Pump Slippage’s Impact on System Efficiency

Lynn Rowlan

TTU Test Well
Data Acquisition Devices

- ABB VSD Controller
- MicroMotion Mass Flow Meter F-100
- Wood Group Smart Guard™ RTU package
- Lufkin SAM Controller ION System Power Measurement System
- (3) Echometer Well Analyzers
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.
What is System Efficiency?

System Efficiency:

Hydraulic Pump Hp

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Input HP

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

OR

\[ \eta_{\text{system}} = \frac{(Q, \text{BPD})(\text{Depth} - \text{PIP}/.433XSG)(SG)(7.368 \times 10^{-6})}{(\text{Kw} / 0.746)} \]
**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 =**

\[
\text{BPD Tank} / \text{BPD Pump}
\]
ARCO-HF Slippage Equation

\[ BPD = 870 \times \frac{DPC^{1.52}}{Lu} \]

**Inputs to Pump Slippage Calculations**

- \( D \): Plunger Diameter (inches)  
  - 2
- \( *P \): Pressure Differential  
  - 1547
- \( C \): Clearance (inches)  
  - 0.009
- \( u \): Fluid Viscosity (centipoise)  
  - 1
- \( \text{Plunger length (inches)} \)  
  - 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
Dynamometer Cards – 5.01 SPM
2” Plunger, 0.009” Clearance, 12” Sheave, 31.5 HZ

Rod Design

Peak Load 12,324 Lb

76 API Taper Rods

91.3” Pump Stroke
215 BPD @ Pump

163 BPD in Tank,
51 BPD Slippage
76% Pump Eff.

Peak Load 16,588 Lb

1 Inch Rod String

95.2” Pump Stroke
226 BPD @ Pump

170 BPD in Tank,
56 BPD Slippage
75% Pump Eff.
When Producing Water the Surface Flow Rate is Directly Related to the Plunger Velocity on Upstroke & Down Stroke
Used ABB Variable Speed Controller or Sheaves

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

- 0.6 HP
  - 0.6 SPM, Input 4.8 HP, 0% System Efficiency
  - 100 Sec/Stroke
  - 0 BPD in Tank, 29.0 BPD @ 104” Pump Stroke

- 0.7 HP
  - 0.7 SPM, Input 5 HP, 2.4% System Efficiency
  - 85.53 Sec/Stroke
  - 4.7 BPD in Tank, 34.4 BPD @ 105” Pump Stroke

85.53 Sec/Stroke
As SPM increases the Slippage Volume Increases: More strokes per day results in more slippage volume.
Pump Speed vs. Pump Efficiency

As SPM increases, the Pump Efficiency increases: Slippage Volume is a smaller fraction of Pump Displacement.
Patterson Slippage Equation

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

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

9.73 SPM
Motor Outputs what Gearbox Requires
Torque Analysis: 283.9, 300.1, 324.5, 335.5 Peak Kin-Lb

- 6” Sheave – 5.08 SPM
- 8.5” Sheave – 6.99 SPM
- 10” Sheave – 8.22 SPM
- 12” Sheave – 9.76 SPM
Power Data @ 4 SPMs

2” Plunger, 76 Rod String, 0.009” Clearance

9.73 SPM
### Summary of Test

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

<table>
<thead>
<tr>
<th>Card Selected</th>
<th>SPM</th>
<th>Motor Input, HP</th>
<th>Polished Rod, HP</th>
<th>Power Cost, $/BBL Lifted</th>
<th>System Effic %</th>
<th>Pump Effic %</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 - Sheave:6 Card #15</td>
<td>5.08</td>
<td>11.3</td>
<td>6.6</td>
<td>0.143</td>
<td>44.7</td>
<td>81.6%</td>
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<td>1 - Sheave 8.5 Card #5</td>
<td>6.99</td>
<td>14.9</td>
<td>9.5</td>
<td>0.132</td>
<td>50.2</td>
<td>84.5%</td>
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<tr>
<td>1 - Sheave 10 Card #5</td>
<td>8.22</td>
<td>17.4</td>
<td>11.4</td>
<td>0.130</td>
<td>51.6</td>
<td>85.7%</td>
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<tr>
<td>2 - Sheave 12 Card #5</td>
<td>9.73</td>
<td>21.0</td>
<td>14.3</td>
<td>0.127</td>
<td>52.3</td>
<td>87.0%</td>
</tr>
</tbody>
</table>
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)
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. \( \frac{106+296}{576} = 70\% \text{ Pump Eff.} \)
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

\[ \text{Slippage} = \left[ (0.14 \cdot SPM) + 1 \right] \frac{453}{L \mu} \frac{DPC^{1.52}}{L^2} \]

**Inputs to Pump Slippage Calculations**

- \( D \)= Plunger Diameter (inches) \( 2.25 \)
- \( *P \)= Pressure Differential \( 3155 \)
- \( C \)= Clearance (inches) \( 0.009 \)
- \( \mu \)= 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** \( 121.2 \)
Design Pump Clearance of 0.006” to Achieve 90% Pump Efficiency with 65 BPD Slippage

Patterson Equation Pump Slippage vs Clearance @ SPM = 9.52

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

1. Patterson Equation should be used to Design Pump Clearances – *Better than Rule-of-Thumb*

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
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