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Optimization of sucker rod pump performance using tubing anchors

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ABSTRACT

Sucker rod pumps (SRPs) remain the backbone of artificial lift, yet their efficiency is undermined by tubing displacement and irregular valve operation. Tubing anchors (TA) are designed to stabilize tubing and restore stroke fidelity, but their true impact has often been generalized rather than quantified. This study delivers a systematic evaluation of TA performance using QRod 3.0 simulations across seven plunger diameters and depths from 500 to 2000 m, supported by a full calculation table of production values (Qf) with and without anchor. The results are unambiguous: TA has no measurable effect in shallow wells with small plungers, but its influence grows steadily with depth and plunger size. In mid-range configurations, anchored systems consistently outperform non-anchored ones, while in large plungers beyond 1200 m, TA becomes critical to sustaining production. At extreme depths with very large plungers, however, both anchored and non-anchored systems collapse, exposing the physical limits of SRP technology. These findings prove that TA is not a universal solution but a targeted optimization tool. Its selective application extends the operational envelope of SRPs, improves volumetric efficiency, and delivers tangible economic gains where tubing displacement is a dominant factor. The study provides operators with quantitative evidence for decision-making, replacing assumptions with data-driven justification for TA deployment.

KEYWORDS

Artificial lift, Sucker rod pump, Tubing anchor, Volumetric efficiency, QRod simulation, Production optimization, Mechanical pumping systems.

1. INTRODUCTION

Artificial lift methods are essential when reservoir pressure declines below economic production limits. Among mechanical methods - gas lift, ESP, hydraulic pumps - sucker rod pumps dominate globally, accounting for more than 80% of installations [1]. Their simplicity and adaptability make them indispensable, but efficiency losses remain a challenge.

Elastic deformation of rods and tubing causes axial displacement, leading to irregular valve operation and reduced VE [2]. Tubing anchors are designed to fix tubing at depth, reducing displacement and stabilizing pump operation [3]. The objective of this study is to quantify the impact of TA on SRP performance, evaluating both technical benefits and economic justification.

2. SUCKER ROD PUMP SYSTEM AND LIMITATIONS

SRPs operate by transferring surface mechanical energy through rod strings to a downhole plunger [4]. During operation, forces such as buoyancy, static weight, elasticity, inertia, and friction act on the system. These stresses cause tubing elongation and contraction, known as "tubing breathing," which reduces pump fillage and efficiency [5]. Figure 1 shows the complete schematic of sucker rod pump components above and below ground, including the tubing anchor.

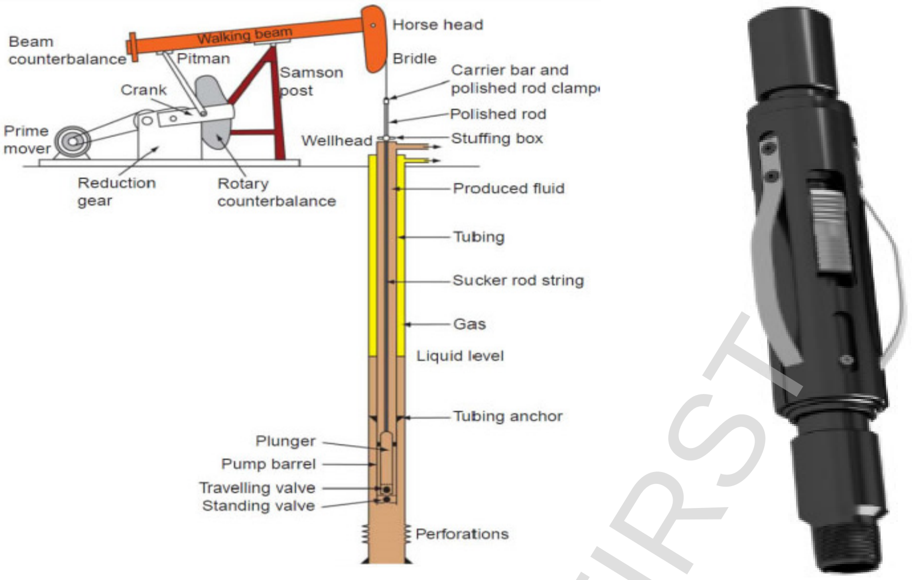

Figure 1: Schematic of sucker rod pump system and tubing anchor

Tubing anchors mitigate these effects by stabilizing tubing, improving valve timing, and ensuring faithful stroke transfer [6]. Their role becomes critical in deep wells and with larger plungers, where elastic strain and fluid column weight are significant.

3. TUBING ANCHOR

Industry literature defines TA as a device installed in the tubing string to eliminate or control axial movement caused by temperature changes, pumping cycles, and pressure fluctuations [7]. Properly designed anchors improve stability and production. Positive effects include reduced tubing displacement, improved valve operation, and higher VE [8]. However, studies warn that TA may create gas-liquid columns above the anchor, increasing pressure below and reducing pump fillage [9]. Thus, TA application must be carefully engineered for specific well conditions.

4. RESEARCH DESIGN AND METHODOLOGY

The study was based on Theoretical modeling using QRod 3.0 [10] to simulate fluid production (Qf) with and without TA across varying depths and plunger diameters. Seven plunger diameters (31.75 – 95.25 mm) were analyzed across depths from 500 to 2000 m. Constant operating parameters included stroke length, strokes per minute, tubing/casing pressures, and fluid properties. A total of 224 simulations were performed.

Table 1: Input parameters

Stroke length [mm]	1500
Strokes per minute [n/min]	5
Pump intake pressure [bar]	50
Seating depth variation [m]	500 - 2000
Tubing pressure [bar]	5
Casing pressure [bar]	5
Pump efficiency [%]	95

Volumetric efficiency was defined following Takács [11] as:

$$VE = \frac{Q_{actual}}{Q_{theoretical}} = \frac{Q_{actual}}{A_{plunger} \times S \times SPM} \qquad (1)$$

Where: Q_{actual} – Daily fluid production [m^3/d], $A_{plunger}$ – Plunger area=$\pi D^2/4$ [m^2], S – Stroke lenght [m], SPM – Strokes per minute [1/m]

5. RESULTS

The following subsections detail the results for each plunger diameter. Each graph displays Q_f [m^3/day] versus seating depth, comparing performance with and without tubing anchor.

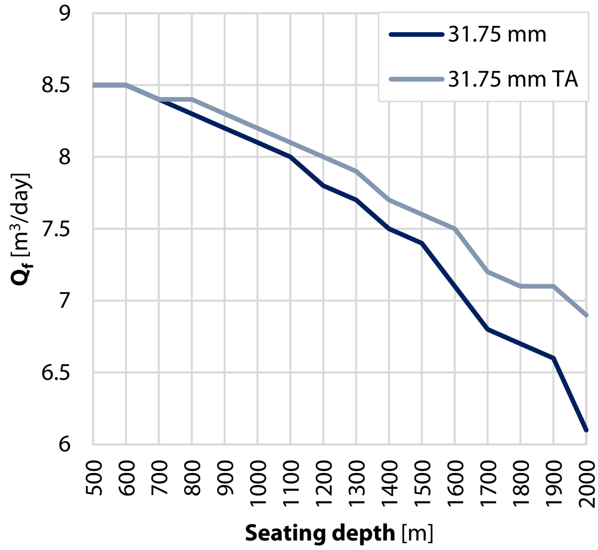

Figure 2: Production comparison with and without tubing anchor for plunger diameter 31.75 mm

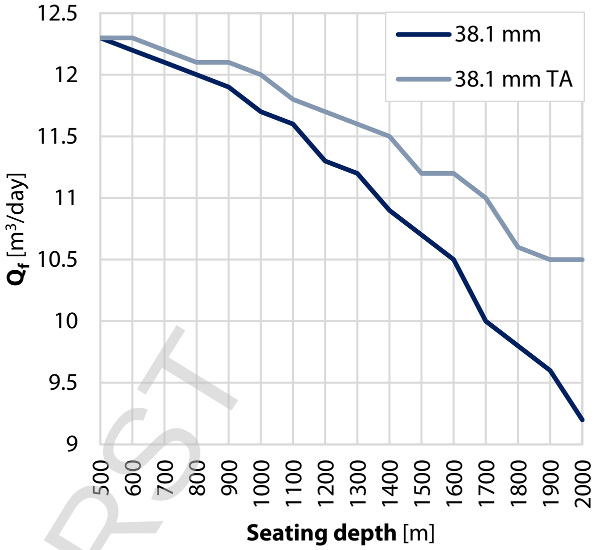

Figure 3: Production comparison with and without tubing anchor for plunger diameter 38.1 mm

At shallow depths, differences are negligible as presented in figure 2. Only beyond ~1200 m does the anchored configuration show a slight improvement, confirming that tubing displacement is not dominant for small plungers. Differences become more visible at greater depths as shown in figure 3. Anchored systems show a slower decline in production, indicating that tubing anchor begins to mitigate elastic losses in mid-range plungers.

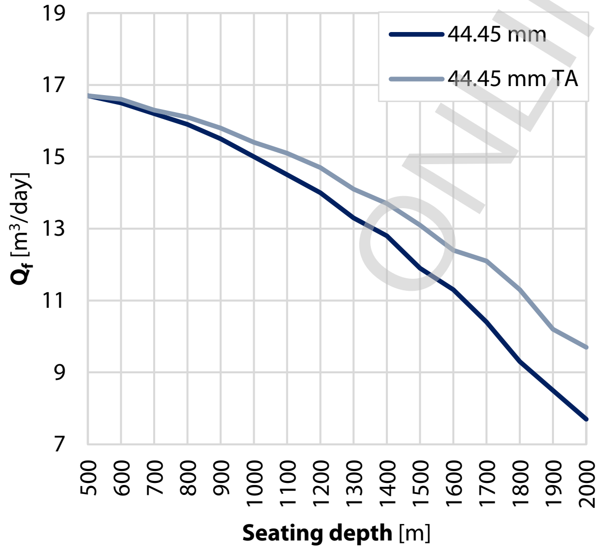

Figure 4: Production comparison with and without tubing anchor for plunger diameter 44.45 mm

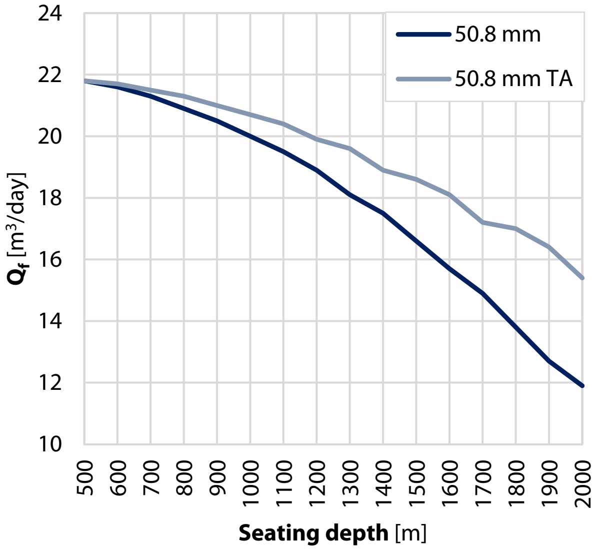

Figure 5: Production comparison with and without tubing anchor for plunger diameter 50.80 mm

Clear divergence appears at mid-depths as shown in figure 4. Anchored systems maintain higher production, demonstrating that tubing anchor stabilizes valve operation and reduces tubing elongation effects. The effect of tubing anchor intensifies with depth. Anchored systems sustain production at significantly higher levels, confirming its role in reducing tubing displacement under heavier fluid loads as shown in figure 5.

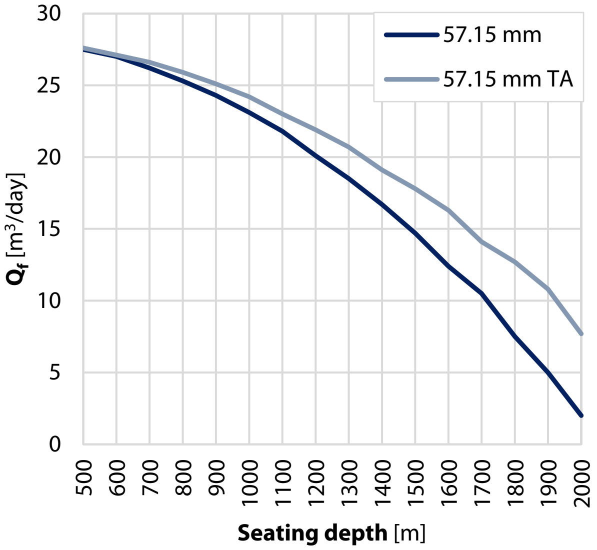

Figure 6: Production comparison with and without tubing anchor for plunger diameter 57.15 mm

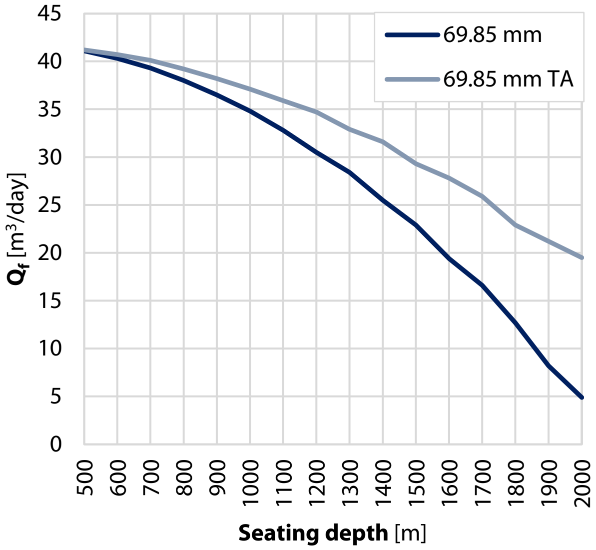

Figure 7: Production comparison with and without tubing anchor for plunger diameter 69.85 mm

Anchored systems consistently outperform non-anchored ones across all depths. As presented in figure 6, differences grow progressively larger, highlighting the anchor's contribution to preserving volumetric efficiency. Differences become dominant at depths beyond 1500 m as shown in figure 7. Anchored systems maintain production while non-anchored systems decline sharply, showing that tubing anchor is critical for large plungers in deep wells.

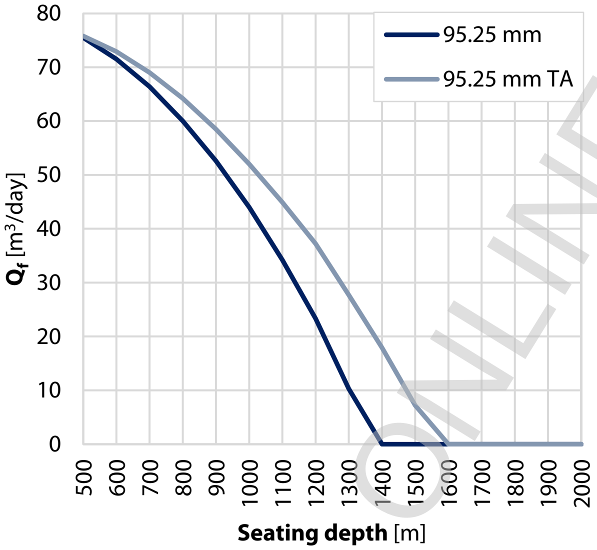

Figure 8: Production comparison with and without tubing anchor for plunger diameter 95.25 mm

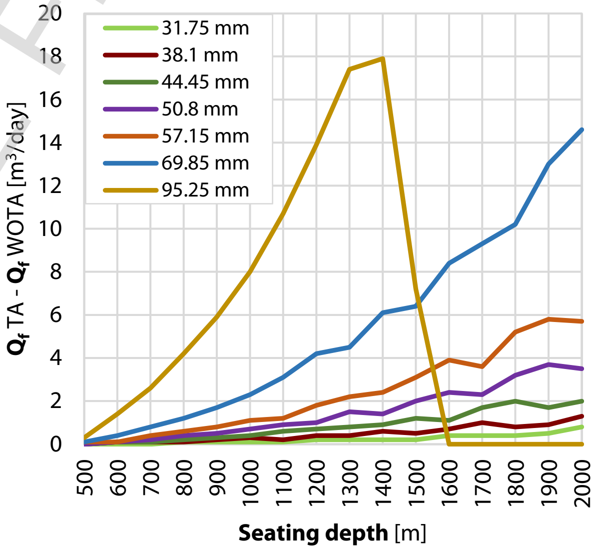

Figure 9: Production difference with/without tubing anchor for different plunger sizes at different seating depths

Anchored systems show strong benefits up to ~1600 m as presented in figure 8, but production collapses beyond this depth in both configurations. This demonstrates the physical limits of SRP systems, where tubing anchor cannot overcome extreme hydraulic constraints.

When the individual production curves for each plunger size are examined in sequence, a clear progression emerges. For the smallest plungers (31.75–38.10 mm), tubing anchor influence is minimal, with anchored and non-anchored systems producing nearly identical results across all depths. As plunger diameter increases into the mid-range (44.45–57.15 mm), the effect of tubing anchor becomes more pronounced. Anchored systems begin to show measurable improvements in production, particularly at intermediate depths, where tubing elongation and valve timing irregularities otherwise reduce efficiency.

For larger plungers (69.85 mm), the divergence between anchored and non-anchored configurations becomes substantial. At depths beyond 1200 m, anchored systems sustain production at levels significantly higher than their non-anchored counterparts, demonstrating the anchor's critical role in stabilizing tubing and preserving volumetric efficiency under heavy fluid loads. The largest plunger (95.25 mm) highlights both the benefits and the limitations of tubing anchors. Up to ~1600 m, anchored systems outperform non-anchored ones, but beyond this threshold, production collapses in both cases, revealing the physical limits of sucker rod pump systems.

Taken together, these individual graphs illustrate that the tubing anchor's impact is strongly dependent on plunger size and well depth. To better visualize the incremental benefit, the figure 9 presents the production difference (ΔQf) between anchored and non-anchored systems across all configurations. This representation isolates the anchor's contribution, highlighting the depths and plunger sizes where its application is most technically and economically justified.

6. DISCUSSION

The comprehensive set of simulations provides a clear framework for understanding how tubing anchors influence sucker rod pump performance across a wide range of operating conditions. Rather than focusing only on individual graphs, the discussion here integrates the full dataset to highlight broader technical and economic implications.

The complete calculation, shown in table 2, consolidates production values (Qf) for each plunger size at every analyzed depth, with and without tubing anchor. This dataset allows direct quantitative comparison and reveals the incremental benefit of TA in a structured way.

Table 1: Fluid production [m^3/day] calculation for different plunger sizes and different seating depths with/without use of tubing anchor

Seat. depth [m]	**31.75** Q_f	**31.75** Q_f TA	**38.1** Q_f	**38.1** Q_f TA	**44.45** Q_f	**44.45** Q_f TA	**50.8** Q_f	**50.8** Q_f TA	**57.15** Q_f	**57.15** Q_f TA	**69.85** Q_f	**69.85** Q_f TA	**95.25** Q_f	**95.25** Q_f TA
500	8.5	8.5	12.3	12.3	16.7	16.7	21.8	21.8	27.5	27.6	41.1	41.2	75.5	75.8
600	8.5	8.5	12.2	12.3	16.5	16.6	21.6	21.7	27	27.1	40.3	40.7	**71.5**	**72.9**
700	8.4	8.4	12.1	12.2	16.2	16.3	21.3	21.5	26.2	26.6	39.3	40.1	66.4	69
800	8.3	8.4	12	12.1	15.9	16.1	20.9	21.3	25.3	25.9	**38**	**39.2**	60	64.2
900	8.2	8.3	11.9	12.1	15.5	15.8	20.5	21	24.3	25.1	36.5	38.2	52.6	58.5
1000	8.1	8.2	11.7	12	15	15.4	20	20.7	**23.1**	**24.2**	34.8	37.1	44	52
1100	7.9	8.1	11.6	11.8	14.5	15.1	19.5	20.4	21.8	23	32.8	35.9	34.2	44.9
1200	7.8	8	11.3	11.7	14	14.7	**18.9**	**19.9**	20.1	21.9	30.5	34.7	23.3	37.2
1300	7.7	7.9	11.2	11.6	13.3	14.1	18.1	19.6	18.5	20.7	28.4	32.9	10.3	27.7
1400	7.5	7.7	10.9	11.5	12.8	13.7	17.5	18.9	16.7	19.1	25.5	31.6	0	17.9
1500	7.4	7.6	10.7	11.2	**11.9**	**13.1**	16.6	18.6	14.7	17.8	22.9	29.3	0	7.2
1600	7.2	7.5	10.5	11.2	11.3	12.4	15.7	18.1	12.4	16.3	19.4	27.8	0	0
1700	6.8	7.2	**10**	**11**	10.4	12.1	14.9	17.2	10.5	14.1	16.6	25.9	0	0
1800	6.6	7.1	9.8	10.6	9.3	11.3	13.8	17	7.5	12.7	12.7	22.9	0	0
1900	6.6	7.1	9.6	10.5	8.5	10.2	12.7	16.4	5	10.8	8.2	21.2	0	0
2000	**6.1**	**6.9**	9.2	10.5	7.7	9.7	11.9	15.4	2	7.7	4.9	19.5	0	0

From the table, several important patterns emerge:

- **Negligible impact in shallow wells:** For small plungers (31.75–38.10 mm), production values remain nearly identical in anchored and non-anchored configurations. This confirms that tubing displacement is not a limiting factor at shallow depths.
- **Progressive benefit in mid-range plungers:** As plunger size increases (44.45–57.15 mm), anchored systems consistently show higher Qf values, particularly at depths beyond 1000 m. This demonstrates that tubing anchor mitigates elastic losses and stabilizes valve operation.
- **Critical role in large plungers:** For 69.85 mm plungers, anchored systems maintain production at significantly higher levels, especially at depths greater than 1200 m. The table highlights that TA extends the operational envelope of SRPs, delaying efficiency collapse.
- **Limits at extreme conditions:** For the largest plunger (95.25 mm), anchored systems outperform non-anchored ones up to ~1600 m, but both configurations show sharp declines beyond this depth. The table confirms that TA cannot overcome fundamental hydraulic and mechanical constraints when system loads exceed design capacity.

By presenting the full calculation table in the Discussion, the analysis moves beyond visual trends to emphasize quantitative evidence. This approach strengthens the argument that tubing anchors are not universally required but provide substantial benefits under specific conditions.

Economically, the incremental production gains observed in the table translate into sustained fluid output, reduced downtime, and extended equipment life. Anchored systems reduce mechanical stress on rods and valves, lowering maintenance costs and improving profitability. However, the table also shows that in shallow wells or with small plungers, the anchor's contribution is negligible, meaning its installation may not be justified.

In summary, the full dataset confirms that tubing anchors are most effective in deep wells with medium to large plungers, where they stabilize system performance and preserve volumetric efficiency. Their role is limited in shallow wells and extreme depths, underscoring the need for selective application based on technical and economic evaluation.

7. CONCLUSION

This work establishes the conditions under which tubing anchors (TA) materially alter sucker rod pump (SRP) performance. By analyzing the full calculation table of production values (Qf) across seven plunger diameters and depths from 500 to 2000 m, the study demonstrates that the anchor's effect is neither uniform nor incidental, but highly dependent on system geometry and operating depth.

The data show that in shallow wells with small plungers, TA has no measurable impact: production values with and without anchor are essentially identical. In mid-range plungers, anchored systems consistently deliver higher Qf, confirming that TA mitigates elastic losses and stabilizes valve operation. For large plungers at depths beyond 1200 m, TA becomes indispensable, sustaining production levels that would otherwise decline sharply. At extreme depths with very large plungers, however, both anchored and non-anchored systems collapse, underscoring the physical limits of SRP technology.

Technically, the findings prove that TA is not a universal solution but a targeted intervention. Its selective application extends the operational envelope of SRPs, improves volumetric efficiency, and delays the onset of efficiency collapse. Economically, the incremental gains translate into sustained fluid output, reduced downtime, and extended equipment life, but only in scenarios where tubing displacement is a dominant factor.

The full calculation table provides the quantitative foundation for these conclusions, offering operators a transparent decision-making tool. Rather than relying on generalized rules of thumb, TA application can now be justified with explicit production data. Future research should validate these simulation results with long-term field measurements, investigate anchor performance under variable reservoir conditions, and integrate TA analysis into broader artificial lift selection frameworks.

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