Design and Optimization of Sucker Rod Pump Using Prosper

Mohd. Kareemuddin Farhan¹, Dr. Somnath Nandi², Prof. P.B. Jadhav³

Department of Petroleum Engineering, MAAER’s Maharashtra Institute of Technology, Pune, India

Abstract: Worldwide, as conventional oil resources are depleted, beam pumping system is becoming the common type of artificial lift method for onshore wells. Production testing of beam pumped wells is an important diagnostic tool to detect potential production problem and for monitoring reservoir performance. In addition, the well test data and the inflow performance relationship (IPR) combined with the production system. Also when larger population of beam pumping wells are connected to central batteries, it is difficult to determine the daily production of each well or to identify the cause of low production in the battery, as there is not any easy way to identify which well is affected. The new method continuously infers the production and by analyzing the down hole pumps card data.

The complete design of a sucker rod pumping system is an involved trial and error process. An ”optimum” design requires that the engineer specify pump size and type; rod string size, taper, and material; surface unit type and size, gear box rating, beam rating, and stroke length; and prime mover type and size. The procedure requires that the engineer first assume an appropriate combination of pump, rod, unit, and prime mover and then perform calculations which lead to refining that initial assumption.

Keywords: Design, Sucker rod pump, Installation, Pumping system, PROSPER.

1. STEPS IN THE DESIGN OF SUCKER ROD INSTALLATION

Objective: - The main objective of designing sucker rod pump is to lift the fluid from the Downhole formation.

Primary design factors that are considered when designing sucker rod pump are

1) Desired mass rate, q, bbl/day
2) Net lift of fluid, L_N, ft

Knowing these two factors help us to estimate the optimized plunger size which results in

a) Minimum rod loads, W_R(1+α), lb
b) Minimum torque on gear box, T_p, in, lb
c) Minimum input power requirements, H_b, hp

Once plunger size is determined, tubing size (A_t) rod sizes (A_r1, A_r2,……), and lengths (L_1, L_2,……), stroke size (S), pumping speed (N), torque rating (T_p) of the unit and power rating of the prime mover (H_b) are calculated.

Such interdependency of these variables makes their selection extremely difficult if design problem were approached entirely from the mathematical standpoint without benefit of previous experience.

Assumptions to Well Conditions:- If certain assumptions to well conditions are made then it becomes possible to prepare charts and tables (Lubinski and Blenkarn) which greatly reduce the efforts necessary in designing a pumping installation. Generally made assumptions are
1) Specific gravity (G) of well fluids is 1.00, and
2) Net lift (L_N), working fluid level (D) and pump setting depth (L) are same

\[ L_N = D + \frac{2.2\pi P_t}{G} = D = L \]

But it must be realized that chart values may have to be adjusted to fit a particular situation. For example, tubing already present in the well to be put on pump dictates the maximum pump size, which might be smaller than the optimum size indicated by the selection chart.

Minimum information required for installing pump constitutes
a) Fluid production rate, \( q \)
b) Depth to pump, \( L \)
c) Working fluid level
d) which is if not known, assume to be equivalent to pump setting depth,
e) Volumetric efficiency of pump (Usually 0.8 for design purposes), \( E_v \)
f) Specific gravity of fluid, \( G \)

1.1 Following steps are involved in designing a pumping installation

1. From maximum anticipated fluid production and estimated volumetric efficiency, calculate pump displacement (V)
\[ V = \frac{q}{E_v} \]
2. From Fig 1 estimate API pumps size and stroke length.

![Figure 1 Sucker rod pumping unit selection chart (Kelley and Willis, 1954).](image)

3. From Tables 1 to 8 select tubing size (A_t), plunger size (A_p), rod sizes (A_r) and pumping speed (N) corresponding to pump setting depth (L).
4. Calculate fractional length of each section of the rod string, using data of Tables 9 and 10
5. Calculate the length of each section of the rod string to nearest 25 feet.
### Table 1: DESIGN DATA FOR API SIZE 40 UNIT WITH 34-INCH STROKE
(After Kelley and Willis)

<table>
<thead>
<tr>
<th>Pump Depth</th>
<th>Plunger Size</th>
<th>Tubing Size</th>
<th>Rod Sizes</th>
<th>Pumping Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>ft</td>
<td>in.</td>
<td>in.</td>
<td>in.</td>
<td>strokes/min</td>
</tr>
<tr>
<td>1000-1100</td>
<td>2 ¾</td>
<td>3</td>
<td>¾</td>
<td>24-19</td>
</tr>
<tr>
<td>1100-1250</td>
<td>2 ½</td>
<td>3</td>
<td>¾</td>
<td>24-19</td>
</tr>
<tr>
<td>1250-1650</td>
<td>2 ¼</td>
<td>2 ½</td>
<td>¾</td>
<td>24-19</td>
</tr>
<tr>
<td>1650-1900</td>
<td>2</td>
<td>2 ½</td>
<td>¾</td>
<td>24-19</td>
</tr>
<tr>
<td>1900-2150</td>
<td>1 ¾</td>
<td>2 ½</td>
<td>¾</td>
<td>24-19</td>
</tr>
<tr>
<td>2150-3000</td>
<td>1 ½</td>
<td>2</td>
<td>¾-¾</td>
<td>24-19</td>
</tr>
<tr>
<td>3000-3700</td>
<td>1 ¼</td>
<td>2</td>
<td>¾-¾</td>
<td>22-18</td>
</tr>
</tbody>
</table>

### Table 2: DESIGN DATA FOR API SIZE 57 UNIT WITH 42-INCH STROKE
(After Kelley and Willis)

<table>
<thead>
<tr>
<th>Pump Depth</th>
<th>Plunger Size</th>
<th>Tubing Size</th>
<th>Rod Sizes</th>
<th>Pumping Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>ft</td>
<td>in.</td>
<td>in.</td>
<td>in.</td>
<td>strokes/min</td>
</tr>
<tr>
<td>1150-1300</td>
<td>2 ¾</td>
<td>3</td>
<td>¾</td>
<td>24-19</td>
</tr>
<tr>
<td>1300-1450</td>
<td>2 ½</td>
<td>3</td>
<td>¾</td>
<td>24-19</td>
</tr>
<tr>
<td>1450-1850</td>
<td>2 ¼</td>
<td>2 ½</td>
<td>¾</td>
<td>24-19</td>
</tr>
<tr>
<td>1850-2200</td>
<td>2</td>
<td>2 ½</td>
<td>¾</td>
<td>24-19</td>
</tr>
<tr>
<td>2200-2500</td>
<td>1 ¾</td>
<td>2 ½</td>
<td>¾</td>
<td>24-19</td>
</tr>
<tr>
<td>2500-3400</td>
<td>1 ½</td>
<td>2</td>
<td>¾-¾</td>
<td>23-18</td>
</tr>
<tr>
<td>3400-4200</td>
<td>1 ¼</td>
<td>2</td>
<td>¾-¾</td>
<td>22-17</td>
</tr>
<tr>
<td>4200-5000</td>
<td>1</td>
<td>2</td>
<td>¾-¾</td>
<td>21-17</td>
</tr>
</tbody>
</table>

### Table 3: DESIGN DATA FOR API SIZE 80 UNIT WITH 48-INCH STROKE
(After Kelley and Willis)

<table>
<thead>
<tr>
<th>Pump Depth</th>
<th>Plunger Size</th>
<th>Tubing Size</th>
<th>Rod Sizes</th>
<th>Pumping Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>ft</td>
<td>in.</td>
<td>in.</td>
<td>in.</td>
<td>strokes/min</td>
</tr>
<tr>
<td>1400-1550</td>
<td>2 ¾</td>
<td>3</td>
<td>¾</td>
<td>24-19</td>
</tr>
<tr>
<td>1550-1700</td>
<td>2 ½</td>
<td>3</td>
<td>¾</td>
<td>24-19</td>
</tr>
<tr>
<td>1700-2200</td>
<td>2 ¼</td>
<td>2 ½</td>
<td>¾</td>
<td>24-19</td>
</tr>
<tr>
<td>2200-2600</td>
<td>2</td>
<td>2 ½</td>
<td>¾</td>
<td>24-19</td>
</tr>
<tr>
<td>2600-3000</td>
<td>1 ¾</td>
<td>2 ½</td>
<td>¾</td>
<td>23-18</td>
</tr>
<tr>
<td>3000-4100</td>
<td>1 ½</td>
<td>2</td>
<td>¾-¾</td>
<td>23-18</td>
</tr>
<tr>
<td>4100-5000</td>
<td>1 ¼</td>
<td>2</td>
<td>¾-¾</td>
<td>21-17</td>
</tr>
<tr>
<td>5000-6000</td>
<td>1</td>
<td>2</td>
<td>¾-¾</td>
<td>19-17</td>
</tr>
</tbody>
</table>

### Table 4: DESIGN DATA FOR API SIZE 114 UNIT WITH 54-INCH STROKE
(After Kelley and Willis)

<table>
<thead>
<tr>
<th>Pump Depth</th>
<th>Plunger Size</th>
<th>Tubing Size</th>
<th>Rod Sizes</th>
<th>Pumping Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>ft</td>
<td>in.</td>
<td>in.</td>
<td>in.</td>
<td>strokes/min</td>
</tr>
<tr>
<td>1700-1900</td>
<td>2 ¾</td>
<td>3</td>
<td>¾</td>
<td>24-19</td>
</tr>
<tr>
<td>1900-2100</td>
<td>2 ½</td>
<td>3</td>
<td>¾</td>
<td>24-19</td>
</tr>
<tr>
<td>2100-2700</td>
<td>2 ¼</td>
<td>2 ½</td>
<td>¾</td>
<td>24-19</td>
</tr>
<tr>
<td>2700-3300</td>
<td>2</td>
<td>2 ½</td>
<td>¾</td>
<td>23-18</td>
</tr>
<tr>
<td>3300-3900</td>
<td>1 ¾</td>
<td>2 ½</td>
<td>¾</td>
<td>22-17</td>
</tr>
<tr>
<td>3900-5100</td>
<td>1 ½</td>
<td>2</td>
<td>¾-¾</td>
<td>21-17</td>
</tr>
<tr>
<td>5100-6300</td>
<td>1 ¼</td>
<td>2</td>
<td>¾-¾</td>
<td>19-17</td>
</tr>
</tbody>
</table>
Table 5 DESIGN DATA FOR API SIZE 160 UNIT WITH 64-INCH STROKE  
(After Kelley and Willis)

<table>
<thead>
<tr>
<th>Pump Depth (ft)</th>
<th>Plunger Size (in.)</th>
<th>Tubing Size (in.)</th>
<th>Rod Sizes (in.)</th>
<th>Pumping Speed (strokes/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000-2200</td>
<td>2 ¾</td>
<td>3</td>
<td>⅛</td>
<td>24-19</td>
</tr>
<tr>
<td>2200-2400</td>
<td>2 ½</td>
<td>3</td>
<td>⅛-⅜</td>
<td>23-19</td>
</tr>
<tr>
<td>2400-3000</td>
<td>2 ¼</td>
<td>2 ½</td>
<td>⅜-⅞</td>
<td>23-19</td>
</tr>
<tr>
<td>3000-3600</td>
<td>2</td>
<td>2 ½</td>
<td>⅜-⅞</td>
<td>23-18</td>
</tr>
<tr>
<td>3600-4200</td>
<td>1 ¾</td>
<td>2 ½</td>
<td>⅞</td>
<td>22-17</td>
</tr>
<tr>
<td>4200-5400</td>
<td>1 ½</td>
<td>2</td>
<td>⅞-⅜-⅞</td>
<td>21-17</td>
</tr>
<tr>
<td>5400-6700</td>
<td>1 ¼</td>
<td>2</td>
<td>⅞-⅜-⅞</td>
<td>19-15</td>
</tr>
<tr>
<td>6700-7750</td>
<td>1</td>
<td>2</td>
<td>⅞-⅜-⅞</td>
<td>17-15</td>
</tr>
</tbody>
</table>

Table 6 DESIGN DATA FOR API SIZE 228 UNIT WITH 74-INCH STROKE  
(After Kelley and Willis)

<table>
<thead>
<tr>
<th>Pump Depth (ft)</th>
<th>Plunger Size (in.)</th>
<th>Tubing Size (in.)</th>
<th>Rod Sizes (in.)</th>
<th>Pumping Speed (strokes/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2400-2600</td>
<td>2 ¾</td>
<td>3</td>
<td>⅛</td>
<td>24-20</td>
</tr>
<tr>
<td>2600-3000</td>
<td>2 ½</td>
<td>3</td>
<td>⅛</td>
<td>23-18</td>
</tr>
<tr>
<td>3000-3700</td>
<td>2 ¼</td>
<td>2 ½</td>
<td>⅜-⅞</td>
<td>22-17</td>
</tr>
<tr>
<td>3700-4500</td>
<td>2</td>
<td>2 ½</td>
<td>⅞-⅞</td>
<td>21-16</td>
</tr>
<tr>
<td>4500-5200</td>
<td>1 ¾</td>
<td>2 ½</td>
<td>⅞-⅞</td>
<td>19-15</td>
</tr>
<tr>
<td>5200-6800</td>
<td>1 ½</td>
<td>2</td>
<td>⅞-⅞-⅞</td>
<td>18-14</td>
</tr>
<tr>
<td>6800-8000</td>
<td>1 ¼</td>
<td>2</td>
<td>⅞-⅞-⅞</td>
<td>16-13</td>
</tr>
<tr>
<td>8000-8500</td>
<td>1/2</td>
<td>2</td>
<td>⅞-⅞-⅞</td>
<td>14-13</td>
</tr>
</tbody>
</table>

Table 7 DESIGN DATA FOR API SIZE 320 UNIT WITH 84-INCH STROKE  
(After Kelley and Willis)

<table>
<thead>
<tr>
<th>Pump Depth (ft)</th>
<th>Plunger Size (in.)</th>
<th>Tubing Size (in.)</th>
<th>Rod Sizes (in.)</th>
<th>Pumping Speed (strokes/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2800-3200</td>
<td>2 ¾</td>
<td>3</td>
<td>⅛</td>
<td>23-18</td>
</tr>
<tr>
<td>3200-3600</td>
<td>2 ½</td>
<td>3</td>
<td>⅛</td>
<td>21-17</td>
</tr>
<tr>
<td>3600-4100</td>
<td>2 ¼</td>
<td>2 ½</td>
<td>⅞-⅞-⅞</td>
<td>21-17</td>
</tr>
<tr>
<td>4100-4800</td>
<td>2</td>
<td>2 ½</td>
<td>⅞-⅞-⅞</td>
<td>20-16</td>
</tr>
<tr>
<td>4800-5600</td>
<td>1 ¾</td>
<td>2 ½</td>
<td>⅞-⅞-⅞</td>
<td>19-16</td>
</tr>
<tr>
<td>5600-6700</td>
<td>1 ½</td>
<td>2 ½</td>
<td>⅞-⅞-⅞</td>
<td>18-15</td>
</tr>
<tr>
<td>6700-8000</td>
<td>1 ¼</td>
<td>2 ½</td>
<td>⅞-⅞-⅞</td>
<td>17-13</td>
</tr>
<tr>
<td>8000-9500</td>
<td>1 1/6</td>
<td>2 ½</td>
<td>⅞-⅞-⅞</td>
<td>14-11</td>
</tr>
</tbody>
</table>
Table 8 DESIGN DATA FOR API SIZE 640 UNIT WITH 144-INCH STROKE
(After Kelley and Willis)

<table>
<thead>
<tr>
<th>Pump Depth</th>
<th>Plunger Size</th>
<th>Tubing Size</th>
<th>Rod Sizes</th>
<th>Pumping Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>ft</td>
<td>in.</td>
<td>in.</td>
<td>in.</td>
<td>strokes/min</td>
</tr>
<tr>
<td>3200-3500</td>
<td>2 ¾</td>
<td>3</td>
<td>¾-1</td>
<td>18-14</td>
</tr>
<tr>
<td>3500-4000</td>
<td>2 ½</td>
<td>3</td>
<td>¾-1</td>
<td>17-13</td>
</tr>
<tr>
<td>4000-4700</td>
<td>2 ¼</td>
<td>2 ½</td>
<td>¾-¾-1</td>
<td>16-13</td>
</tr>
<tr>
<td>4700-5700</td>
<td>2</td>
<td>2 ½</td>
<td>¾-¾-1</td>
<td>15-12</td>
</tr>
<tr>
<td>5700-6600</td>
<td>1 ¾</td>
<td>2 ½</td>
<td>¾-¾-1</td>
<td>14-12</td>
</tr>
<tr>
<td>6600-8000</td>
<td>1 ½</td>
<td>2 ½</td>
<td>¾-¾-1</td>
<td>14-11</td>
</tr>
<tr>
<td>8000-9600</td>
<td>1 ¼</td>
<td>2 ½</td>
<td>¾-¾-1</td>
<td>13-10</td>
</tr>
<tr>
<td>9600-11,000</td>
<td>1 7/16</td>
<td>2 ½</td>
<td>¾-¾-1</td>
<td>12-10</td>
</tr>
</tbody>
</table>

Table 9 DATA FOR DESIGN OF TAPERED SUCKER ROD STRING

<table>
<thead>
<tr>
<th>Rod sizes in string, in.</th>
<th>Values of R*</th>
</tr>
</thead>
<tbody>
<tr>
<td>⅝-¾</td>
<td>R₁ = 0.759-0.0896 Aₚ</td>
</tr>
<tr>
<td></td>
<td>R₂ = 0.241+0.0896 Aₚ</td>
</tr>
<tr>
<td>¾-7/8</td>
<td>R₁ = 0.627-0.1393 Aₚ</td>
</tr>
<tr>
<td></td>
<td>R₂ = 0.199+0.0737 Aₚ</td>
</tr>
<tr>
<td>¾-1</td>
<td>R₁ = 0.627-0.1393 Aₚ</td>
</tr>
<tr>
<td></td>
<td>R₂ = 0.199+0.0737 Aₚ</td>
</tr>
<tr>
<td>¾-¾-7/8</td>
<td>R₁ = 0.627-0.1393 Aₚ</td>
</tr>
<tr>
<td></td>
<td>R₂ = 0.199+0.0737 Aₚ</td>
</tr>
<tr>
<td></td>
<td>R₃ = 0.175+0.0655 Aₚ</td>
</tr>
<tr>
<td>¾-¾-1</td>
<td>R₁ = 0.664-0.0894 Aₚ</td>
</tr>
<tr>
<td></td>
<td>R₂ = 0.175+0.0478 Aₚ</td>
</tr>
<tr>
<td></td>
<td>R₃ = 0.155+0.0416 Aₚ</td>
</tr>
<tr>
<td>¾-¾-1-1⅛</td>
<td>R₁ = 0.582 – 0.1110 Aₚ</td>
</tr>
<tr>
<td></td>
<td>R₂ = 0.158+0.0421 Aₚ</td>
</tr>
<tr>
<td></td>
<td>R₃ = 0.137+0.0364 Aₚ</td>
</tr>
<tr>
<td></td>
<td>R₄ = 0.123+0.0325 Aₚ</td>
</tr>
</tbody>
</table>

Table 10 PUMP PLUNGER DATA

<table>
<thead>
<tr>
<th>Diameter, in.</th>
<th>Area, sq in.</th>
<th>Pumping Constant, bbl/day/in./spm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.785</td>
<td>0.116</td>
</tr>
<tr>
<td>1 7/16</td>
<td>0.886</td>
<td>0.131</td>
</tr>
<tr>
<td>1 ¼</td>
<td>1.227</td>
<td>0.182</td>
</tr>
<tr>
<td>1 ½</td>
<td>1.767</td>
<td>0.262</td>
</tr>
<tr>
<td>1 ¾</td>
<td>2.405</td>
<td>0.357</td>
</tr>
<tr>
<td>1 7/32</td>
<td>2.488</td>
<td>0.369</td>
</tr>
<tr>
<td>2</td>
<td>3.142</td>
<td>0.466</td>
</tr>
<tr>
<td>2 ¼</td>
<td>3.976</td>
<td>0.590</td>
</tr>
<tr>
<td>2 ½</td>
<td>4.909</td>
<td>0.728</td>
</tr>
<tr>
<td>2 ¾</td>
<td>5.940</td>
<td>0.881</td>
</tr>
<tr>
<td>3 ¼</td>
<td>11.045</td>
<td>1.639</td>
</tr>
<tr>
<td>4 ¼</td>
<td>17.721</td>
<td>2.630</td>
</tr>
</tbody>
</table>

6. Calculate acceleration factor

\[ \alpha = SN^2/70,500 \]
7. Determine effective plunger stroke

\[ S_p = S + 40.8 \frac{L^2 \sigma}{E} - 5.20 \frac{GDA_p}{E} \left[ \frac{L}{A_t} + \frac{L_1}{A_1} + \frac{L_2}{A_2} + \ldots \right] \]

8. Using estimated volumetric efficiency, calculate the maximum probable production rate and check it against the desired production rate

\[ q = K S_p N E \]

9. Calculate dead weight of the rod string

\[ W_r = L_1 M_1 + L_2 M_2 + L_3 M_3 + \ldots \]

10. Calculate fluid load

\[ W_f = 0.433G(LA_p - 0.294W_r) \]

11. Determine peak polished rod load and check it against the maximum bean load for the unit selected.

\[ W_{max} = W_f + W_r (1 + \alpha) \]

12. Calculate maximum stress at the top of the rod string and check it against the maximum permissible working stress for the unit selected

\[ \text{Maximum rod stress} = \frac{W_{max}}{A_3} \]

13. Calculate ideal counterbalance effect and check it against the counterbalance available for the unit selected

\[ C_i = 0.5W_f + W_r (1 - 0.127G) \]

14. From the manufacturer’s literature determine the position of counter weight to obtain the ideal counterbalance effect.

15. On the assumption that unit will no more than 5 per cent out of counterbalance effect, calculate the peak torque on the gear reducer and check it against the API rating of the unit selected

\[ T_P = (W_{max} - 0.95 C_i) (S/2) \]

16. Calculate the hydraulic horsepower, friction horsepower and brake horsepower of the prime mover and select prime mover

\[ H_h = 7.36 \times 10^6 qGL \]

\[ H_f = 6.31 \times 10^7 W_r SN \]

\[ H_b = 1.5 (H_h + H_f) \]

17. From the manufacturer’s literature obtain the gear reduction ratio and unit sheave size for the unit selected, and the speed of the prime mover. From this determine engine sheave size to obtain the desired pumping speed.

\[ d_e = Z d_u (N/N_e) \]

If at any step, the unit or any component of the unit is found to be either undersized or over-sized as to load, torque, or production capacity, the design should be changed accordingly.

2. PROSPER

PROSPER is a well performance, design and optimisation program which is part of the Integrated Production Modelling Toolkit (IPM). This tool is the industry standard well modelling with the major operators worldwide.

PROSPER is designed to allow the building of reliable and consistent well models, with the ability to address each aspect of well bore modelling viz, PVT (fluid characterisation), VLP correlations (for calculation of flow-line and tubing pressure loss) and IPR (reservoir inflow).
PROSPER provides unique matching features, which tune PVT, multiphase flow correlations and IPRs to match measured field data, allowing a consistent well model to be built prior to use in prediction (sensitivities or artificial lift design). PROSPER enables detailed surface pipeline performance and design: Flow Regimes, Hydrates Flag, Pipeline Stability Studies, Slug Size and Frequency.

2.1 APPLICATIONS:

1) Design and optimise well completions including multi-lateral, multi-layer and horizontal wells
2) Design and optimise tubing and pipeline sizes
3) Design, diagnose and optimise Gas lifted, Hydraulic pumps, PCP, Jet Pump and ESP wells
4) Flow Assurance Studies - well and surface pipelines
5) Generate lift curves for use in reservoir simulators
6) Calculate pressure losses in wells, flow lines and across chokes

Figure: - 2 PROSPER First Page (Overview)
2.2 INFLOW PERFORMANCE MODELS (IPR):

1) Multilateral well models
2) Single branch (Simple) inflows
3) Several proprietary inflow models for various fluids

Fig: -3 artificial lift design workflow in PROSPER
3. COMPUTER MODELLING OF SUCKER ROD PUMPING

3.1 Fluid Data:

<table>
<thead>
<tr>
<th></th>
<th>Model</th>
<th>Black Oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reservoir Fluid</td>
<td>Water and Oil</td>
<td></td>
</tr>
<tr>
<td>Separator</td>
<td>Single Stage</td>
<td></td>
</tr>
<tr>
<td>Solution GOR</td>
<td>160 scf/stb</td>
<td></td>
</tr>
<tr>
<td>Oil Gravity (API)</td>
<td>25°</td>
<td></td>
</tr>
<tr>
<td>Gas Gravity (sp. gravity)</td>
<td>0.68</td>
<td></td>
</tr>
<tr>
<td>Water Salinity</td>
<td>80,000</td>
<td></td>
</tr>
<tr>
<td>Mole Per cent H2S</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Mole Per cent CO2</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Mole Per cent N2</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Pb, Rs, Bo Correlation</td>
<td>Glaso</td>
<td></td>
</tr>
<tr>
<td>Oil Viscosity correlation</td>
<td>Beal et al</td>
<td></td>
</tr>
<tr>
<td>Water Cut, %</td>
<td>80</td>
<td></td>
</tr>
</tbody>
</table>

Equipment Data:–

1) Deviation Survey

<table>
<thead>
<tr>
<th>MD, ft</th>
<th>TVD, ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3500</td>
<td>3500</td>
</tr>
</tbody>
</table>

2) Downhole Equipment:–

<table>
<thead>
<tr>
<th>Equipment Type</th>
<th>Measured Depth, inch</th>
<th>Tubing ID, inch</th>
<th>Tubing Inside Roughness, inch</th>
<th>Tubing OD, inch</th>
<th>Casing ID, inch</th>
<th>Casing Inside Roughness, inch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xmas</td>
<td>0</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Tubing</td>
<td>3500</td>
<td>2.441</td>
<td>0.0012</td>
<td>2.625</td>
<td>6.3</td>
<td>0.0012</td>
</tr>
</tbody>
</table>

3) Geothermal Gradient:–

<table>
<thead>
<tr>
<th>Measured Depth in ft</th>
<th>Static Ambient Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>60</td>
</tr>
<tr>
<td>3500</td>
<td>130</td>
</tr>
</tbody>
</table>

Overall Heat Transfer Coefficient: 8 Btu/h/ft²/F

3.2 INFLOW PERFORMANCE RELATION:

Inflow Performance Data:–

<table>
<thead>
<tr>
<th>Reservoir model</th>
<th>PI Entry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reservoir pressure</td>
<td>1500 psig</td>
</tr>
<tr>
<td>Reservoir Temperature</td>
<td>130 degF</td>
</tr>
<tr>
<td>Water Cut</td>
<td>80 %</td>
</tr>
<tr>
<td>Total GOR</td>
<td>160 scf/stb</td>
</tr>
<tr>
<td>Compaction Permeability model:</td>
<td>NO</td>
</tr>
<tr>
<td>Relative Permeability</td>
<td>NO</td>
</tr>
<tr>
<td>Productivity Index</td>
<td>0.25 stb/psi</td>
</tr>
</tbody>
</table>
### 3.3 SRP-DESIGN PARAMETERS:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anchored Tubing</td>
<td>Yes</td>
</tr>
<tr>
<td>Pump depth</td>
<td>3500 ft</td>
</tr>
<tr>
<td>Pump Diameter</td>
<td>2 inches</td>
</tr>
<tr>
<td>Surface stroke length</td>
<td>48 inches</td>
</tr>
<tr>
<td>Pump Speed</td>
<td>12 strokes / minutes</td>
</tr>
<tr>
<td>Rode Selection - Rod type</td>
<td>Steel Rods</td>
</tr>
<tr>
<td>Rod Number</td>
<td>ROD99/04</td>
</tr>
<tr>
<td>Gas Anchor Method</td>
<td>Entered</td>
</tr>
<tr>
<td>Gas Anchor Efficiency</td>
<td>0.8 (fraction)</td>
</tr>
<tr>
<td>Type</td>
<td>Poor Boy</td>
</tr>
<tr>
<td>Annulus Area</td>
<td>1.5 in²</td>
</tr>
</tbody>
</table>

Further design parameters are:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculation mode</td>
<td>Enter Production Rate, Estimate Stroke Rate</td>
</tr>
<tr>
<td>Pumping Unit Selection</td>
<td>LUFKIN C-320-305-100 LC044</td>
</tr>
<tr>
<td>Rod Grad</td>
<td>D</td>
</tr>
<tr>
<td>Service Factor</td>
<td>Non-corrosive</td>
</tr>
<tr>
<td>Pump Intake Pressure Method</td>
<td>Entered</td>
</tr>
<tr>
<td>Mid Perforation Depth</td>
<td>3500 ft</td>
</tr>
<tr>
<td>Design Input - Unit type</td>
<td>Conventional Clockwise</td>
</tr>
<tr>
<td>Design Input - Anchored tubing</td>
<td>Yes</td>
</tr>
<tr>
<td>Design Input – Mid Point Perforation depth</td>
<td>3500 ft</td>
</tr>
<tr>
<td>Design Input - Pump Depth</td>
<td>3500 ft</td>
</tr>
<tr>
<td>Design Input – Pump Volumetric Efficiency:</td>
<td>80%</td>
</tr>
<tr>
<td>Design Input - Unit Efficiency</td>
<td>75%</td>
</tr>
<tr>
<td>Design Input - Pump Diameter</td>
<td>2&quot;</td>
</tr>
<tr>
<td>Design Input - Surface Stroke length</td>
<td>48 &quot;</td>
</tr>
<tr>
<td>Design Input - Bottom Hole Temperature</td>
<td>130 degF</td>
</tr>
<tr>
<td>Design Input - Well Head Temperature</td>
<td>90 degF</td>
</tr>
<tr>
<td>Design Input - Well Head Pressure</td>
<td>100 psig</td>
</tr>
</tbody>
</table>
Figure: 4 Complete Design of Sucker Rod Pump (SRP)
## 3.4 DESIGN RESULTS.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frictional Power</td>
<td>9.14756 (hp)</td>
</tr>
<tr>
<td>Polished Rod Power</td>
<td>12.753 (hp)</td>
</tr>
<tr>
<td>Name Plate Power</td>
<td>19.1823 (hp)</td>
</tr>
<tr>
<td>Work Done By Pump</td>
<td>6337.36 (lbf)</td>
</tr>
<tr>
<td>Work Done By Polished Rod</td>
<td>23914.6 (lbf)</td>
</tr>
<tr>
<td>Top Rod % Of Goodman Diagram</td>
<td>68.8292 (percent)</td>
</tr>
<tr>
<td>Top Rod Loading</td>
<td>71.4076 (percent)</td>
</tr>
<tr>
<td>Volumetric Efficiency</td>
<td>80.1768 (percent)</td>
</tr>
<tr>
<td>Actual Liquid Production Rate</td>
<td>421.347 STB/day</td>
</tr>
<tr>
<td>Cyclic Load Factor</td>
<td>1.20331</td>
</tr>
<tr>
<td>Peak Polished Rod Load</td>
<td>21402.8 (lbf)</td>
</tr>
<tr>
<td>Minimum Polished Rod Load</td>
<td>2479.32 (lbf)</td>
</tr>
<tr>
<td>Pump Stroke Length</td>
<td>49.7679 (in)</td>
</tr>
<tr>
<td>Static Stretch</td>
<td>2.16758 (in)</td>
</tr>
<tr>
<td>Plunger OverTravel (Ep)</td>
<td>5.89969 (in)</td>
</tr>
<tr>
<td>Fluid Load (Fo)</td>
<td>1539.01 (lbf)</td>
</tr>
<tr>
<td>Weight Of Rods In Fluid (Wrf)</td>
<td>11250.7 (lbf)</td>
</tr>
<tr>
<td>Total Load (Wrf + Fo)</td>
<td>12789.7 (lbf)</td>
</tr>
<tr>
<td>Maximum Torque</td>
<td>322693 (lb.ins)</td>
</tr>
<tr>
<td>Fo/Kr</td>
<td>0.044102</td>
</tr>
<tr>
<td>1/Kr</td>
<td>0.0013755</td>
</tr>
<tr>
<td>CounterWeight Required (CBE)</td>
<td>12741.4 (lbf)</td>
</tr>
<tr>
<td>CounterWeight Position</td>
<td>29.7482 (in)</td>
</tr>
<tr>
<td>Damping Factor</td>
<td>0.16008</td>
</tr>
<tr>
<td>Stress (Max)</td>
<td>21531.5 (psi)</td>
</tr>
<tr>
<td>Stress (Min)</td>
<td>2494.23 (psi)</td>
</tr>
<tr>
<td>Stress (Max Allowable)</td>
<td>30153 (psi)</td>
</tr>
<tr>
<td>Torsional Effectiveness (ITE)</td>
<td>15.3744 (percent)</td>
</tr>
<tr>
<td>Lift Efficiency (LE)</td>
<td>75.1964 (percent)</td>
</tr>
<tr>
<td>Economic Index (EI)</td>
<td>596.838</td>
</tr>
</tbody>
</table>
3.5 ROD SENSITIVITY RUN:

Following picture and plot shows the variation of production rates and horse power requirements with rod types.

---

### Sucker Rod Pump Design - Rod Sensitivity

<table>
<thead>
<tr>
<th>Rod Index</th>
<th>Rod Name</th>
<th>Production</th>
<th>Horsepower</th>
<th>Bbls./HP</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>ROD04/05</td>
<td>123.62</td>
<td>15.7596</td>
<td>77.9532</td>
</tr>
<tr>
<td>15</td>
<td>ROD05/05</td>
<td>137.81</td>
<td>17.5194</td>
<td>65.3956</td>
</tr>
<tr>
<td>22</td>
<td>ROD06/05</td>
<td>763.112</td>
<td>11.6453</td>
<td>65.5259</td>
</tr>
<tr>
<td>37</td>
<td>ROD07/05</td>
<td>625.06</td>
<td>10.2052</td>
<td>65.5052</td>
</tr>
<tr>
<td>46</td>
<td>ROD08/05</td>
<td>575.389</td>
<td>10.4552</td>
<td>54.823</td>
</tr>
<tr>
<td>57</td>
<td>ROD09/05</td>
<td>594.123</td>
<td>11.5074</td>
<td>45.8095</td>
</tr>
<tr>
<td>62</td>
<td>ROD10/05</td>
<td>525.029</td>
<td>10.8058</td>
<td>50.9628</td>
</tr>
<tr>
<td>73</td>
<td>ROD11/05</td>
<td>486.805</td>
<td>10.9553</td>
<td>46.1004</td>
</tr>
<tr>
<td>86</td>
<td>ROD12/05</td>
<td>500.459</td>
<td>10.5076</td>
<td>45.8634</td>
</tr>
<tr>
<td>96</td>
<td>ROD13/05</td>
<td>400.612</td>
<td>10.6150</td>
<td>45.6406</td>
</tr>
<tr>
<td>107</td>
<td>ROD14/05</td>
<td>444.007</td>
<td>11.4351</td>
<td>36.9986</td>
</tr>
<tr>
<td>124</td>
<td>ROD15/05</td>
<td>461.221</td>
<td>11.5222</td>
<td>38.9586</td>
</tr>
<tr>
<td>133</td>
<td>ROD16/05</td>
<td>436.806</td>
<td>11.754</td>
<td>37.9771</td>
</tr>
<tr>
<td>144</td>
<td>ROD17/05</td>
<td>424.375</td>
<td>12.7559</td>
<td>34.0834</td>
</tr>
<tr>
<td>162</td>
<td>ROD18/05</td>
<td>457.114</td>
<td>13.2277</td>
<td>34.9022</td>
</tr>
<tr>
<td>173</td>
<td>ROD19/05</td>
<td>433.39</td>
<td>13.6404</td>
<td>31.7725</td>
</tr>
</tbody>
</table>
3.6 PUMPING SPEED SENSITIVITY:
In the same way, different pumping speeds on the behalf of vertical lift performance can be checked.

4. INFLOW (IPR) V OUTFLOW (VLP) PLOT
REFERENCES


[3] Heriot-Watt University - Production Technology volume 1 (Unpublished work) Members of Heriot-Watt University have free access to the above journals www.hw.ac.uk/is/njindex.php.

[4] Heriot-Watt University - Production Technology volume II (Unpublished work) Members of Heriot-Watt University have free access to the above journals www.hw.ac.uk/is/njindex.php.


[10] J.R. Eickmeier, Shell Canada Ltd, SPE 1643, Diagnostic Analysis of Dynamometer cards, Paper was presented at the meeting held in Canadian Institute of Mining and Metallurgy at Canada, May 1966.

