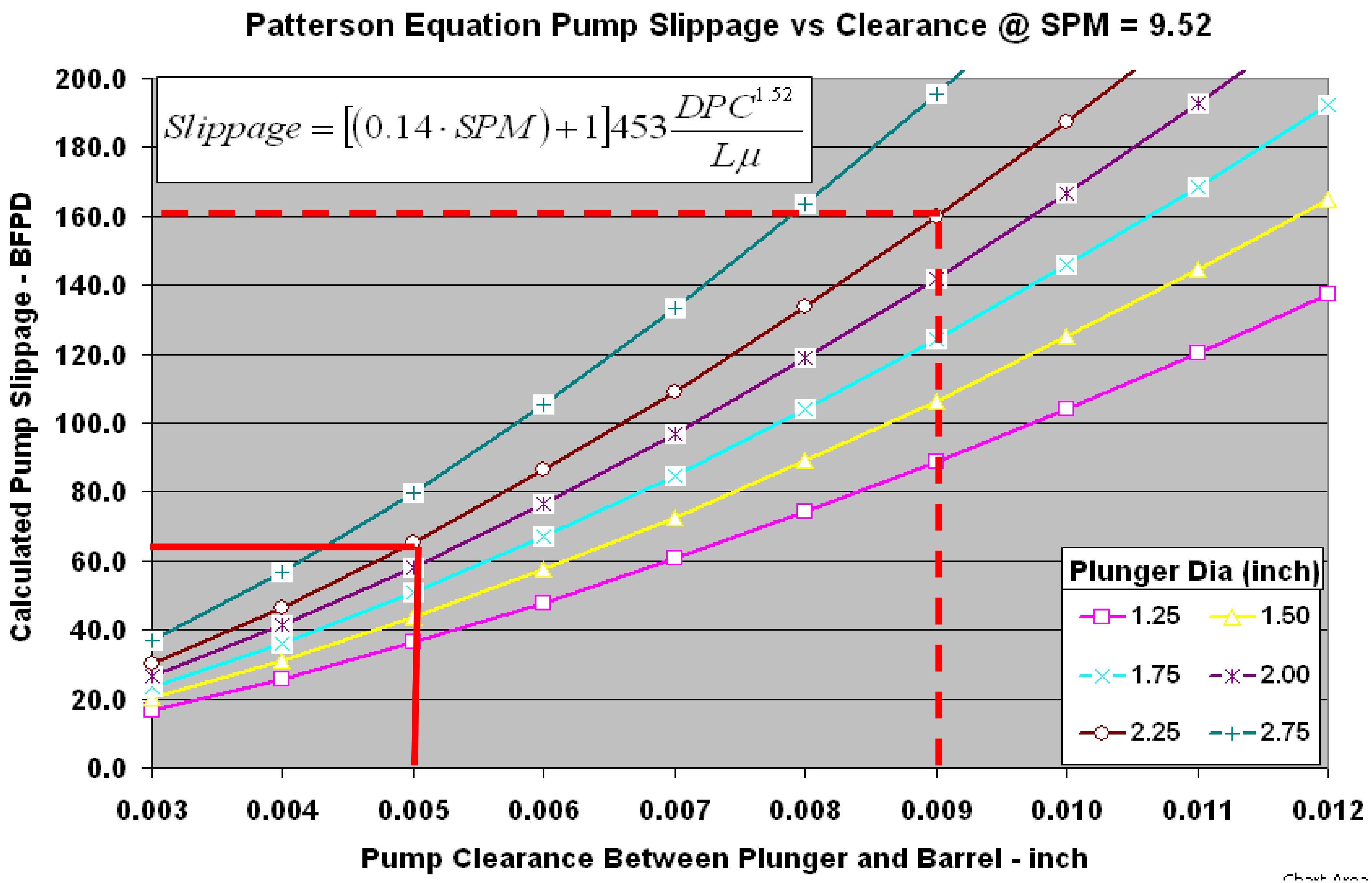




Peak GearBox Torque	851 Kin-lb
Counter Balance Moment	1,525 Kin-lb
Counter Balance Effect	22,157.3 lb

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

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



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

Conclusions

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.

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