Adjustment of Fluid Viscosity for Use in the Patterson Pump Slippage Equation

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Clint Haskins, Fluid Finder
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Introduction

1. Progress Report #4 “Fluid Slippage in Down-Hole Rod-Drawn Oil Well Pumps”, SWPSC 2007, Published Patterson Slippage Equation

2. USE OF THE PUMP SLIPPAGE EQUATION TO DESIGN PUMP CLEARANCES, SWPSC 2012, Design Pump Clearances

3. SUCKER ROD PUMPING SYSTEM DESIGN TOOLS FOR QROD, SWPSC 2013, Slippage Equation in Predictive Rod Design

4. Equivalent Gas Free Pump Fillage Line, SWPSC 2015, Adjustment of Pump Card Displacement to Match Measured Production

- Due to temperature effect on water at the pump depth of the TTU test well a default value of 0.76 cp water viscosity used in all calculation
- Using a viscosity of 0.76 in many cases has yielded reasonably accurate results, but there may be a more accurate option.
- We have Discovered when oil is viscous or waxy with oil gravity below 30-32 Deg API, Viscosity should be determined.
Patterson Pump Slippage Equation
modified ARCO-HF equation to include the effect of SPM on slippage

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

EXCEL Spreadsheet Available on USB: “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
- \(\mu\) = viscosity of fluids, cp
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

Sept. 11 - 13, 2018
1) **TV Close to SV Open** pressure acting on closed SV gradually transferred from tubing at point A to be fully carried by the Closed TV at point B.

2. **SV Open to SV Close**, plunger carries full differential pressure across Closed TV

3) **SV Close to TV Open** pressure across closed TV gradually transferred from rods to be fully carried by the Closed SV at point D.

4) **TV Open to TV Close**, TV open as fluid in the pump is displaced through the traveling valve on the down stroke

**Slippage Occurs when the TV Ball is on the Seat**

Sept. 11 - 13, 2018
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)

Rule-of-Thumb Table

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

If You Use Recommended Clearances from 2007 Rule of Thumb Table

<table>
<thead>
<tr>
<th>Inputs to Pump Slippage Calculations</th>
</tr>
</thead>
<tbody>
<tr>
<td>D=Plunger Diameter (inches)</td>
</tr>
<tr>
<td>P=Pressure Differential</td>
</tr>
<tr>
<td>C=Clearance (inches)</td>
</tr>
<tr>
<td>u=Fluid Viscosity (centipoise)</td>
</tr>
<tr>
<td>Plunger length (inches)</td>
</tr>
<tr>
<td>Strokes per Minute</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

*Calculating Differential Pressure

<table>
<thead>
<tr>
<th>Pump Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tubing Discharge Pressure (Psi)</td>
</tr>
<tr>
<td>Tubing Fluid Gradient (Psi/Ft)</td>
</tr>
<tr>
<td>Pump Intake Pressure (Psi)</td>
</tr>
<tr>
<td>Input your production rate, BPD</td>
</tr>
<tr>
<td>Slippage in BPD</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Plunger Size Inch</th>
<th>Total Clearance Inch</th>
<th>Slippage BPD</th>
<th>100&quot; Stroke Pump Disp. BPD</th>
<th>Slippage %</th>
<th>144&quot; Stroke Pump Disp. BPD</th>
<th>Slippage %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.25</td>
<td>0.005</td>
<td>37.8</td>
<td>131</td>
<td>28.9</td>
<td>208</td>
<td>18.2</td>
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<tr>
<td>1.50</td>
<td>0.006</td>
<td>59.9</td>
<td>143</td>
<td>41.9</td>
<td>274</td>
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<tr>
<td>1.75</td>
<td>0.007</td>
<td>88.4</td>
<td>172</td>
<td>51.4</td>
<td>324</td>
<td>27.3</td>
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<tr>
<td>2.00</td>
<td>0.008</td>
<td>123.7</td>
<td>200</td>
<td>61.9</td>
<td>349</td>
<td>35.4</td>
</tr>
<tr>
<td>2.25</td>
<td>0.009</td>
<td>166.5</td>
<td>211</td>
<td>78.9</td>
<td>401</td>
<td>41.5</td>
</tr>
</tbody>
</table>

86 API Rod String | Anchored Tubing | Red - D Rod Loading > 100%
Viscosity is used in Slippage Calculation
As the SPM increases the Pump Efficiency Increases: Slippage Volume is a Smaller % of Pump Displacement

\[ \text{Pump Efficiency} \% = \frac{\text{Surface Rate}}{\text{Pump Displacement}} \times 100 \]
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
EXCEL Spreadsheet Available on USB: “Pump Slippage Calculator_SPM_PattersonEq.xls”

Inputs to Pump Slippage Calculations
- D = Plunger Diameter (inches) = 2.25
- *P = Pressure Differential = 3155
- C = Clearance (inches) = 0.009
- \( \mu = \text{Fluid Viscosity (centipoise)} \) = 0.76
- 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) = 0.4271
- Pump Intake Pressure (Psi) = 151
- Input your production rate, BPD = 580.0
- Slippage in BPD = 159.8
Design Pump Clearance of 0.005” to Achieve 90% Pump Efficiency with 65 BPD Slippage

Patterson Equation Pump Slippage vs Clearance @ SPM = 9.52

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

**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 from SPM or Target Rate**
- Stroke Rate (SPM): 9.52
- Target Rate: 489

**Dynamometer Cards**
- Rod Load (lb): 651 BPD

**Pump Volumetric Efficiency**: 75.12%

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

*Sept. 11 - 13, 2018*
Design 651 BPD Pump Displacement

Results

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

Dynamometer Cards

Pump Velocity vs. Position

Torque

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

Echometer Company Phone: (940) 767-4334 E-Mail: info@echometer.com
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Patterson Slippage 155.5 BPD

Slippage Calculator

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

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

Patterson Equation Pump Slippage vs Clearance

Pressure Differential (P): 78.96 psi
Tubing Fluid Gradient: 0.985701 psi/ft

Use Calculation | Cancel
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 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. \(\frac{106+296}{577} = 70\% \text{ Pump Eff.}\)
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.*
### Measured Rate Matches Calculated

**Viscosity of Fluids**

\[ \mu = 0.76 \text{ cp} \]

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

<table>
<thead>
<tr>
<th>Liquid</th>
<th>Pump Discharge</th>
<th>(Calc) Surface Stock Tank</th>
<th>(Input) Surface Stock Tank</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BBL/D</td>
<td>BBL/D</td>
<td>BBL/D</td>
</tr>
<tr>
<td>Oil</td>
<td>110</td>
<td>103</td>
<td>106</td>
</tr>
<tr>
<td>Water</td>
<td>306</td>
<td>301</td>
<td>296</td>
</tr>
<tr>
<td>Total Liquid</td>
<td>416</td>
<td>404</td>
<td>402</td>
</tr>
</tbody>
</table>
475 BPD at TV Open on Pump Card but
Why 447 BPD Produced into the Tank

EPT 164.2” = 475 BPD

Production: 08/01/18
14 BOPD  433 BWPD
Using Default 0.76 \( \mu \) Calculates TOO MUCH Slippage

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

Pump Disp of 391 BPD
Adjusted for \( \mu=0.76 \) cp
Calculates 79 BPD Slippage

Slippage:
\( \mu=0.76 \) cp ~ 79 BPD
Using Default $0.76 \mu$ Calculates **TOO MUCH** Slippage
For Oil Gravity of 24.4 Deg Used Oil Viscosity of Fluids $\mu=2.539$ cp

Pump Disp of 445 BPD
Adjusted for $\mu=0.2.539$ cp
Matches 447 BPD in Tank

Slippage: $\mu=2.539$ cp $\sim 23$ BPD
Plunger Length, Diameter, Clearance

Important

Pump

Intake Depth  7701.0 ft
Pump Run Date  1/19/2018
API Pump Designation  25-200 RXBC 26-5

Pump Length  26.0 ft
Plunger Length  60.000 in
Plunger Diameter  2.000 in
Plunger Clearance  0.009 in

\[ 453 \cdot [(0.14 \cdot SPM) + 1] \cdot \frac{DPC^{1.52}}{L \mu} \]
Viscosity $f(P, T, Pb, Oil Wat Gas SG)$

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

<table>
<thead>
<tr>
<th>Pressure (psia)</th>
<th>$R_s$ (SCF/BO)</th>
<th>$B_o$ (vol/vol)</th>
<th>$\mu_o$ (cp)</th>
<th>$z_g$ (vol/vol)</th>
<th>$B_g$ (vol/vol)</th>
<th>$\mu_g$ (cp)</th>
<th>$B_w$ (vol/vol)</th>
<th>$\mu_w$ (cp)</th>
<th>$c_w$ (1/psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>10.3</td>
<td>1.0815</td>
<td>4.440</td>
<td>0.991</td>
<td>0.19049</td>
<td>0.0133</td>
<td>1.0459</td>
<td>0.274</td>
<td>9.07E-07</td>
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<tr>
<td>500</td>
<td>57.8</td>
<td>1.1011</td>
<td>3.610</td>
<td>0.957</td>
<td>0.03678</td>
<td>0.0138</td>
<td>1.0455</td>
<td>0.279</td>
<td>1.08E-06</td>
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<tr>
<td>350</td>
<td>38.5</td>
<td>1.0931</td>
<td>3.906</td>
<td>0.969</td>
<td>0.05323</td>
<td>0.0136</td>
<td>1.0457</td>
<td>0.277</td>
<td>1.04E-06</td>
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<tr>
<td>600</td>
<td>71.3</td>
<td>1.1067</td>
<td>3.427</td>
<td>0.949</td>
<td>0.03040</td>
<td>0.0140</td>
<td>1.0454</td>
<td>0.280</td>
<td>1.17E-06</td>
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<tr>
<td>850</td>
<td>106.9</td>
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<td>3.024</td>
<td>0.930</td>
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<td>0.0145</td>
<td>1.0451</td>
<td>0.283</td>
<td>1.30E-06</td>
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<td>1100</td>
<td>144.7</td>
<td>1.1381</td>
<td>2.690</td>
<td>0.914</td>
<td>0.01597</td>
<td>0.0150</td>
<td>1.0448</td>
<td>0.286</td>
<td>1.44E-06</td>
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<td>1350</td>
<td>184.2</td>
<td>1.1555</td>
<td>2.412</td>
<td>0.900</td>
<td>0.01282</td>
<td>0.0157</td>
<td>1.0444</td>
<td>0.289</td>
<td>1.57E-06</td>
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<td>1600</td>
<td>225.3</td>
<td>1.1738</td>
<td>2.180</td>
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<td>0.01069</td>
<td>0.0165</td>
<td>1.0440</td>
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<td>1850</td>
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<td>1.984</td>
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<td>1.818</td>
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<td>1.96E-06</td>
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<tr>
<td>2326</td>
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<td>1.2319</td>
<td>1.688</td>
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<td>2626</td>
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</table>
Use Oil Only Viscosity at Average of PDP to PIP at Pump Temp at Oil Pb

<table>
<thead>
<tr>
<th>Production</th>
<th>Oil</th>
<th>Water</th>
<th>Total Fluid</th>
<th>Oil Cut</th>
<th>Water Cut</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>13.5</td>
<td>433</td>
<td>446.5</td>
<td>0.0302</td>
<td>0.9698</td>
</tr>
</tbody>
</table>

**PIPELINE**

<table>
<thead>
<tr>
<th>Psia</th>
<th>Viscosity</th>
<th>Oil</th>
<th>Water</th>
<th>Total Fluid</th>
</tr>
</thead>
<tbody>
<tr>
<td>843</td>
<td></td>
<td>3.16279</td>
<td>0.28311</td>
<td>0.37018</td>
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</table>

**Discharge**

<table>
<thead>
<tr>
<th>Psia</th>
<th>Viscosity</th>
<th>Oil</th>
<th>Water</th>
<th>Total Fluid</th>
</tr>
</thead>
<tbody>
<tr>
<td>3532</td>
<td></td>
<td>1.91612</td>
<td>0.32094</td>
<td>0.36917</td>
</tr>
</tbody>
</table>

**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 USB
# Measured Rate Matches Calculated

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

<table>
<thead>
<tr>
<th>Liquid</th>
<th>Pump Discharge</th>
<th>(Calc) Surface Stock Tank</th>
<th>(Input) Surface Stock Tank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil</td>
<td>14</td>
<td>12</td>
<td>14</td>
</tr>
<tr>
<td>Water</td>
<td>438</td>
<td>432</td>
<td>433</td>
</tr>
<tr>
<td>Total Liquid</td>
<td>451</td>
<td>445</td>
<td>447</td>
</tr>
</tbody>
</table>

Viscosity of Fluids $\mu = 2.539$ cp
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
Problems:

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

Actions:

1. **Increase clearance**
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
Conclusions

• 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 $\mu$ 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
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