Pump Slippage's Impact on System Efficiency

Data Acquisition Devices

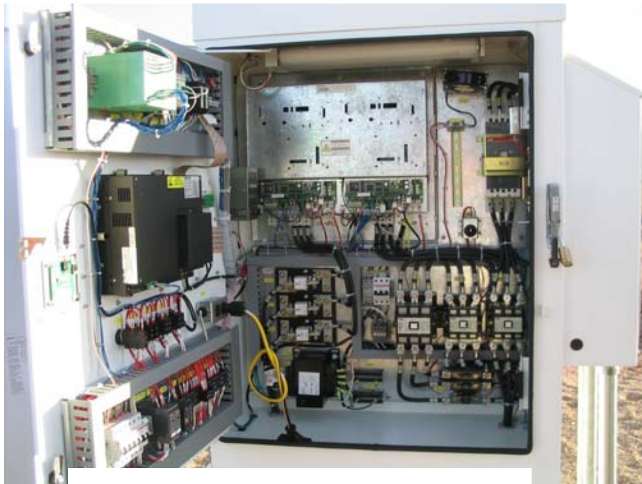
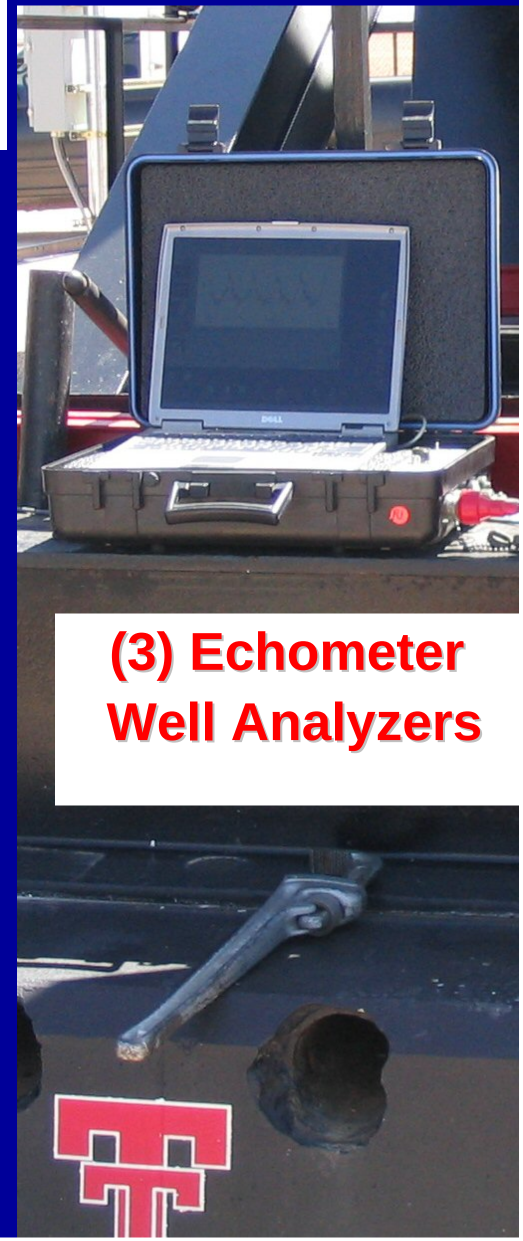


ABB VSD Controller

Wood Group Smart Guard™ RTU package

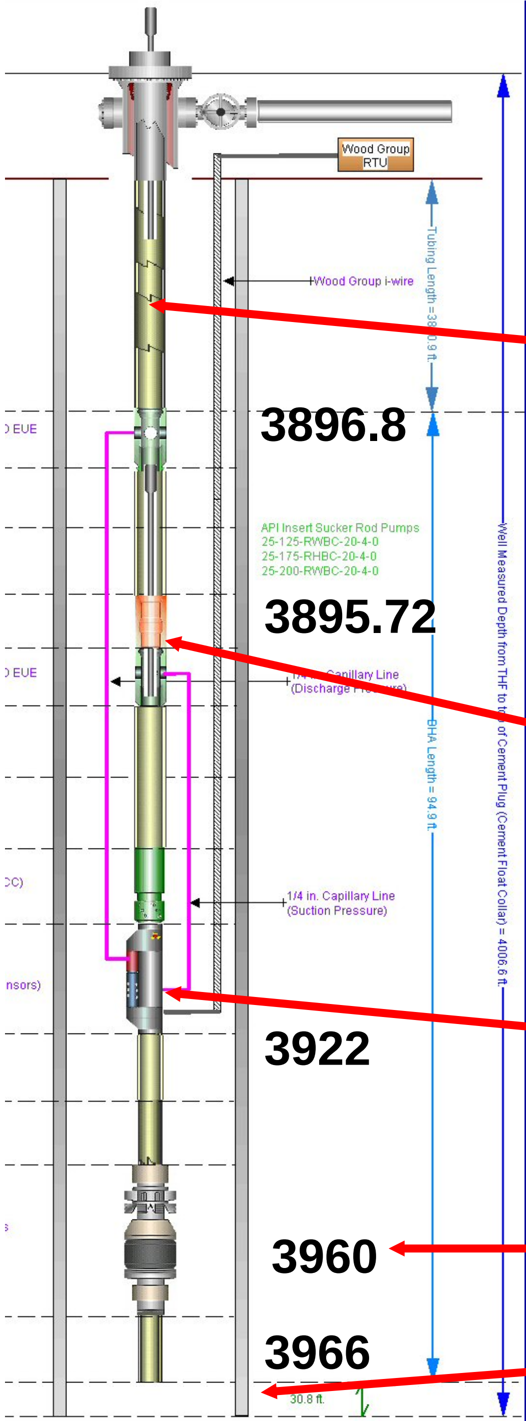


(3) Echometer Well Analyzers

MicroMotion Mass Flow Meter F-100

Lufkin SAM Controller ION System Power Measurement System

Test Well Wellbore



2-7/8 in., 6.5 lb/ft, J-55, API 8RD EUE

Norris 76 OR 1" Rod String

Harbison-Fischer - 2.00" pump

0.009" clearance (25-200-RWBC-20-4-0)

Wood Group Instrument (1 per 6 sec)

Pump Intake & Discharge Pressure

Temperature and Vibration

Baker Oil Tool Tubing Anchor-Catcher

9-5/8 in., 43.5 lb/ft, N-80, ID = 8.755"

Pump Diametrical Clearance Impact System Efficiency

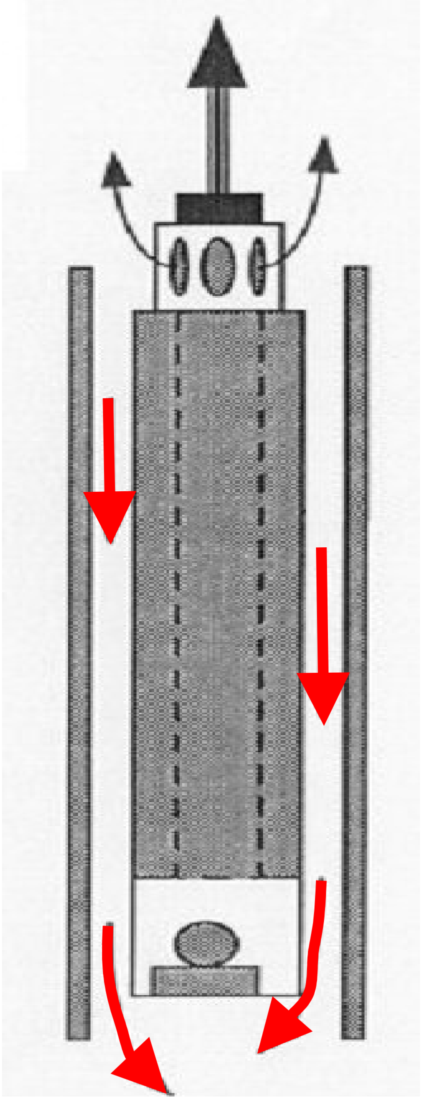
1. New Patterson Slippage Equation predicts slippage vs. pumping speed, SPM, Pump diameters and Clearances (other parameters)
2. Patterson Equation modified the ARCO-HF equation to include the effect of SPM on slippage.
3. Data shows increase in power cost per barrel due to slippage.
4. Pump efficiency dramatically decreases at slow pumping speed when pump clearances are large.
5. Increased Pump Clearance Reduce the System Efficiency (Significantly at slower pumping speeds)
6. More power must be input to the sucker rod pumping system to re-pump the portion of the pump's displacement lost to slippage.
7. Some Slippage Required for Proper pump lubrication.
8. 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

BPD Tank = BPD Pump - Slippage



ARCO-HF Slippage Equation

$$BPD = 870 \times \frac{DPC^{1.52}}{L\mu}$$

Inputs to Pump Slippage Calculations

D=Plunger Diameter (inches)	2
*P=Pressure Differiential	1547
C=Clearance (inches)	0.009
u=Fluid Viscosity (centipoise)	1
Plunger length (inches)	48

***Calculating Differential Pressure**

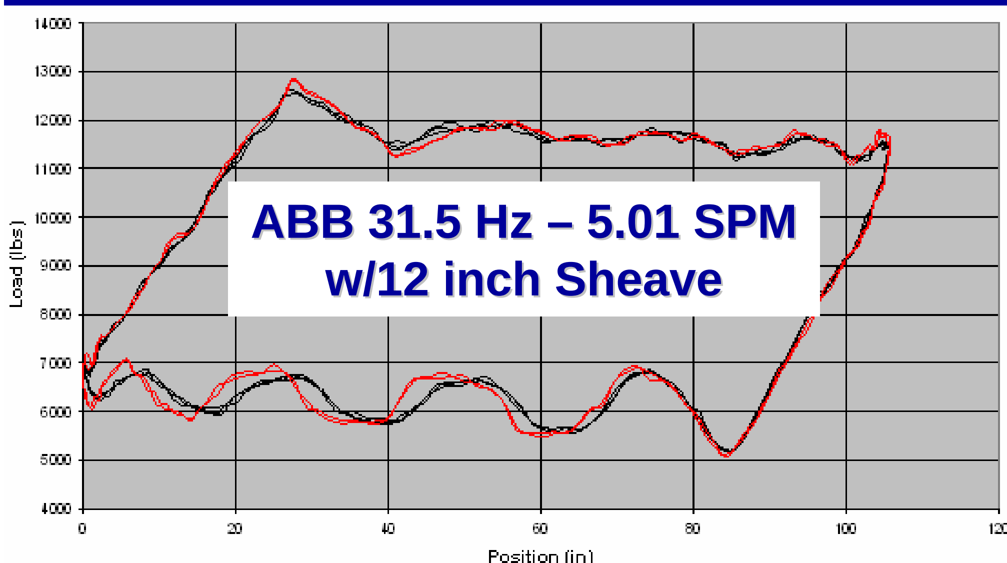
Pump Depth	3896
Fluid Level Above Pump	324
Water Gravity	1

Slippage in BPD	43.56

ARCO-HF Slippage Equation Does Not Include Effects of:

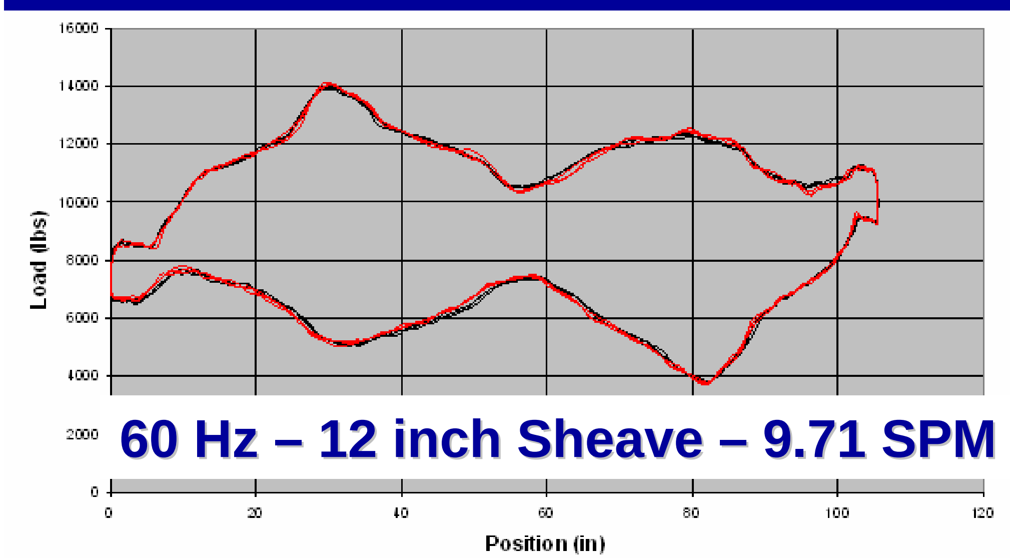
1) Rod Design
2) Speed (SPM)
3) Plunger Velocity

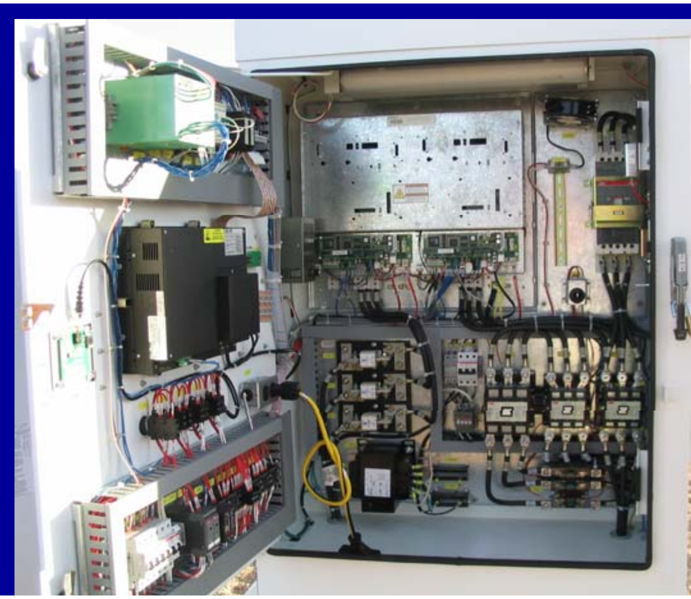
How to Change SPM?



Used Gantry Crane to Lift Belt Guard

Quick Sheave Change ~ 2 hours



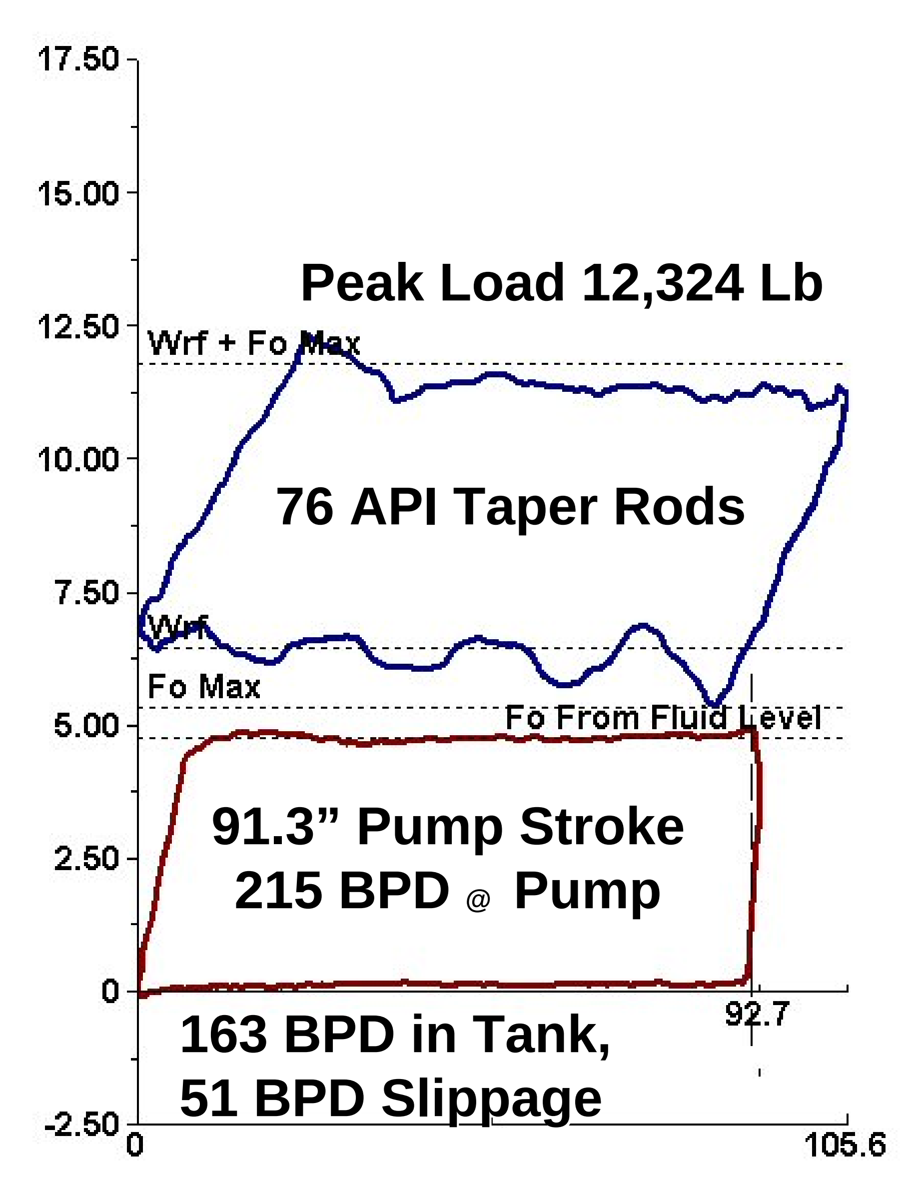


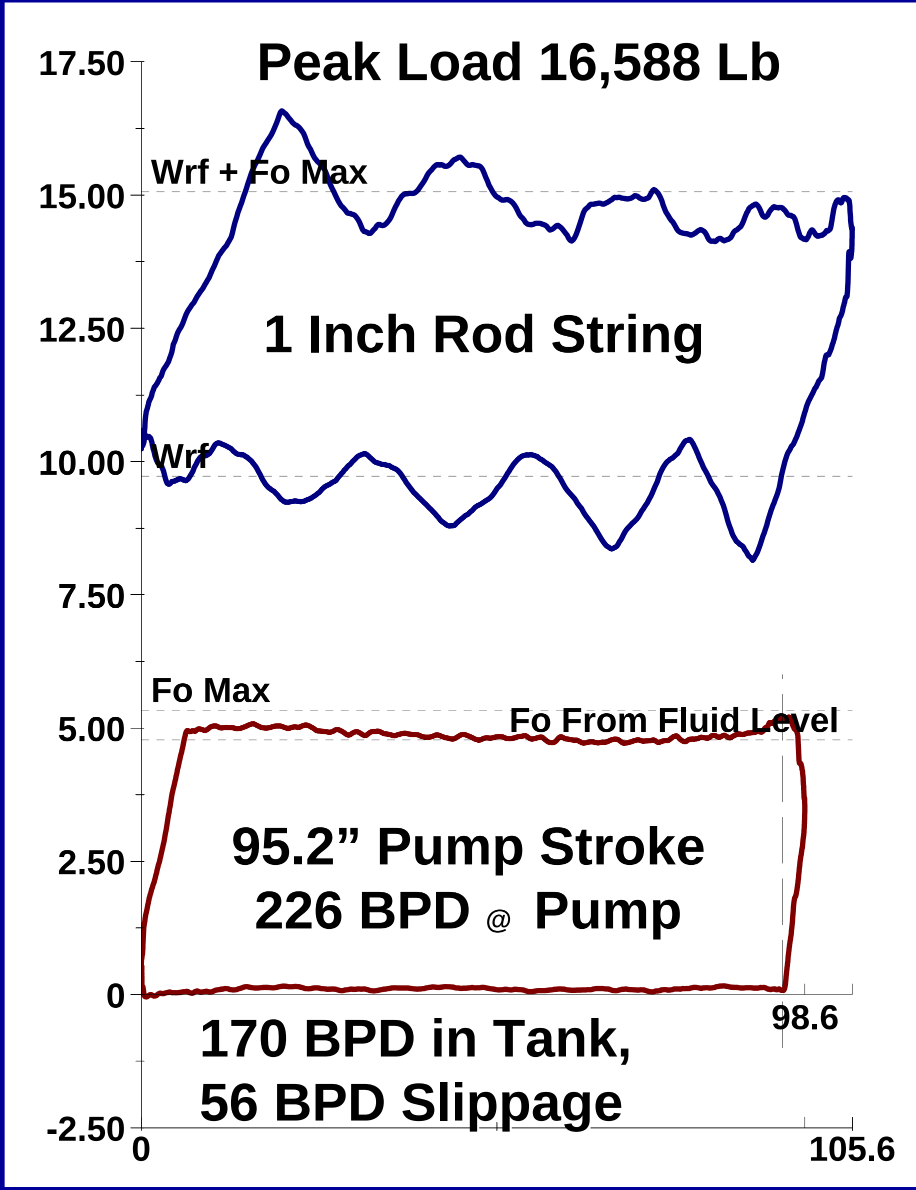
Used ABB VSD to Change SPM

No Sheave Change ~ few Seconds

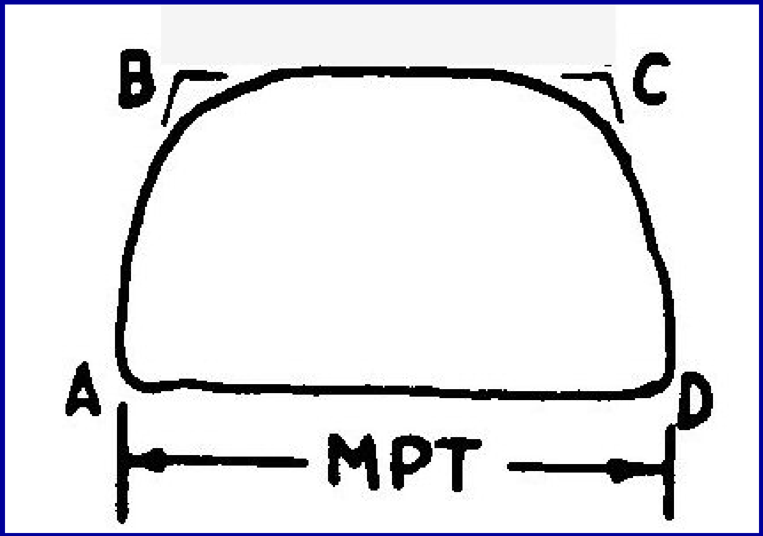
Dynamometer Cards – 5.01 SPM

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

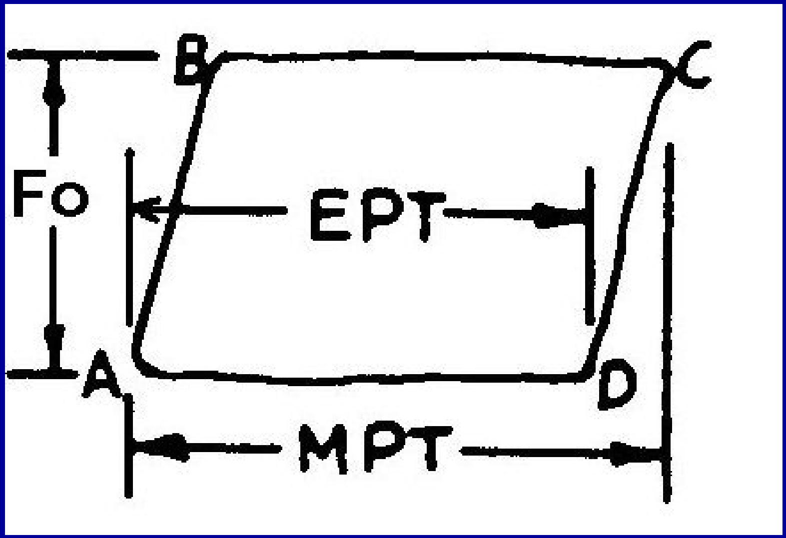




Leaky TV



Unanchored



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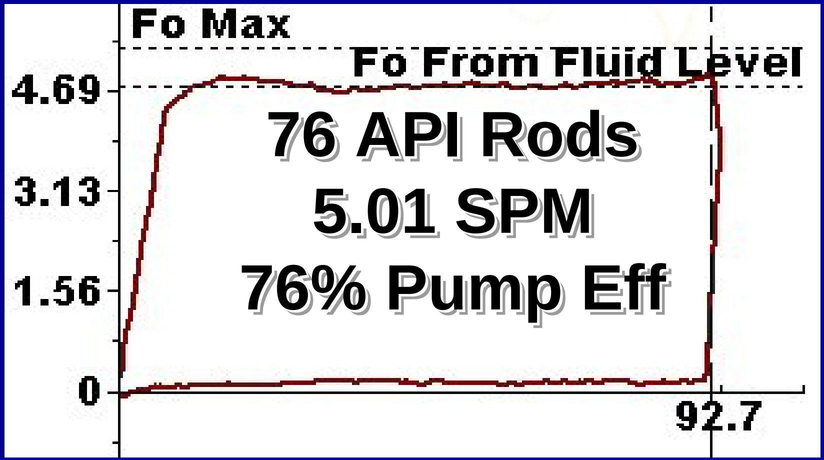
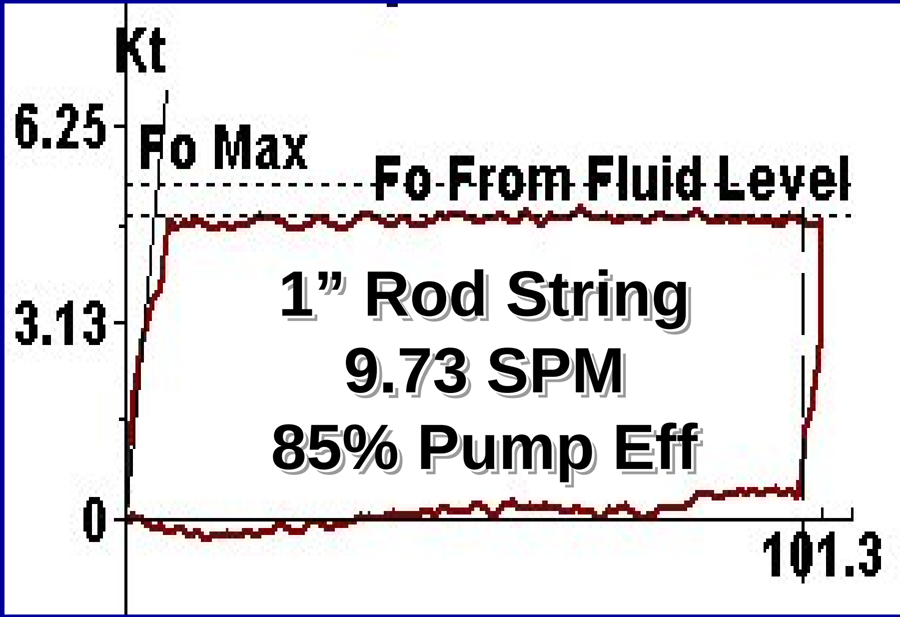
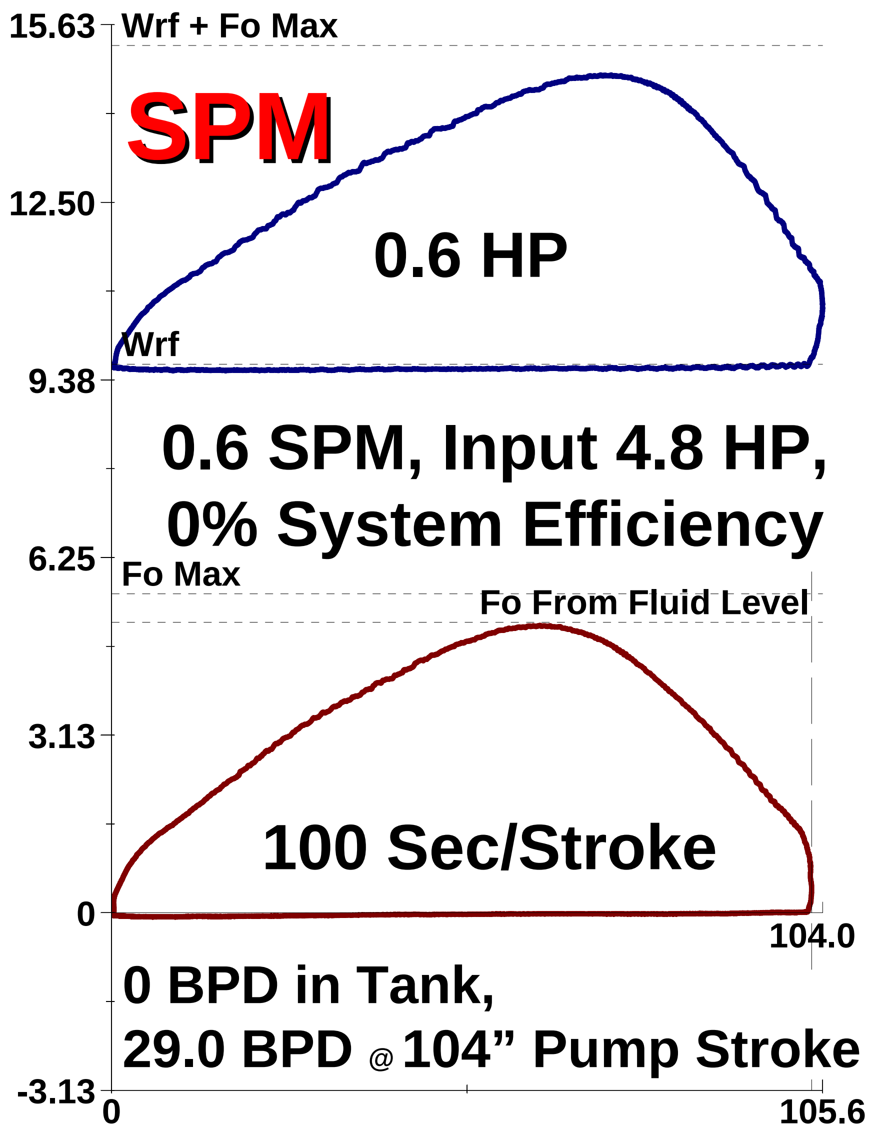
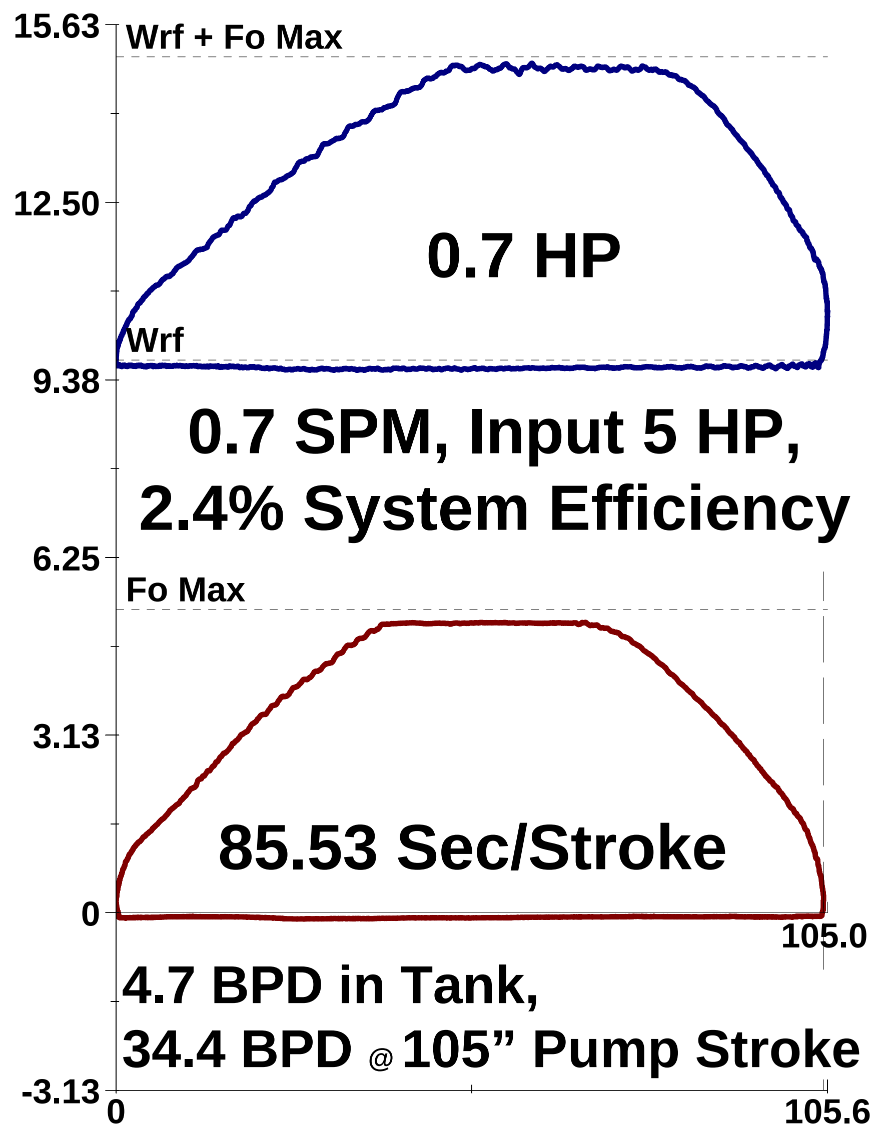


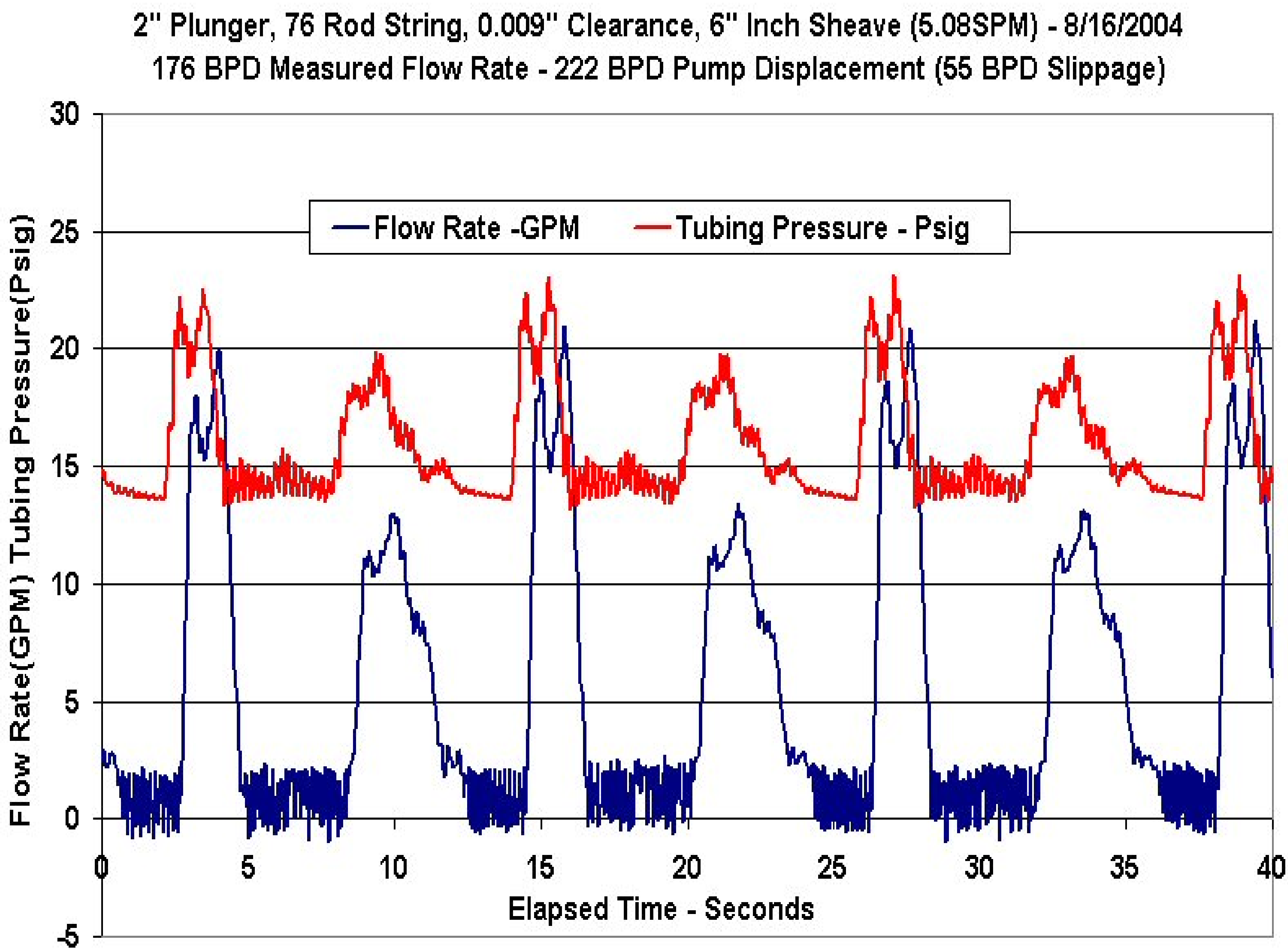


Used ABB Variable Speed Controller or Sheaves

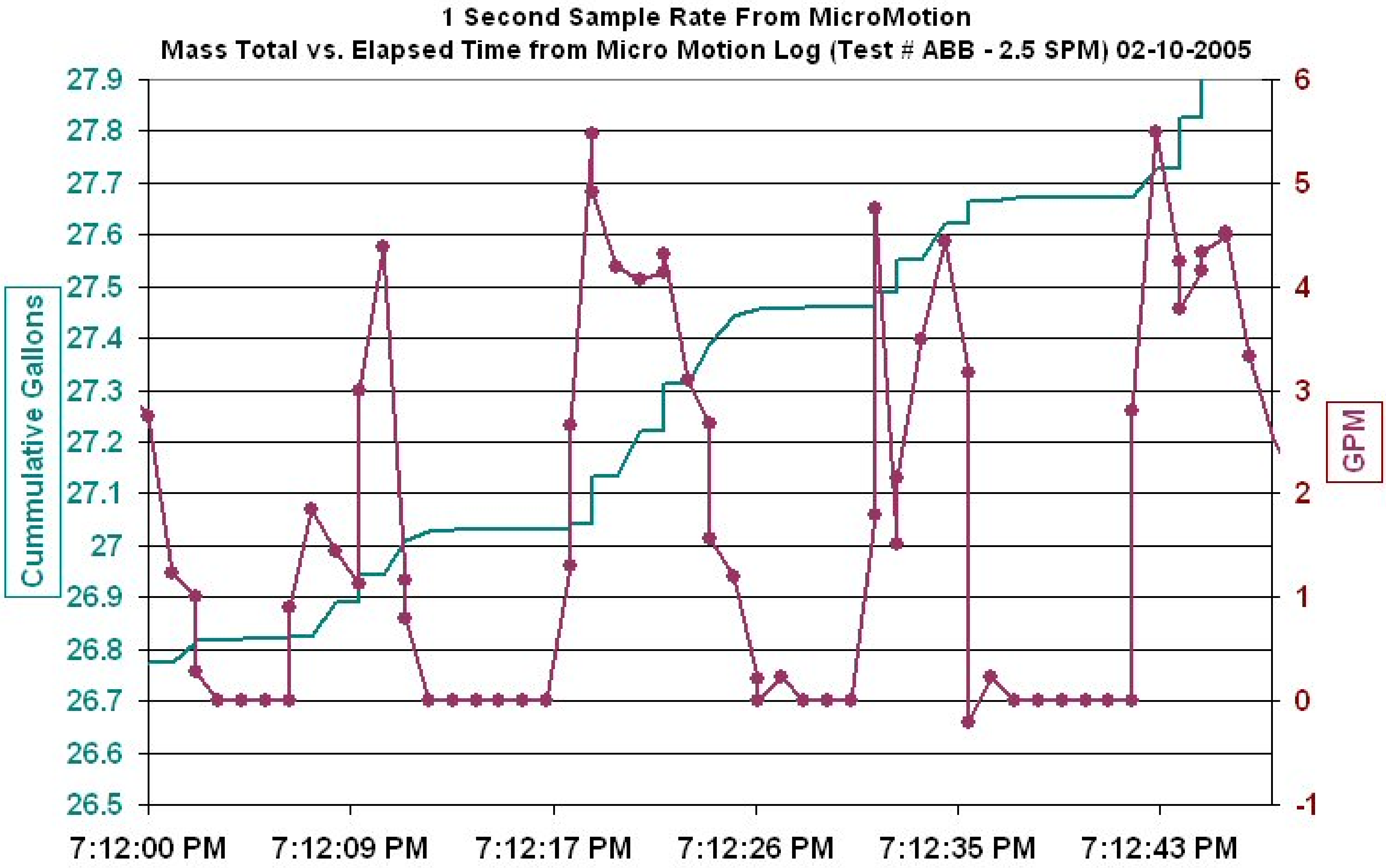
2” Plunger, 1” Rod String, 0.009” Clearance, 12” Sheave





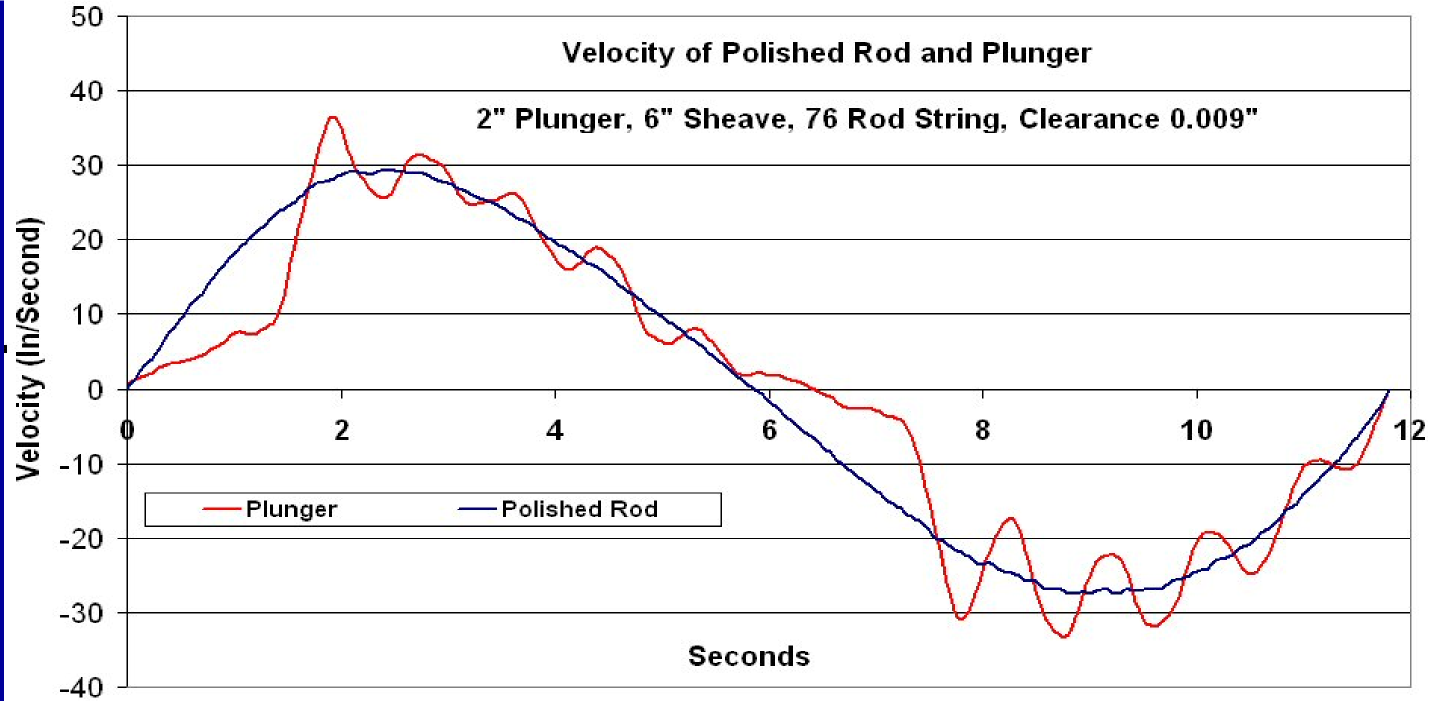

2" Plunger, 76 Rod String, 0.009" Clearance, 6" Inch Sheave (5.08SPM) - 8/16/2004
176 BPD Measured Flow Rate - 222 BPD Pump Displacement (55 BPD Slippage)
Flow Rate -GPM
Tubing Pressure - Psig
Flow Rate(GPM) Tubing Pressure(Psig)
Elapsed Time - Seconds
30
25
20
15
10
5
0
-5
0
5
10
15
20
25
30
35
40

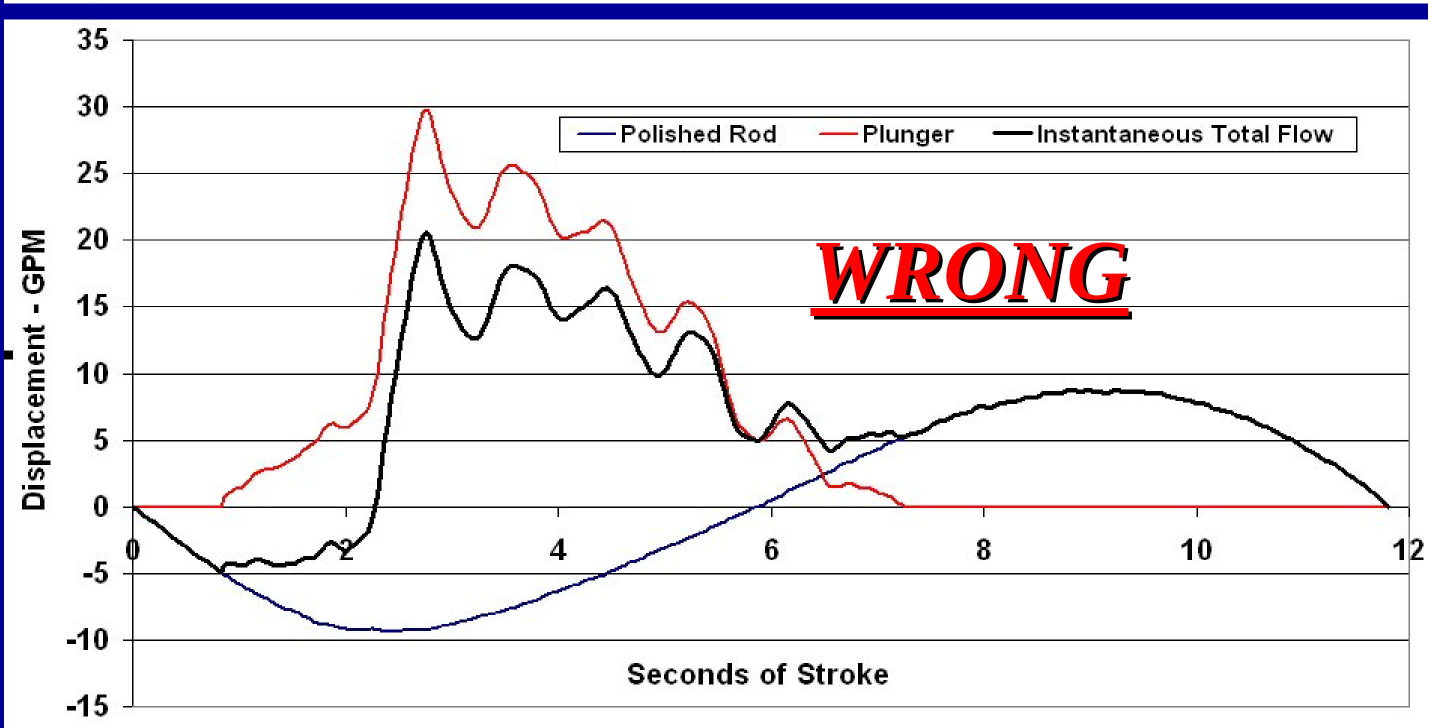
High Speed Sampling Rate Required to See Instantaneous Flow Rates

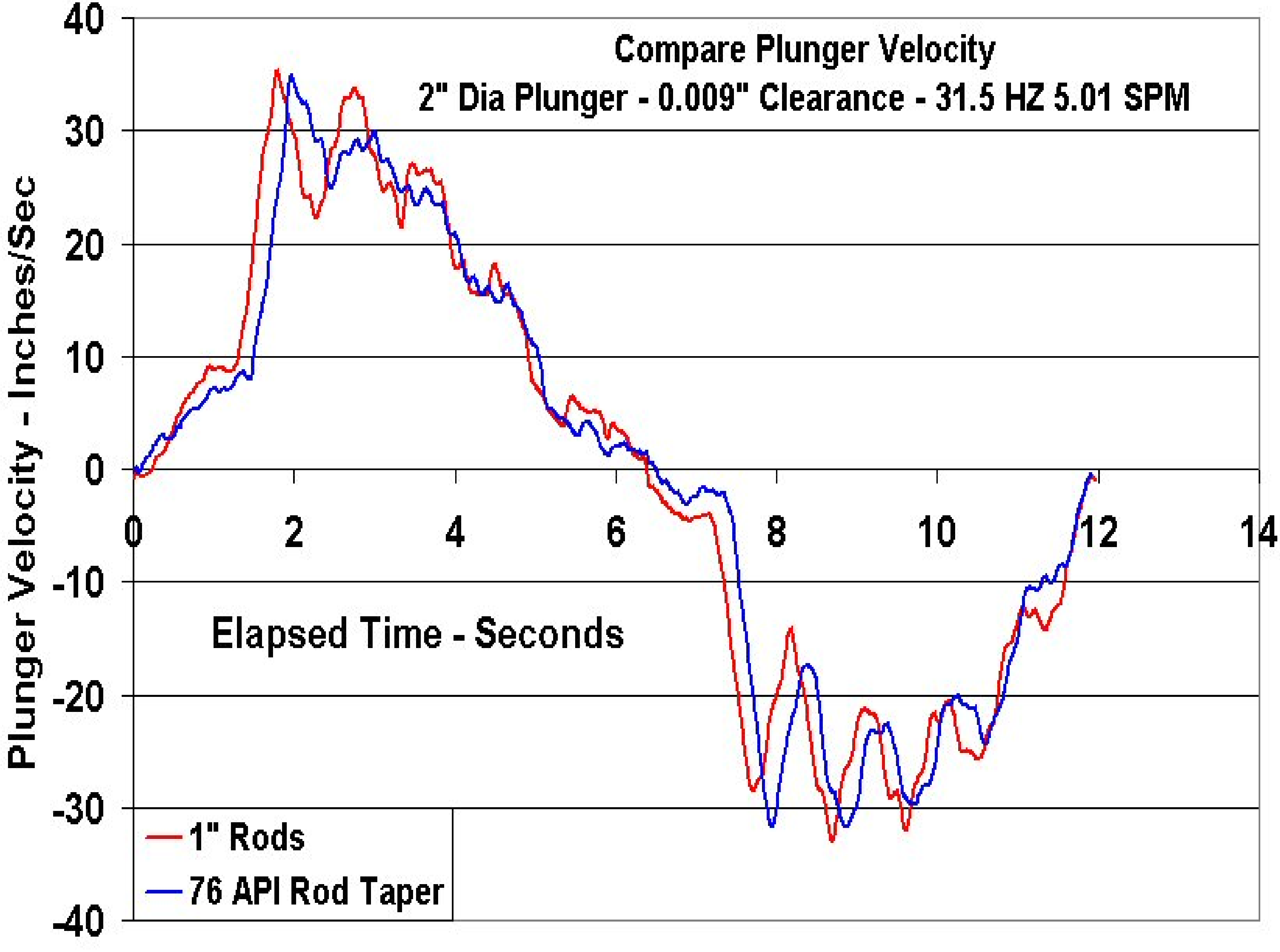


What People Think Surface Flow Rate Looks Like Producing Water:

Displacement of Polished Rod and Plunger

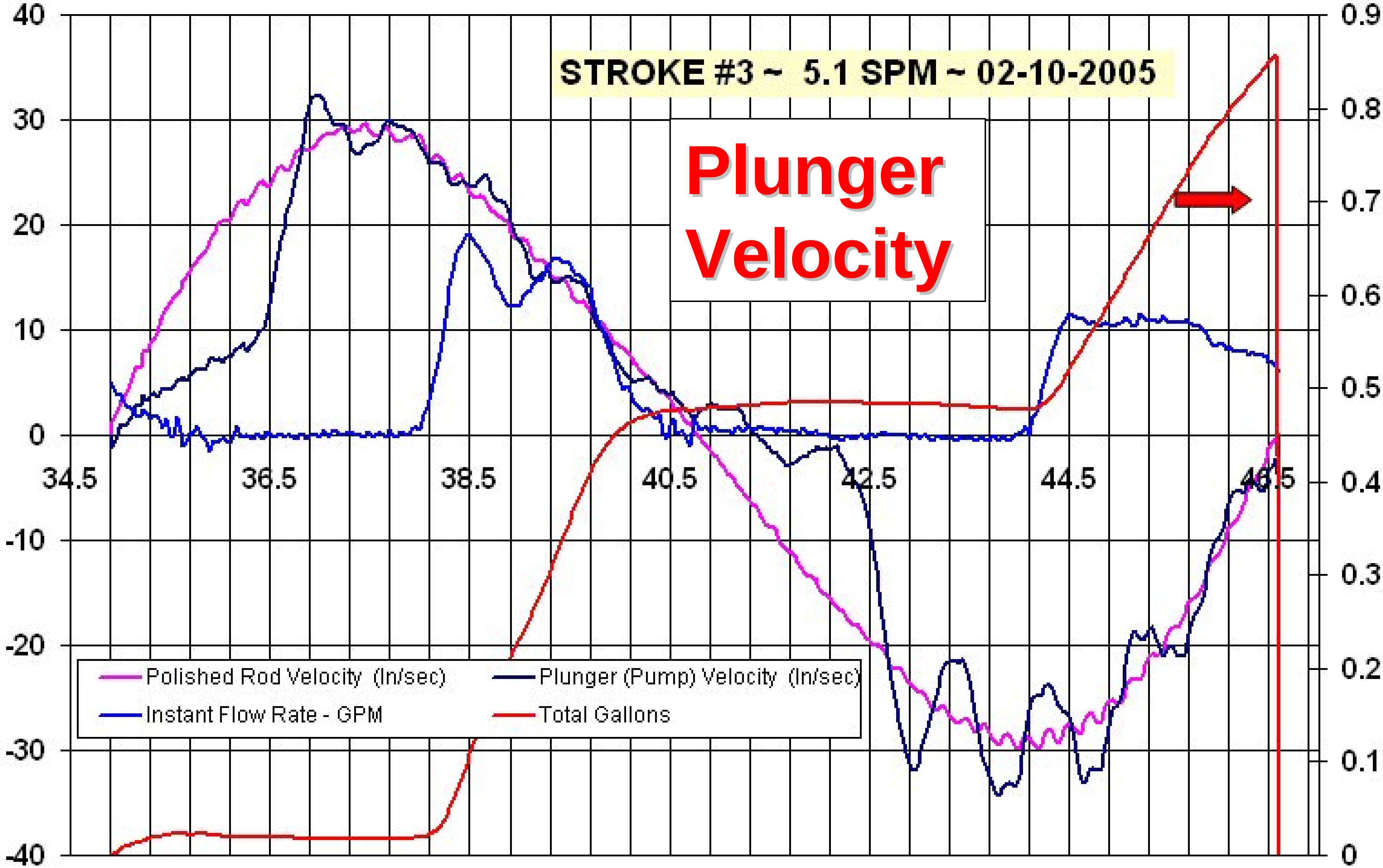




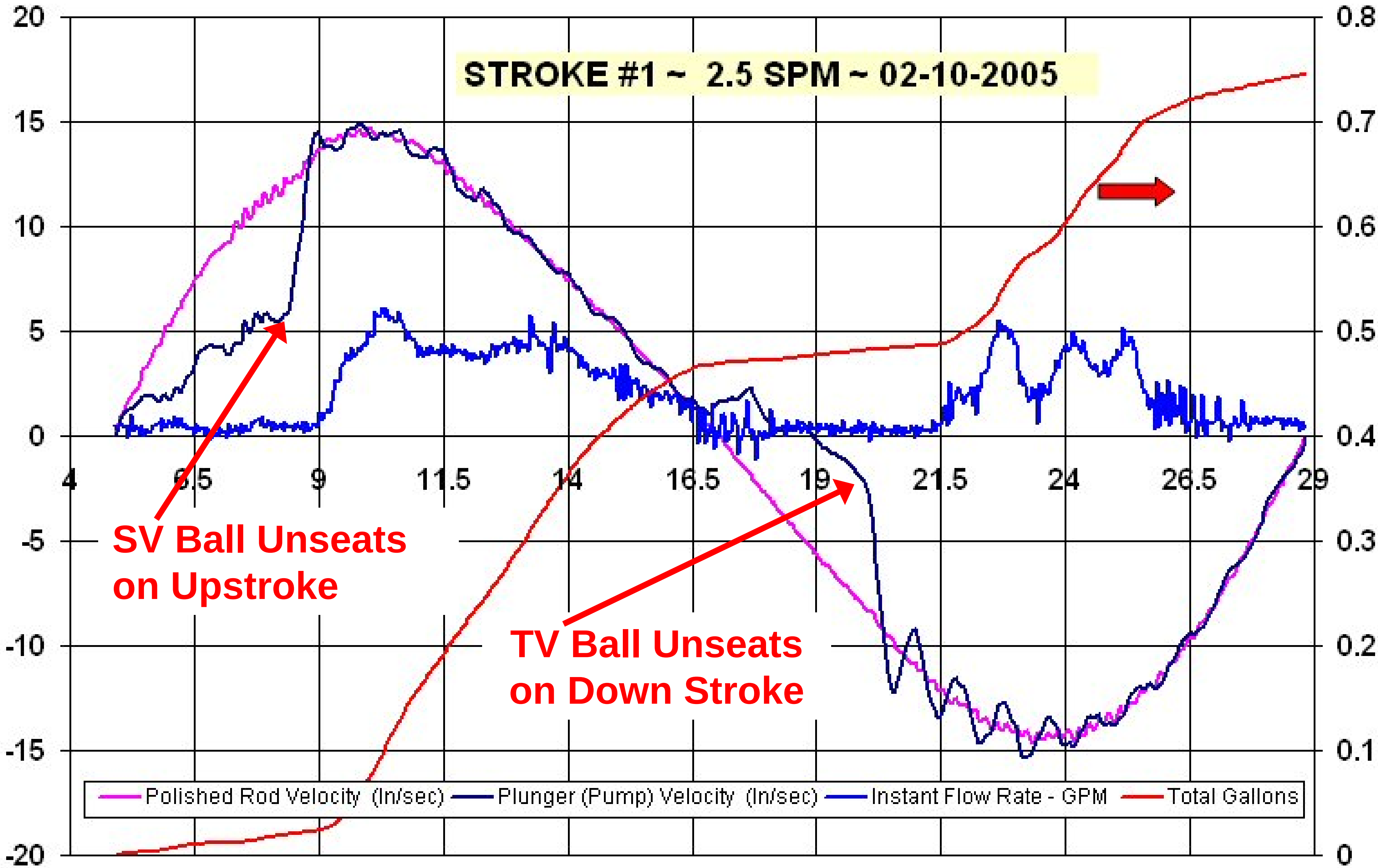


Compare Plunger Velocity
2" Dia Plunger - 0.009" Clearance - 31.5 HZ 5.01 SPM
Plunger Velocity - Inches/Sec
Elapsed Time - Seconds
40
30
20
10
0
-10
-20
-30
-40
0
2
4
6
8
10
12
14
1" Rods
76 API Rod Taper

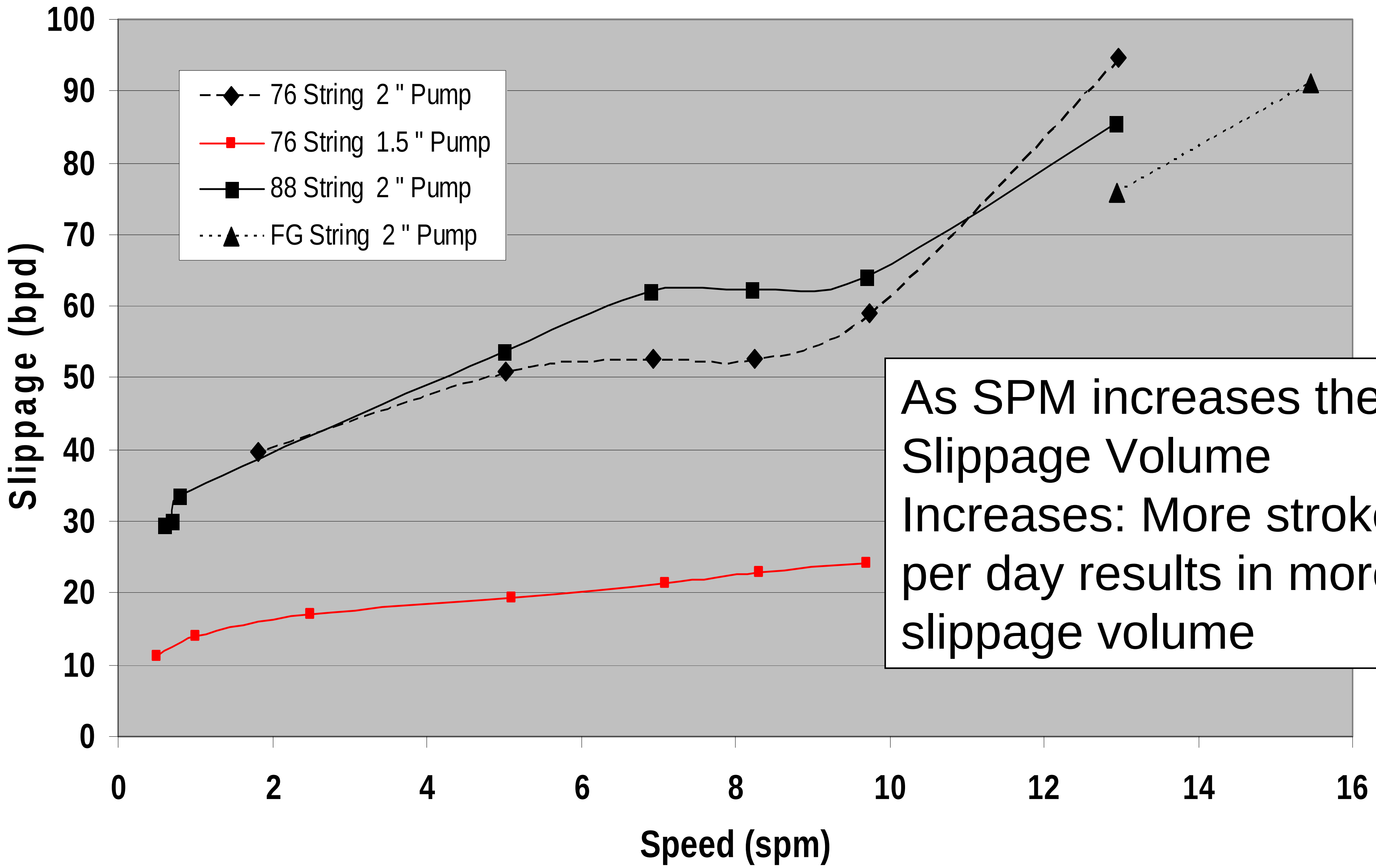
When Producing Water the Surface Flow Rate is Directly Related to the Plunger Velocity on Upstroke & Down Stroke



Approximate 0.4 Second Lag in Time From Ball Seats Upstroke & Down Stroke

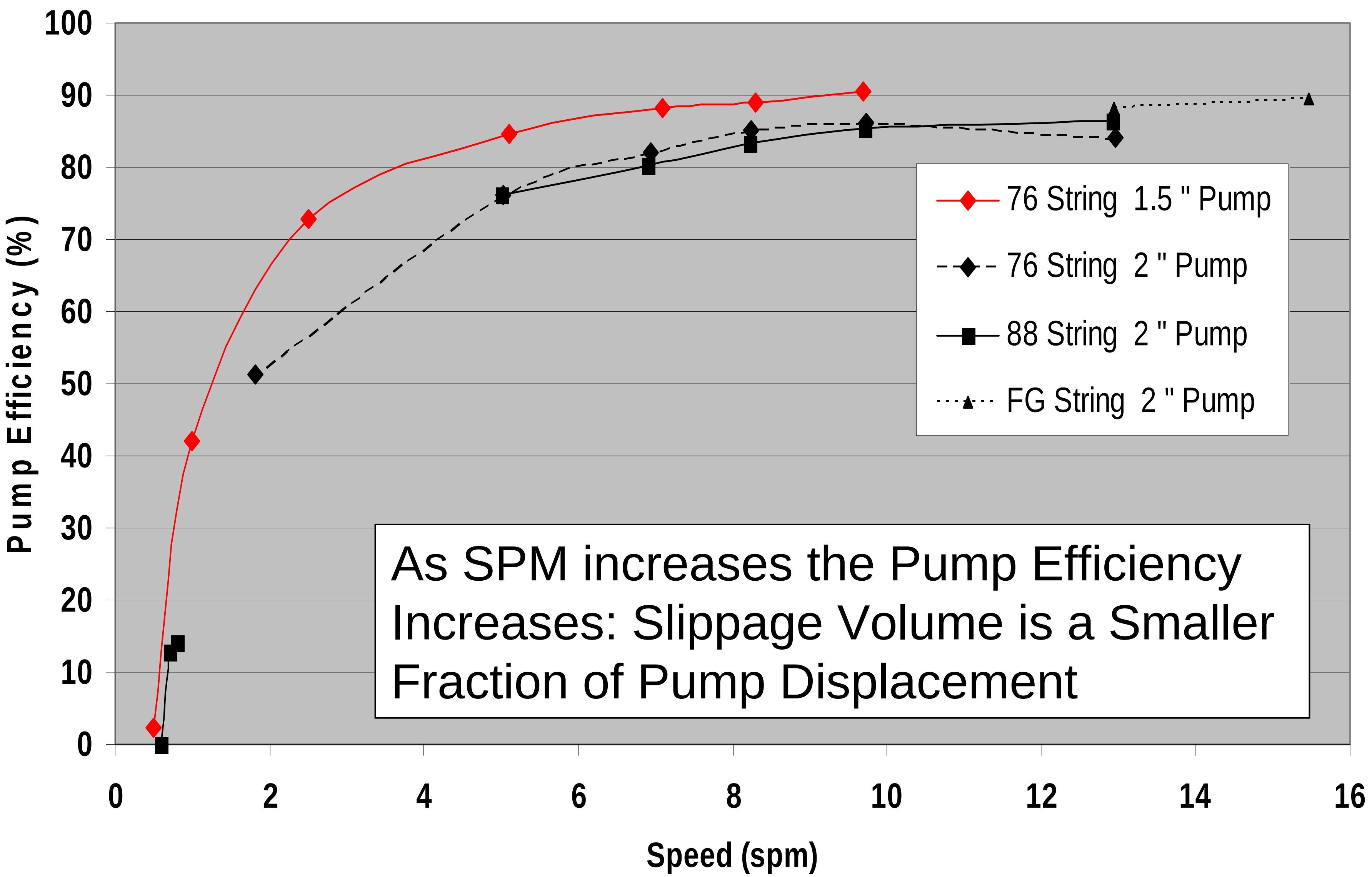


Pump Slippage Volume vs. Pump Speed



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

Pump Speed vs. Pump Efficiency



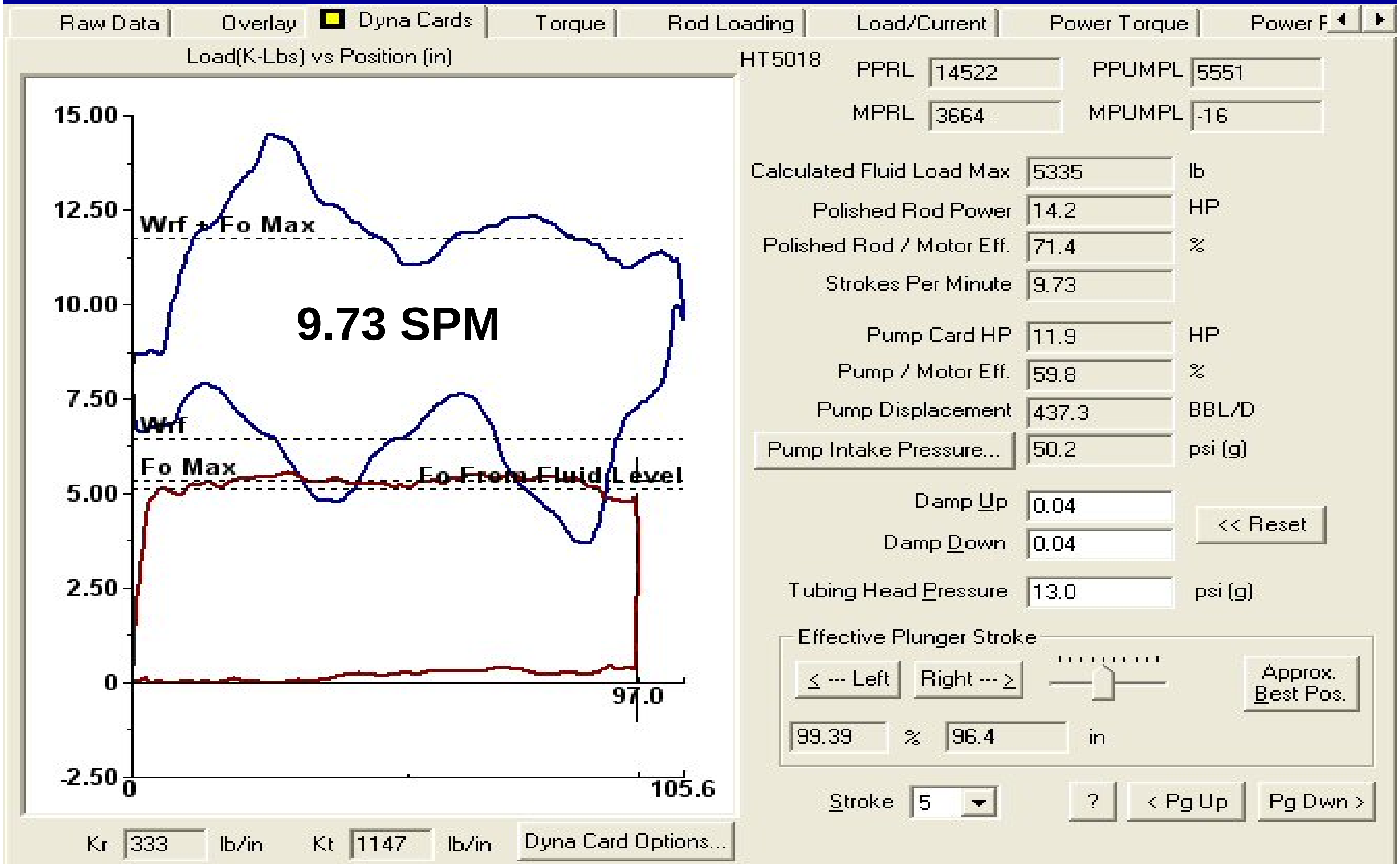
Patterson Slippage Equation

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

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

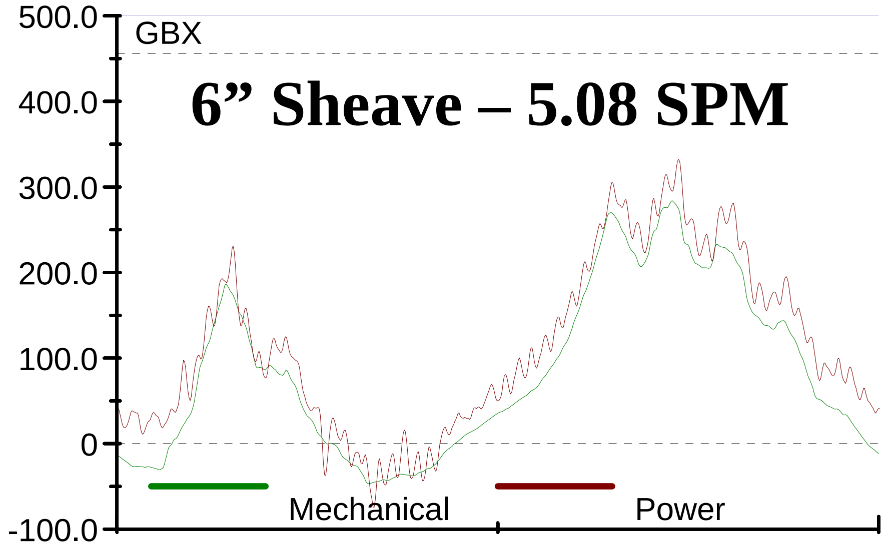
Dynamometer Data @ 4 SPMs

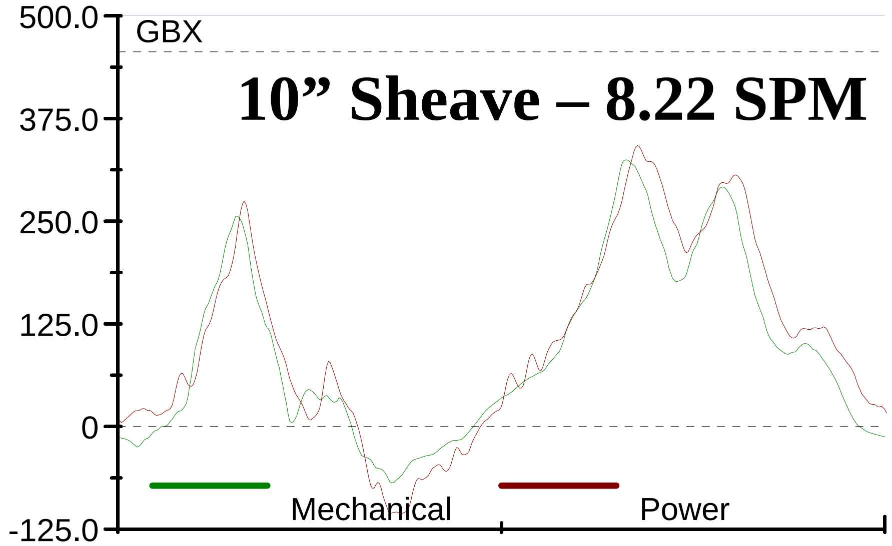
2" Plunger, 76 Rod String, 0.009" Clearance

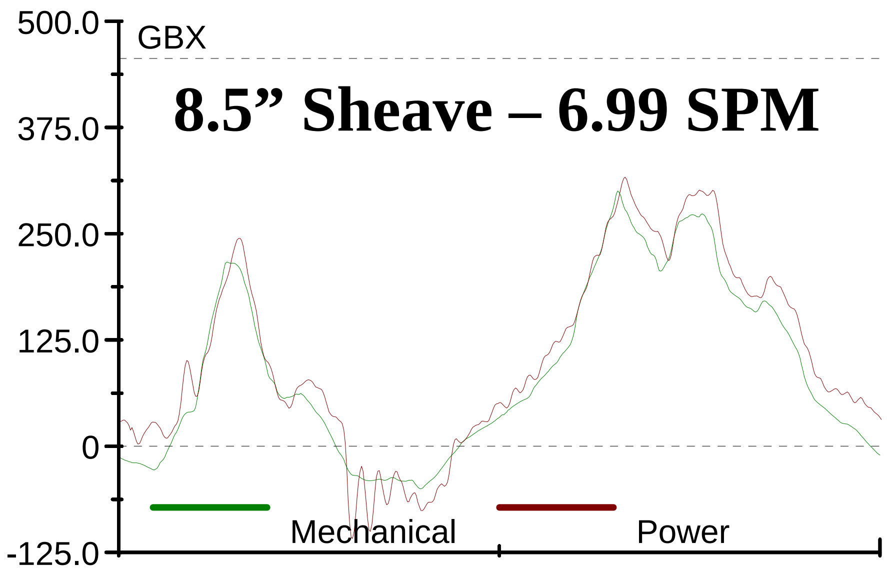


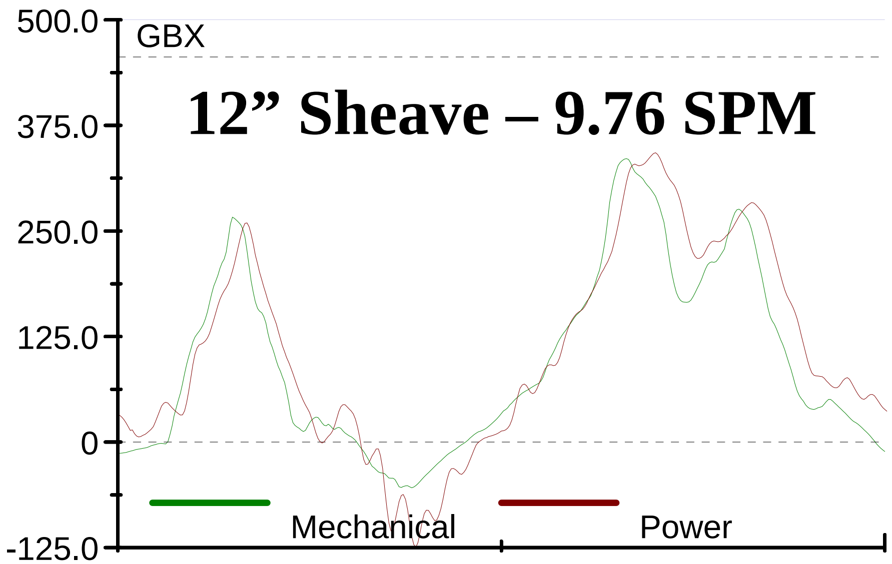
Motor Outputs what Gearbox Requires

Torque Analysis:283.9, 300.1, 324.5, 335.5 Peak Kin-Lb









Power Data @ 4 SPMs

2” Plunger, 76 Rod String, 0.009” Clearance

Overlay | Dyna Cards | Torque | Rod Loading | Load/Current | Power Torque | Power Results | Ana

Monthly Operation Costs (30 Days per Month):

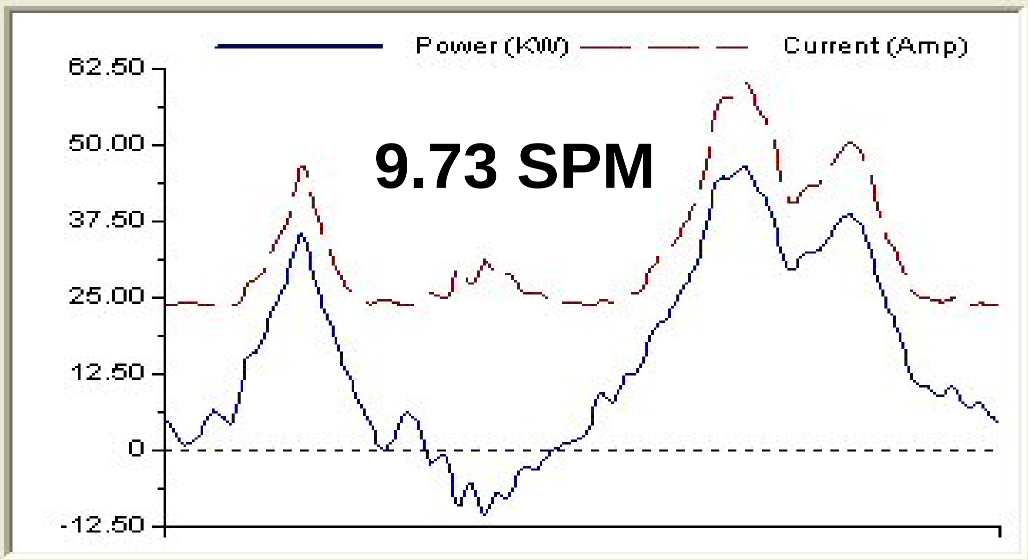
Run Time	24	hr/day
Cost With Gen. Credit	1071.28	$
Cost No Gen. Credit	1126.11	$
Demand Cost	328.04	$
Oil Prod. Cost		¢/bbl
Liquid Prod. Cost	12.7	¢/bbl
Oil Production	0	BBL/D
Water Production	380.5	BBL/D

Recommended Minimum NEMA D Motor	28.8	HP
Rated HP	50	HP

Rated Full Load AMPS	60	
Thermal AMPS	33.9	
Gross Input	21.0	HP
Net Input	19.9	HP
Demand	16.4	KW
Average	15.5	KVA

Average Power

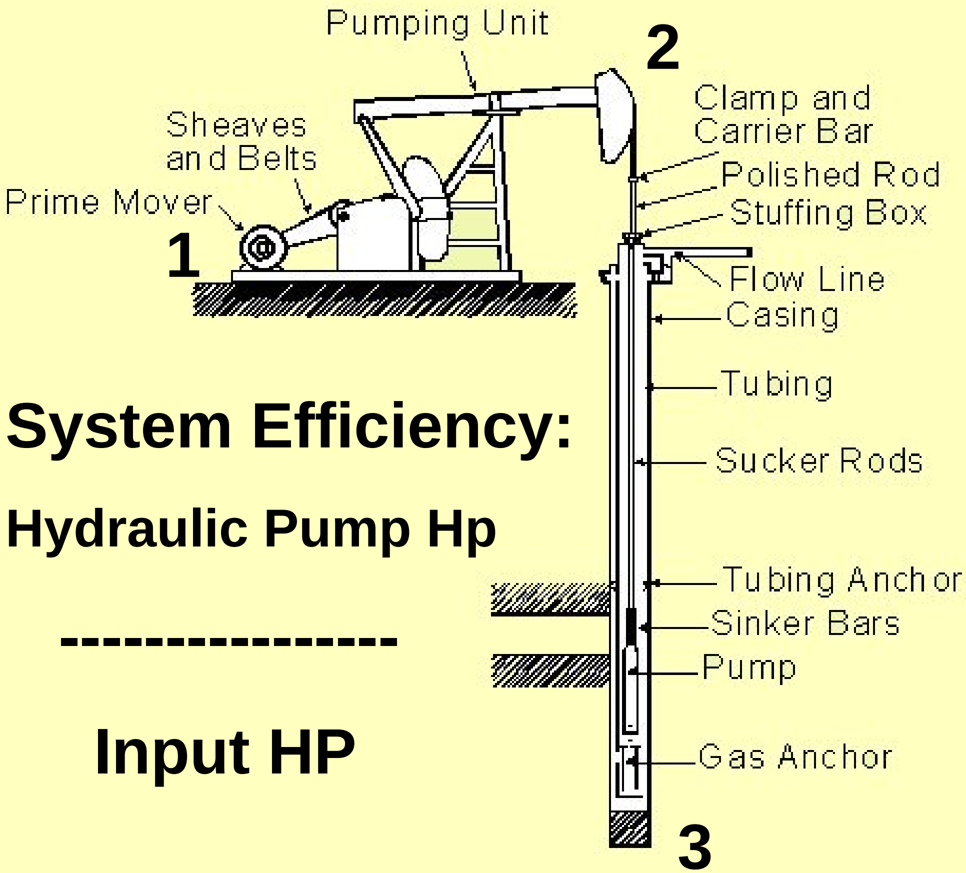
With Generation Credit	14.9	KW
No Generation Credit	15.6	KW
Avg. Power Factor	80.3	%
System Efficiency	52.3	%



Stroke 5

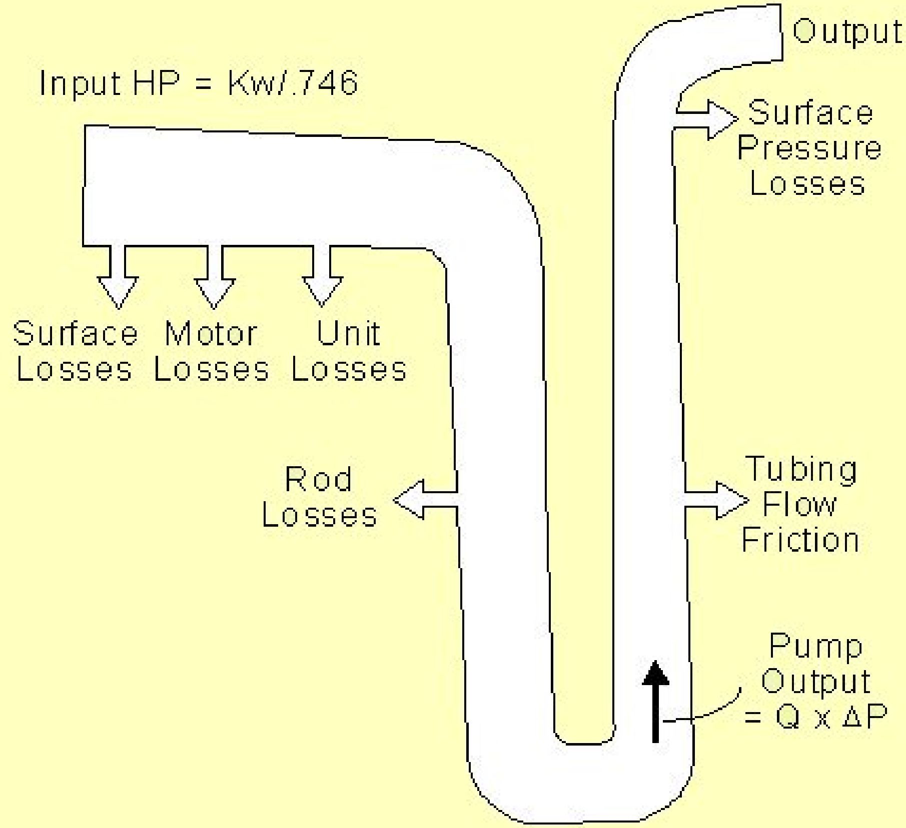
? | < Pg Up | Pg Dwn >

What is System Efficiency?



System Efficiency:

$$\frac{\text{Hydraulic Pump Hp}}{\text{Input HP}}$$



$$\eta_{\text{BEAM, system}} = \eta_{\text{surface}}\ \eta_{\text{motor}}\ \eta_{\text{unit}}\ \eta_{\text{rods}}\ \eta_{\text{tubing friction}}\ \eta_{\text{surface pressure}}$$

OR

$$\eta_{\text{system}} = \frac{(Q,_{\text{BPD}})\ (\text{Depth} - \text{PIP}/.433\text{XSG})\ (\text{SG})\ (7.368\ \text{E-06})}{(\text{Kw} / 0.746)}$$

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%

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

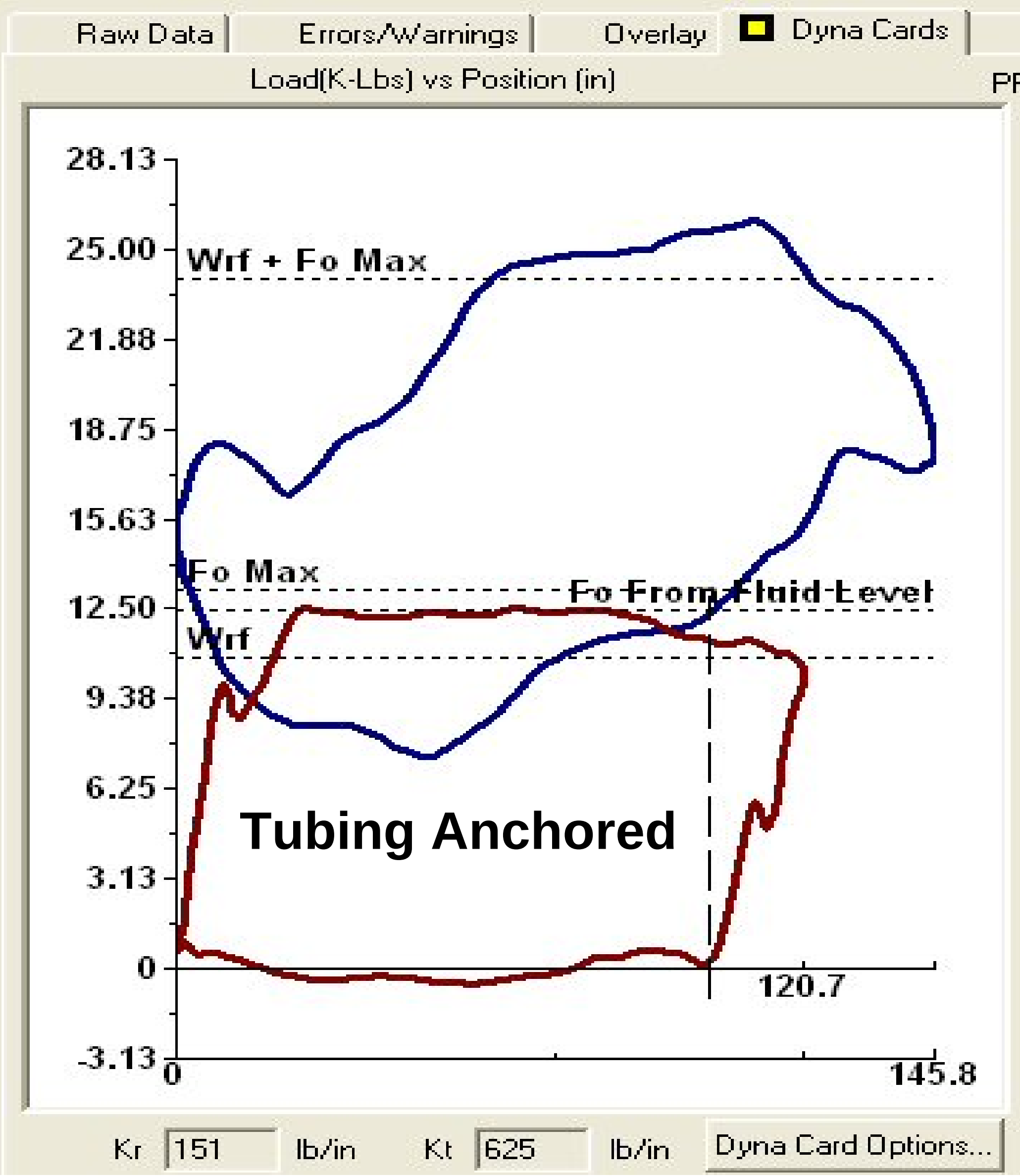
Based on Slippage test, "the following minimum pump clearances are recommended for a 48" Plunger with a "+1 Barrel". These clearances have become widely used in the Permian Basin for well depths up to 8000 feet"

- 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)

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

Field Example of 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 121 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 too low by 48 BPD (174-121-5).

Patterson Slippage Calculation

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

Inputs to Pump Slippage Calculations

D=Plunger Diameter (inches)	2.25
*P=Pressure Differential	3155
C=Clearance (inches)	0.009
u=Fluid Viscosity (centipoise)	1
Plunger length (inches)	48
Strokes per Minute	9.52

***Calculating Differential Pressure**

Pump Depth	7156
Tubing Discharge Pressure (Psi)	250
Tubing Fluid Gradient (Psi/Ft)	0.427
Pump Intake Pressure (Psi)	151

Slippage in BPD	121.2

655 BPD Pump Displacement

File Tools Help

Title: My QRod Test Run

Design Inputs

Unit	CWConv	
Pump Depth	7156	ft
Surface Stroke Length	145.8	in
Pump Diameter	2.25	in
Tubing Size	2.875" (6.4 lb/ft) 2.441" ID	

☑ Anchored Tubing

Rods

○ Steel Rods

◉ Fiberglass and Steel Rods

F-Glass Size: 1.250 in — Steel Size: 0.875 in

Percent Fiberglass: 34

Results

Rate (100% Pump eff.)	655	bbl/day
Rate (90 % Pump eff.)	590	bbl/day
Rod Taper, %	34.0, 66.0	
Top Rod Loading	103.8	%
Min API Unit Rating	912-305-146	
Min NEMA D Motor Size	62.6	hp
Polished Rod Power	41.6	hp
TVLoad	23,849	lbs
SVLoad	11,135	lbs
Max Fiberglass Load	24,840	lbs
Min Fiberglass Load	3,333	lbs
Max Fiberglass Stress	20,569	psi
Min Fiberglass Stress	2,760	psi
Fiberglass Load	91.7	%

Calculate from SPM or Target Rate

◉ Stroke Rate << 9.52 >> SPM

○ Target Rate << 590 >> bbl/day

Calculate

Default Settings

Total Sinker Bar Weight	816	lbs	Damping Factor	0.1	
Fluid Specific Gravity	1	$H_2O = 1$	Unit Efficiency	95	%
Tubing Pressure	250	psi	Pump Efficiency	90	%
Casing Pressure	45	psi			

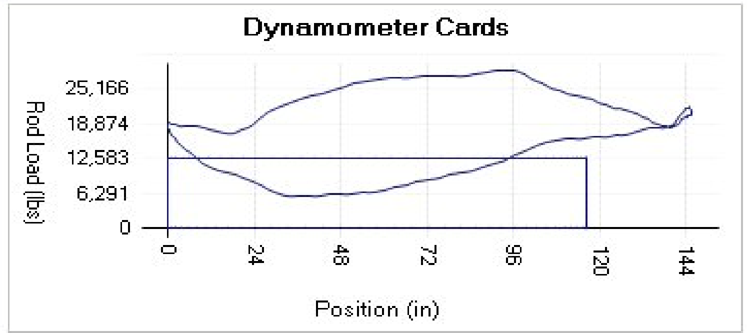
You may enter Pump Intake Pressure directly, or calculate it from Reservoir Pressure and Productivity Index.

◉ Pump Intake Pressure 151

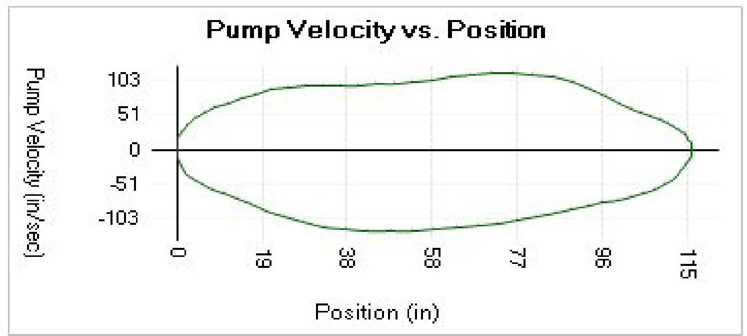
○ Reservoir Pressure 1000 psi

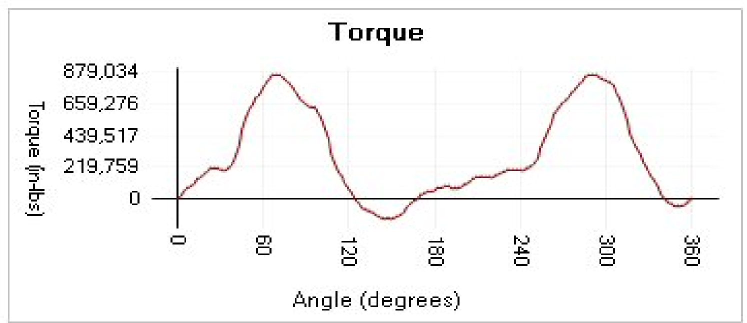
Productivity Index 2.000 bbl/day/psi

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



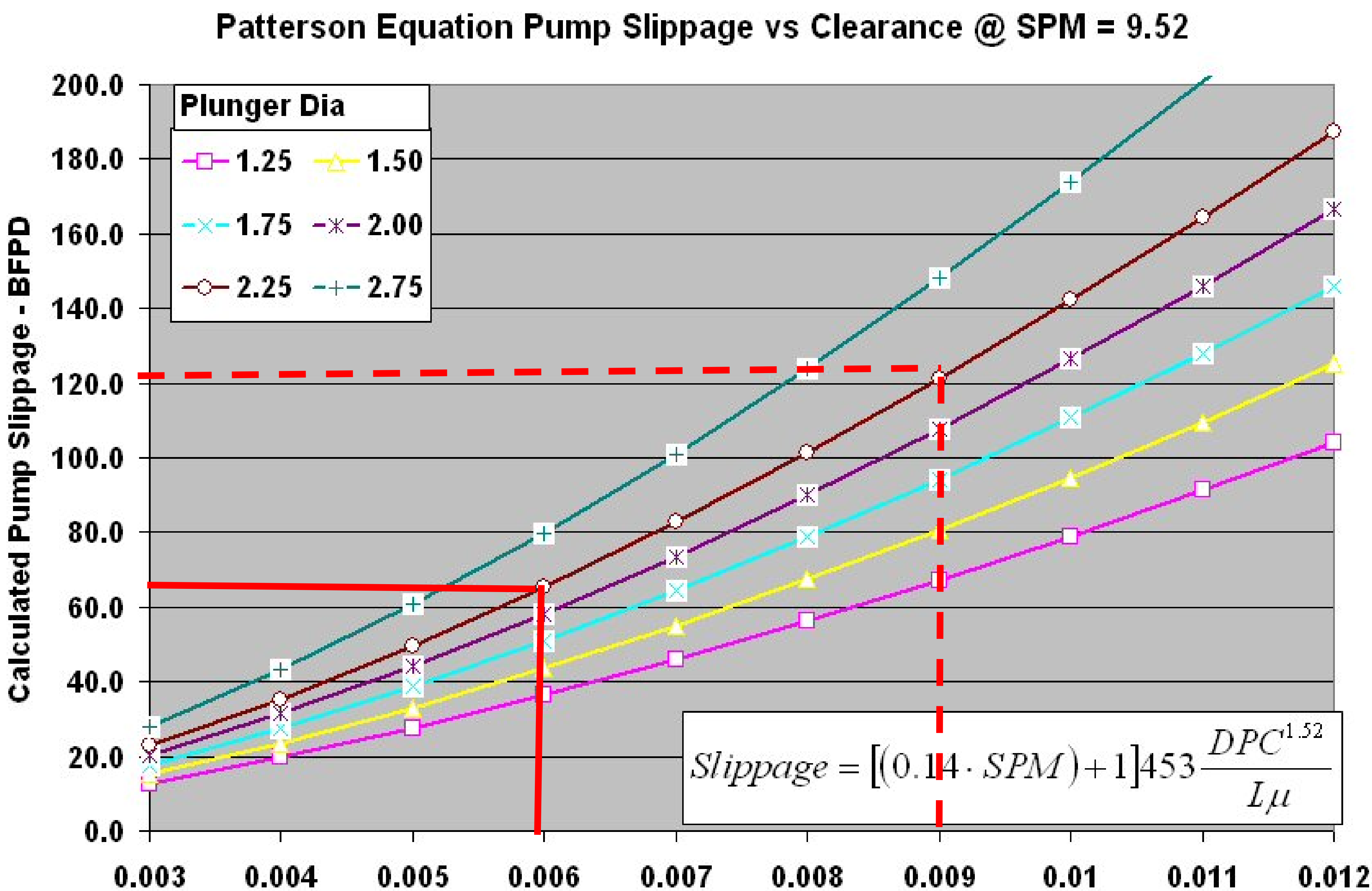
PPRL 28,598 lbs	MPRL 5,743 lbs	Fo 12,714 lbs
Pump Stroke 116.6 in	Static Stretch 81.7 in	Overtravel 52.5 in
Fo/Skr 0.560	Kr 156 lb/in	Kt 625 lb/in





Peak Gear Box Torque	861	Kin-lbs
Counter Balance Moment	1,535	Kin-lbs
Counter Balance Effect	22,179	lbs

Design Pump Clearance of 0.006" 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 – *<u>Better than Rule-of-Thumb</u>***
2. **Pump Slippage is a Function of SPM**
3. **Slippage may be Excessive for large clearance pumps when pumping from deeper depths**
4. **Production from a leaky Pump can be increased by increasing SPM**
5. **System Efficiency can be Significantly Reduced at Slow SPMs with "large" Pump Clearance**