ROD PUMP CLEARANCE GUIDANCE

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ABSTRACT

Slippage is required when lubricating the plunger/barrel interface of beam pumping systems. Increasing the pump clearance increases the amount of slippage, which leads to inefficient operations. Operators could run their field more efficiently while reducing failure rates and electrical costs by calculating the optimum design using the Patterson Slippage Equation for individual well conditions. This paper discusses the economic tradeoffs of changing pump clearances and recommends theoretical optimum designs given well conditions. The paper also presents nomographs and a calculator used to recommend optimum designs.

INTRODUCTION

Occidental Petroleum's EOR business unit operates 6,500 beam pump units across the Permian Basin. Creating standards and best practices is necessary when operating such a large number of wells to expedite decision-making and return wells to production quickly after repairs. However, having strict standards does not take individual wells' circumstances into account, which may lead to inefficient operations. Operators can reduce Lease Operator Expense (LOE) while decreasing electricity costs and increasing the run life of wells by designing beam pumping systems to account for individual well circumstances.

We found that the way we standardized pump designs across the Permian Basin has led to wells being unable to lift the designed fluid volumes to the surface and wells running inefficiently due to slippage in the pumps.

Rod pumps are designed to allow slippage between the outside of the plunger and the inside of the barrel to lubricate the system and prevent galling at the pump. The amount of slippage in barrels of fluid per day (bfpd) varies depending on the clearance between the plunger and barrel, as expressed in the Patterson Slippage Equation. Using that equation and our knowledge of individual well characteristics, we were able to optimize well performance and reduce associated costs.

PUMP SLIPPAGE HISTORY

The paper titled "Progress Report #4 – Fluid Slippage in Downhole Rod-Drawn Oil Well Pumps" discusses the accepted standard for pump clearances using the Texas Tech University Test Well to describe empirically the amount of slippage in a well through the Patterson Slippage Equation:

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

This paper will use the Patterson Equation for all slippage calculations, as it is the industry standard and widely acknowledged as the most accurate approximation when calculating downhole slippage. The Patterson Equation is a progressive refinement of many pump slippage formulas developed over the years. Initial equations developed in the 1940s would overestimate the amount of slippage by a factor of 2 or 3, compared with measured field values.

In a perfectly operating pump, any deviation in fluid production from the theoretical output volume is attributed to slippage. The percent of slippage varies based on design and reservoir characteristics, but only 2–5% of the designed production volume is required to lubricate and operate the pump, according to a well-known pump company.

PUMP OPERATIONS

A plunger pump consists of a plunger, standing valve, traveling valve, and barrel. Total plunger clearance is the difference between the internal diameter of the barrel and the outer diameter of the plunger and is expressed in thousandths of an inch. Industry standards recommend that barrels have a tolerance of 0.001 in., while the plunger clearance will vary based on the design. On the beginning of the upstroke, the travelling valve closes and sets on the seat, holding the fluid in the tubing. Slippage can only occur when the traveling ball is on the seat. The rods then begin to stretch while the plunger remains stationary. As the plunger travels upward, the standing valve begins to open when the pressure in the pump drops below the pump intake pressure, which allows fluid to enter the pump. The rods will then pull the plunger, carrying the full load of the fluid in tubing, while drawing additional fluid into the pump. The standing valve then closes, and as the plunger falls, the traveling valve will remain seated until the pressure inside the pump is greater than the pump discharge pressure. This usually occurs by the travelling valve compressing gas (if present) until enough pressure is created to unseat the valve. The fluid in the pump is then displaced into the tubing, as the standing valve now holds that fluid load within the tubing.

Fluid that is lost to slippage falls between the plunger and barrel and collects in the pump. This collected fluid will then be re-pumped on the following cycle. Fluid lost to slippage takes priority over reservoir fluid, as it is already in the pump, leading to volumetric inefficiencies, i.e., this does not translate to increased production on surface.

The traveling valve itself leaks each time it closes. The total volume lost to this leakage is not considered in the Patterson Equation because it is so small. The benefit of calculating this is negligible, so we will ignore it for the purposes of this paper.

STANDARD DESIGN

Standardizing pump designs with a one-size-fits-all mentality can lead to logistical efficiencies, but sacrifice performance. As an example, when applying the clearance recommendations given in the 2007 SWPSC paper “Progress Report #4 – Fluid Slippage in Downhole Rod-Drawn Oil Well Pumps” to a shallow San Andres formation well (Figure 1), there are pump designs that fall outside the spectrum the paper recommends for which different clearances would be more appropriate.

As depth of the pump increases, differential pressure across the plunger becomes a larger factor in the Patterson Slippage Equation. Deeper wells (>8,000 ft) risk the following:

- Deferring production due to reservoir fluid input exceeding system output;
- Increasing failure frequency due to tight clearances causing increased pump galling and wear;
- Increased system costs to compensate for slippage.

BASIS OF DESIGN

Because only 2–5% of production is needed to supply lubrication, any additional pump slippage within the pump is a balance between increasing system run life and decreasing volumetric efficiency of the system. Pump systems are commonly designed to run 20 hours a day to meet production estimates. This is to compensate for loss of efficiency over time, being able to pump wells off quickly after being down, and not “over cycling” the wells, which could potentially increase failure rate.

A good starting point to balance run life and volumetric efficiency is to target a pump efficiency between 80 and 90%. The reasons we came to this recommendation are as follows:

- Tighter Fit Issues – Smaller pump clearances (-3 to -4) increase the chances of the plunger sticking. With tighter fits, larger numbers of sinker bars are needed, and this increases the chances of rod-on-tubing wear.
- Tighter Fit Benefits – Little slippage allows wells to run at slower speeds (fewer strokes per minute).
- Electrical Cost Savings – Excluding sand from the barrel-plunger interface when large-grained sand is present (0.015 to 0.020 in. and above).

- Looser Fit Benefits – Allows sand to pass between the plunger and the barrel when fine sand (0.002 in.) is present. Also reduces compression on the bottom rod and reduces pump galling.
- Looser Fit Issues – To achieve target production, equipment needs to be oversized compared with tighter fits. Also, oversized equipment increases costs and can potentially lead to increased failures.

A pump design targeting 80–90% efficiency is recommended, but it might not be appropriate for every field and every well condition. Field experience should shape design recommendations according to the specific factors shown in Table 1.

In typical waterflood, a well's daily liquid production rate is usually high, compared with the volume of liquid lost to slippage. Large-diameter plungers are run to produce such high liquid rates, and to reduce workover costs pump clearances are typically increased. This results in less downhole sticking, lower peak loads, and higher minimum loads. If the well is in a field where a CO_2 EOR flood is active, then a variable-speed drive is often used to maintain a pump filled with liquid, as the amount of gas present at the pump changes throughout the alternating water / CO_2 injection cycle. Maximum slippage will occur when the fluid level is drawn down to the pump intake with a large diameter plunger with large clearance when the variable-speed drive slows to keep the pump filled with liquid. This specific configuration when combined with high pump clearances can result in low producing efficiency and high electricity costs. Care should be exercised when running large-diameter pumps having a high pump clearance to be aware of the impact of slowing SPM to maintain liquid-filled pumps in pumped-off wells, as this can result in pumping the same barrels of water over and over due to the high slippage rates. When SPM are decreased, then a redesign with a tighter pump clearance may be appropriate to maintain cost-efficient operations.

CALCULATING CLEARANCE GUIDANCE

To increase an operator's accuracy when picking pump clearances, we recommend operators either use the nomographs in Figures 1–3, create their own slippage calculator tool, or use software applications like Qrod to calculate the most efficient designs and cost savings.

The nomographs in Figures 1–3 show three different reservoir cases: San Andes 4,500-ft wells, Clearfork 7,000-ft wells, and Wolfberry 10,000-ft wells, which are common in the Permian Basin. These easy-to-use graphs allow us to make ballpark estimates of the recommended pump clearance based on general field conditions, but they are not as accurate as the calculator, which is based on specific well conditions.

QRod is a very accurate, easy-to-use, predictive computer program for sucker rod design. The QRod Pump Slippage Calculator allows users to specify the pump clearance, and it will calculate the resulting pump slippage and efficiency based on the design conditions, and predict the net pump displacement. The following are the steps to design the proper pump clearances:

1. Use the predictive sucker rod design program to calculate pump displacement, assuming 100% liquid pump fillage.
2. Input correct well parameters; be sure to adjust water viscosity for the temperature at the pump.
3. Examine the Pump Slippage plot and select the pump clearance that gives the desired percentage of pump slippage.

The total in barrels per day of pump slippage increases with increasing pump speed. Pump displacement increases faster than pump slippage, resulting in greater pump efficiency with increasing speed. At slower strokes per minute, the percent of the pump stroke lost to slippage increases, resulting in lower efficiency. Proper selection of pump clearance is therefore very important in sucker rod pump design.

For a more detailed, field-specific solution, we recommend building a calculator tool to drive improvement in the design process. Figures 4–8 show what Oxy uses internally to calculate potential design parameters and savings. Given the specific reservoir and equipment inputs, engineers can calculate the recommended plunger clearance, recommended SPM, and the electrical costs and annualized failure frequency costs compared with the previous well design.

It is necessary to input generalized field data (Figure 4), such as reservoir data, pump depths, average well failure frequency, and lifting costs ($/bbl), along with well-specific data (Figure 5). To see the potential cost savings for the new system compared with the equipment already downhole, input the plunger clearance and SPM of the current system. This allows the tool to compare current vs. proposed designs. Then input proposed downhole configuration: plunger diameter (in.), plunger length (in.), stroke length (in.), API rod code configuration (dropdown box), conventional or special geometry unit, sinker bar size and number, target fluid above pump (FAP), target runtime, and target production (oil and water).

Given those inputs, a recommendation is provided for the pump design. Recommended target SPM and clearance will be calculated along with yearly cost savings, as shown in Figure 6. The recommendation provided will meet an 80–87% efficiency standard as well as give a solution that will meet the expected fluid volume (Figure 7). Cost savings are calculated from the difference between the current and recommended designs, taking into account electrical cost savings from more efficient designs and a reduction in failure costs from running slower, more efficient designs.

Initial well designs can be engineered using the clearance nomographs or the slippage calculator as a starting point, but because each field is different, field experience must be used to refine the recommended clearance tolerance. Figure 8 shows an extended range of SPM and clearance combinations that meet the expected fluid outputs, while targeting at least 95% efficiency to allow enough slippage to prevent galling. If you do not have stuck and grooved plungers, you can use more clearance. If the slippage is excessive, consider tightening the clearance or running a longer plunger. Field experience and personal judgment are key in reducing failures and improving cost savings.

CONCLUSIONS AND RECOMMENDATIONS

There is economic value in designing pump clearance tolerances for individual beam wells rather than standardizing pump design throughout the basin. When standardizing, operators risk increasing failure rates and lifting costs and risk deferring production due to inefficient and improperly designed pumps. We recommend using the Patterson Slippage Equation and the attached nomographs to identify deficiencies in current designs, optimize wells to run more efficiently, and maximize field output through beam pump designs that account for slippage properly.

ACKNOWLEDGMENTS

The information in this paper is based on the findings of John Patterson, Kyle Chambliss, Lynn Rowlan, and Jim Curfew and their work on empirically calculating the Patterson Slippage Equation.

REFERENCES

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Table 1 – Factors and Considerations for Design

Factor	Consideration
Specific gravity of the fluid to be produced	Increase clearance for more viscous fluids.
Length of the plunger and/or barrel	Increase clearance for longer plunger types and consider setting depth.
The surface pumping speed (SPM), particularly with small bore pumps	Use close plunger clearances in slow pumping speeds (< 5.5 SPM).
Barrel thickness	Plungers used with heavy wall barrels can be a tighter fit because the heavy wall barrels are more rigid and do not flex as much as thin-walled barrels.
Bottomhole temperature (BHT)	Increase the clearance to allow for metal mass expansion when BHT exceeds 100°F.
Bore size of the pump	Increase clearance for larger bore pumps to lubricate the pump for the increased contact area.
Additional system friction created by the pump friction due to pump fit	Increase clearance to reduce pump friction.
Presence of solids in the produced fluids relative to pump and system friction	Increase clearance to reduce pump friction.

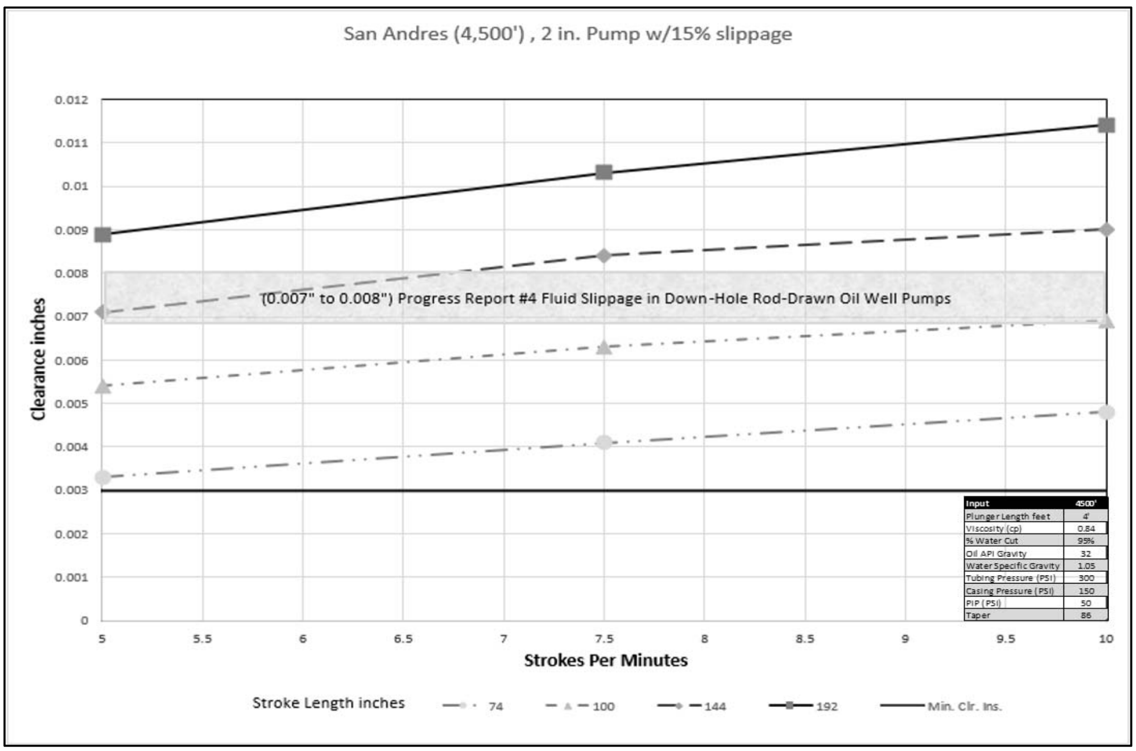

Figure 1 – San Andres 4,500-ft Well, 2 in. Pump with 15% Slippage Nomograph

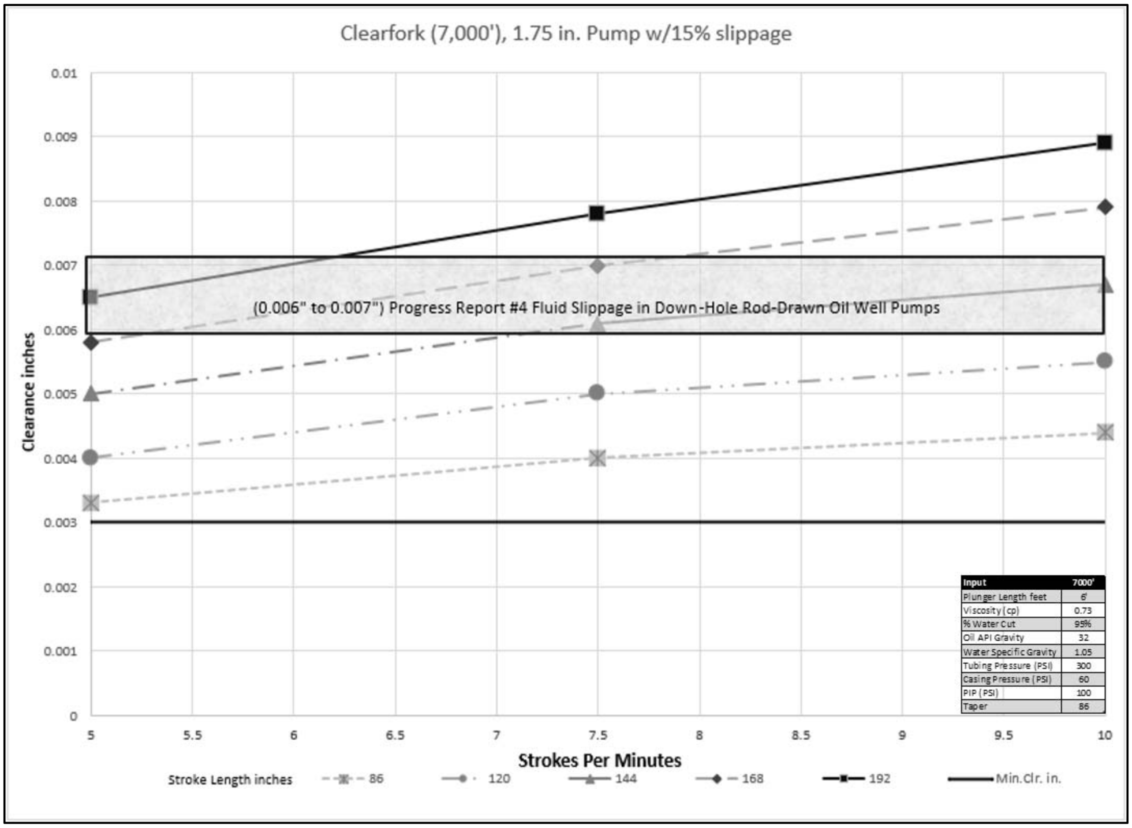

Figure 2 – Clearfork 7,000-ft Well, 1.75 in. Pump with 15% Slippage Nomograph

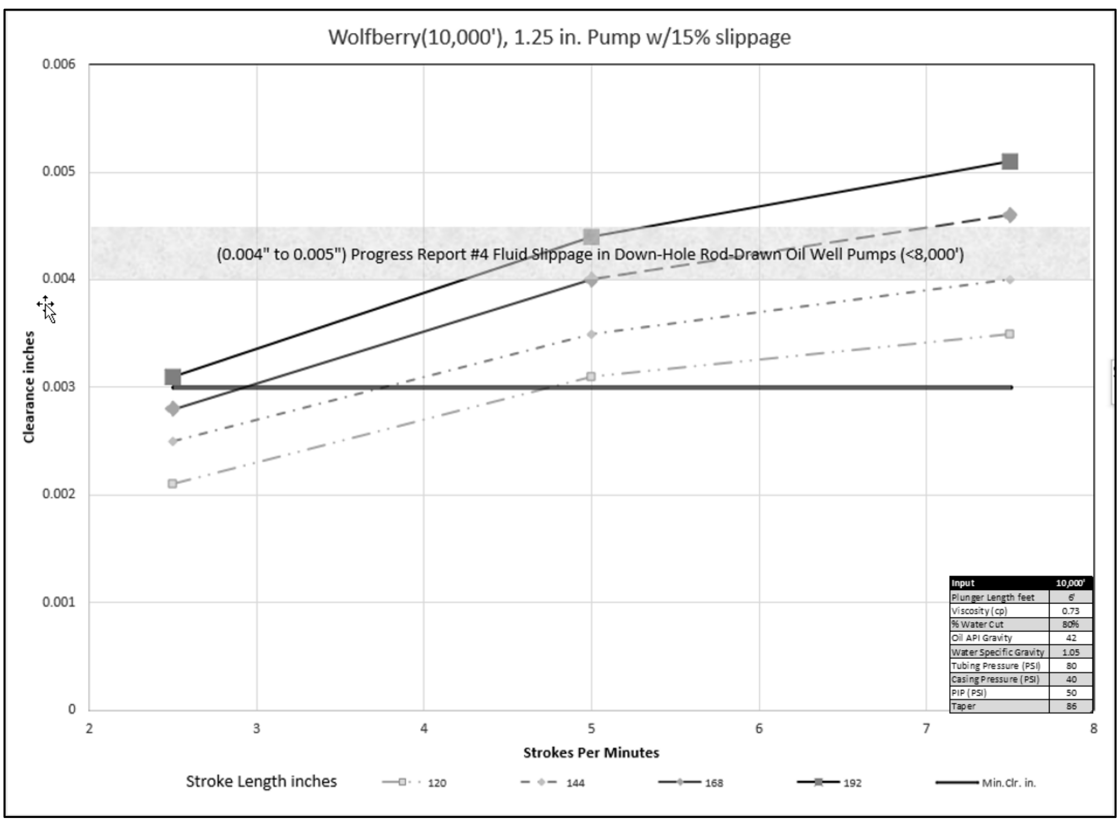

Figure 3 – Wolfberry 10,000-ft Well, 1.25 in. Pump with 15% Slippage Nomograph

OPTIONAL INPUTS	
Bo (RB/STB)	
Oil API Gravity (°)	
Solution GOR	
Reservoir Temperature (°F)	
Bubble Point (psi)	
Fluid SG	
Water SG	
Gas SG	
Viscosity	
Pump Depth	
Tubing Discharge Pressure	
Failure Frequency	
Electrical Costs ($/bbl fluid)	

Figure 4 – Reservoir and Field Inputs

Legend	Input Cells Input Cells Calculated Value
	Proposed Design Inputs
Reservoir/Field	
Entity	
Lease	
Well No	
Current SPM (round up)	7
Current Plunger/barrel Clearance	0.008
Current Plunger Length	48
Plunger Diameter (in)	2
Plunger Length (in)	48
Stroke Length	144
Sinker Bars?	1-5/8"
API Rod Code	86
Target FAP	200
Target Runtime (hrs)	18
Expected Oil	10
Expected Water	170
Conventional or Special Geometry?	C

Calculate Sinker Bars

Figure 5 – Equipment Inputs for Slippage Calculator

Recommendations	
Target SPM	6
Total Clearance, mils	0.006
	Cost Savings
Electrical $/year	$ 981.25
Failure $/year	$ 271.65
Total yearly savings	$1,252.90

Figure 6 – Design Recommendations and Cost Savings

Legend	
	Current System Design
	Proposed System Design

Table 1 shows the recommended pump efficincy between 80% to 87% to achieve the desired displacement of reservoir barrels.

	Table 1	Recommendations - 80% to 87% Efficiency. Total Fluid = 1 to 1.1 * BFPD						
	SPM	5	6	7	8	9	10	
	Polished Rod Velocity	720	864	1008	1152	1296	1440	1584
	100% bfpd Pdisp	262.4	320.9	382.8	448.5	518.6	593.6	
Total Clearance	0.003							
	0.004							
	0.005							
	0.006		260					
	0.007							
	0.008			280				
	0.009							
	0.01							
	0.011							
	0.012							

Figure 7 – Recommendations – 80–87% Efficiency, Total Fluid = 1 to 1.1 * BFPD

Table 2 shows the range of possible solutions (yellow cells) that achieve the desired displacement of reservoir barrels.

	Table 2	Expanded Recommendations - Total Fluid = 1 to 1.15 * BFPD & <95% Efficiency						
	SPM	5	6	7	8	9	10	
	Polished Rod Velocity	720	864	1008	1152	1296	1440	1584
	100% bfpd Pdisp	262.4	320.9	382.8	448.5	518.6	593.6	
Total Clearance	0.003	243 & 92.5%						
	0.004							
	0.005		275 & 85.5%					
	0.006		260 & 80.9%					
	0.007		244 & 75.8%					
	0.008			281 & 73.3%				
	0.009			261 & 68.0%				
	0.01							
	0.011				271 & 60.4%			
	0.012				246 & 54.8%			

Figure 8 – Expanded Recommendations – Total Fluid = 1 to 1.15 * BFPD and <95% Efficiency