LPS TECHNICAL PAPER

The Effect of Force on Production in Deviated Wellbores

HI RISE SYSTEM™
LIFTING ROD PUMPING TO NEW HEIGHTS

The cyclic pumping operation can result in tubing failures, rod parts, and coupling breaks due to the rods and couplings rubbing against the tubing. This is exacerbated when there is significant deviation throughout the wellbore. These failures increase operating expenses and necessitate innovative solutions.

Common Solutions to Downhole Friction

Sucker Rod Guides: These are "sacrificial" and decrease wear on couplings and rods. However, they can introduce more friction into the system, and therefore increase loads at the surface. Sucker rod guides can also wear out quickly, particularly in high side load wells.

Spray Metal Sucker Rod Couplings: Made of hard corrosion-resistant metal powder-based alloys, they reduce overall friction but can accelerate wear on softer tubing strings.

Roller Sucker Rod Guides: Suitable for low side load wells, the wheel axels can break apart in high side load wells due to high side loads.

Continuous Rod as an Alternative

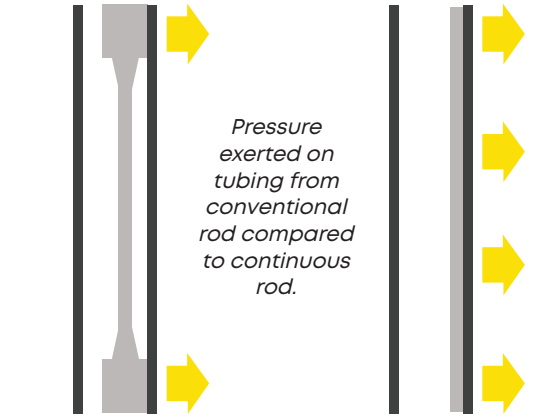
Continuous rod strings have only two connections, eliminating couplings every 25-30 feet. This design:

- Reduces mechanical friction in comparison to a guided sucker rod string
- Decreases failures by distributing wear.
- Potentially increases production with a longer downhole stroke.
- Improves performance in deviated wells.

Wear and Force Analysis

Abrasive Wear: Continuous rod distributes side load over a larger area, reducing the concentrated force on couplings. This results in less wear as the force/ side load is spread over a greater area.

Normal Force and Pressure: Continuous rod disperses side loads along its length, creating a larger contact area. This reduces mechanical wear between rods and tubing. The lighter weight of continuous rod also results in a slightly lower normal force, leading to less pressure and wear.



Pressure exerted on tubing from conventional rod compared to continuous rod.

Weight Comparison of Continuous Rod and Conventional Rod per 1000ft

	CONVENTIONAL ROD		CONTINUOUS ROD		DIFF./1000FT
Diameter	lb/ft	1000ft (lbs.)	lb/ft	1000ft (lbs.)	lbs.
3/4”	1.634	1,634	1.634	1,634	144
7/8”	2.224	2,224	2.224	2,224	184
1”	2.912	2,912	2.912	2,912	242
1-1/8”	3.676	3,676	3.676	3,676	296

The equation for the normal force is given by:

$$F_N = L_r \cdot W_r (1 - 0.127 \cdot \gamma_F) \sin \alpha,$$

Where F_N is the normal force (lbf), L_r is the length of the rod string (ft), W_r is the weight of the rod string (lb/ft), γ_F is the fluid specific gravity and α is the inclination angle (degrees). The normal force is proportional to the weight of the rod. Therefore, the lighter the rod, the smaller the normal force. Pressure is defined as the result of a force acting on an object over a certain area. Wear is the direct result of the applied pressure to the rod or tubing. The equation for pressure is the force divided by contact area as given by:

$$\sigma = \frac{F_N}{A}.$$

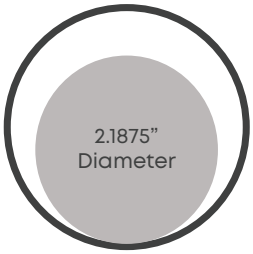
From this it can be concluded that the pressure (psi), or wear, is proportional to the normal force applied and inversely proportional to the contact area (ft^2).

The larger the contact area the smaller the pressure. Vice versa, the smaller the area the greater the pressure.

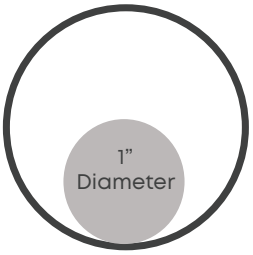
In the case of continuous rod, the contact area is spread over the entire length of the string as opposed to the small surface area of the coupling every 25 or 30 feet in a conventional sucker rod string.

The Difference in Flow Area of Conventional Rod String with Couplings and Continuous Rod

Conventional Rod



Continuous Rod



The area in contact with the tubing depends on the contact angle between the tubing and the rod or rod coupling. This angle is dependent on the radius of the rod and tubing used. It is somewhat diffficualt to estimate, but an angle of 20° is used for continuous rod and an angle of 30° is used for couplings in conventional rods for this calculation. It should be noted that the contact angle will increase over time as the rod or coupling digs into the tubing, and the contact angle is only meant as an initial state angle.

The contact area is calculated as the length of the area times the arc length of contact, s, as in:

$$A_C = L_C \cdot s = L_C \cdot 2\pi r \cdot \left(\frac{\theta}{360}\right),$$

Where A_C is the area of contact (ft²), L_C is the length of the contact area (ft), r is the radius of either the continuous rod or the coupling (ft), and θ is the contact angle between either the continuous rod and the tubing or the coupling and the tubing (degrees).

Using the equations above, the normal force and resulting pressure can be calculated for a segment of a 25 ft continuous rod versus conventional rod string at an inclination of 15 degrees with a specific fluid gravity of 1 and the weight/ft of 1-inch continuous rod and conventional rod.

Rod Type	$A_{Contact}$ (ft)	W_r (lbs)	S (in)	$A_{Contact}$ (ft²)	F_N (lbf)	σ (psf)
Conventional Rod	0.33 ft	72.8	0.0477	0.01574	16.45	1045.1
Continuous Rod	25 ft	66.75	0.3635	0.3635	15.08	41.48

Table 2: Stress applied to a 25 ft segment of 1" Rod

Contact length for a conventional rod string is equal to the length of a coupling which is 0.33 ft, while the length of contact for the continuous rod is equal to 25ft. Due to the lighter rod string, the weight of the continuous rod string is 66.75lbs with a resulting normal force of 15.08lbf, while the weight of the conventional rod string is 72.8lbs with a resulting normal force of 16.45lbf.

The contact area for the continuous rod is 0.3635 ft² compared to the contact area for the conventional rod, which is 23 times smaller with a value of 0.01574 ft².

The resulting pressure between a conventional sucker rod and tubing is 1045.1 lb/ft² compared to 41.48 lb/ft² between continuous rod and tubing. The pressure between the continuous rod string and tubing string is 25 times less than the pressure between the conventional rod string and tubing string. Continuous rod greatly reduces the pressure and wear by increasing the contact area between the rod and the tubing. It should be noted that if rod guides are added to a conventional sucker rod string, the pressure between the rod and the tubing would decrease but would still be significantly higher than the continuous rod case and would introduce more friction into the system. Essentially, with continuous rod the side load behaves like a smaller side load, thus reducing wear and increasing run times.