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Development of the design of the sucker-rod pump for sandy wells

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Abstract. Based on the analysis of field data on operation of a plunger pump in hard conditions (increased concentration of suspended particles in the produced fluid), pump plunger design modification was suggested. The proposed development has a detailed design description, a manufacturing technology and an operation principle. Detailed field tests of the developed equipment proving its performance are described.

1. Introduction

When a large amount of sand (more than 1 mg / l) is contained in the produced formation fluid, operation of production wells is complicated. It increases a hydroabrasive wear of parts and assemblies of a downhole sucker-rod pump, and causes jamming of its plunger pair. In addition, this leads to plug formation which requires cleaning and rinsing [1–3]. To prevent this phenomenon, the design of the plunger pump rod pairs was modified.

The analysis of operation of sucker-rod pumps which failed until the expiration of the warranty period showed that the main causes of failure are: valves clogged with mechanical impurities (56.4 %), cylinder plug wear (34.3 %), valve wear (5.7 %), pump plug flap (1.5 %), stem break (1.5 %), non-tight lock support (0.7 %). As a result, the average life time decreases, and the main problem is sand in the reservoir fluid (the amount of sand exceeds 1 mg/l).

2. Results and discussion

To increase the overhaul period of the underground equipment of the USShN unit under sand formation in the well, it was proposed to change the design of the pump filter and plunger. Figure 1 shows the profile of the shortened plunger. The device consists of a hollow body which has radial and axial bores, a valve box with a cage, a saddle, a ball, and a tip. In the upper part, the body ends with an internal thread, and in the lower part - with an external thread. On the outer surface of the casing, sealing rings are installed. They are made with eccentricity, and are fixed with a key connection. The keyways in the inner hole of the rings are located at a certain angle. So, if the first ring has a keyway in the greatest thickening, the next ring is located at an angle of 30° along the ascending line. 24 eccentric sealing rings are installed. Thus, 12 sealing rings form a package whose rings touch the inner surface of the pump cylinder at points evenly dividing the circumference of the cylinder into equal parts. They contact the cylinder surface in every 30°. The next package of 12 sealing rings is installed in the same way. The axial plane of the keyway of the first ring is shifted relative to the axial plane of the keyway of the first

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ring of the first package at an angle of 45°.

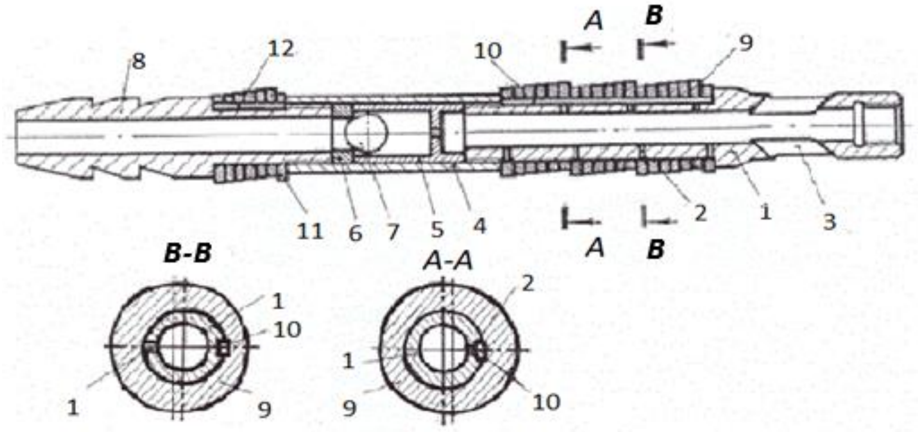

Figure 1. The shortened plunger of the sucker-rod pump in the section: 1 - housing; 2 - radial hole; 3 - hole; 4 - valve box; 5 - cell; 6 - saddle; 7 - ball; 8 - tip; 9 - sealing rings; 10, 12 - keyed connection; 11 - centering rings.

Centering rings made with certain eccentricity and fixed with a keyed joint are installed on the outer surface of the tip in its upper part. The keyways in the inner hole of the rings are made similar to the sealing rings at an angle of 45° instead of 30°, and the keyway axis of the first centering ring is located at an angle of 22.5° relative to the keyway axis of the first ring of the first group of sealing rings. The number of centering rings vary from 6 to 12 (with an increase in diameter, the number increases). In the lower part of the tip, grooves reduce hydraulic resistance of plunger movement.

Figure 2 shows rings patterns. Sealing rings are made with a certain gap in the inner hole when they mate with the outer surface of the housing, that is, the rings radially move them. Sealing and centering rings have outer diameters with intervals of multiples of 0.05 mm and eccentricity of 0.35; 0.45; 0.55 mm. The value of eccentricity is based on the operating conditions of the well.

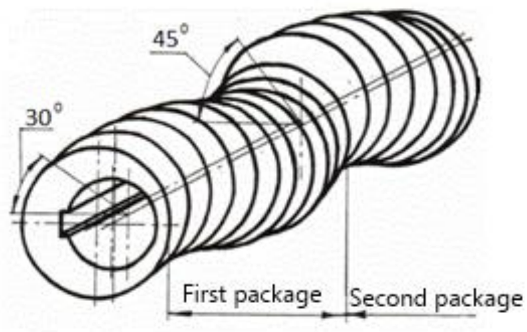

Figure 2. Plunger sealing ring pattern

In the very flooded areas, its value is 0.35 mm with sand content of 0.45 mm. For viscous and highly viscous reservoir fluid, it is 0.55 mm.

The device works as follows. Each eccentric ring is pressed against the cylinder, since they have unequal radial height in different sections due to eccentricity. At the points of contact of the ring with the cylinder, the gap is minimal, and in the opposite side, it is the largest. Its size is regulated by the value of eccentricity. A labyrinth screw slot is formed between the inner surface of the cylinder and the rings. The number of leaks in the plunger pair decreases. When the plunger moves upward, fluid pressure inside the pipes influences the sealing rings through the radial holes additionally pressing them against the cylinder. When moving downward, radial pressure on the sealing rings decreases and the gap between the sealing rings and the surface of the cylinder increases.

To justify the use of the proposed design of the plunger, it is necessary to determine leakage in the plunger pair during the pump operation. Let us consider the laminar regime of viscous fluid movement at low speeds of the plunger. In the equation of hydrodynamics [4] for the liquid volume, it is necessary to select an element whose side are δ_x, δ_y, δ_z. Then the equation of equilibrium of all forces (pressure, shear stresses, gravitational, centrifugal forces, etc.) applied to the fluid element can be written as

$$j_x - \frac{1}{\rho}\frac{\partial \rho}{\partial x} + \frac{\mu}{\rho}\left(\frac{\partial^2 v_x}{\partial x^2} + \frac{\partial^2 v_x}{\partial y^2} + \frac{\partial^2 v_x}{\partial z^2}\right) = \frac{\partial v_x}{\partial t}; \quad (1)$$

$$j_y - \frac{1}{\rho}\frac{\partial p}{\partial x} + \frac{\mu}{\rho}\left(\frac{\partial^2 v_y}{\partial x^2} + \frac{\partial^2 v_y}{\partial y^2} + \frac{\partial^2 v_y}{\partial z^2}\right) = \frac{\partial v_y}{\partial t}; \quad (2)$$

$$j_y - \frac{1}{\rho}\frac{\partial p}{\partial x} + \frac{\mu}{\rho}\left(\frac{\partial^2 v_y}{\partial x^2} + \frac{\partial^2 v_y}{\partial y^2} + \frac{\partial^2 v_y}{\partial z^2}\right) = \frac{\partial v_y}{\partial t}; \quad (3)$$

$$\frac{\partial v_x}{\partial x} + \frac{\partial v_y}{\partial y} + \frac{\partial v_z}{\partial z} = o; \quad (4)$$

$$\mu = F(\rho, p, \chi), \quad (5)$$

where j_x, j_y, j_z –acceleration of mass forces; v_x, v_y, v_z – velocities in directions x, y, z ; ρ – density, kg/m^3; μ – dynamic viscosity, Pa·sec; p – pressure, Pa; χ – fluid temperature, ^{0}C.

For a one-dimensional flow in the gap δ

$$\frac{\partial p}{\partial y} = \frac{\partial p}{\partial z} = o; \quad v_y = v_z = o; \quad \frac{\partial p}{\partial x} = \frac{p_1 - p_2}{l}. \quad (6)$$

Equations (1) – (5) have to be transformed without taking into account mass forces:

$$\frac{d^2 v_x}{dy^2} = \frac{1}{\mu}\frac{dp}{dx} = \frac{1}{\mu}\frac{\Delta p}{l}. \quad (7)$$

Integrating equation (7) for the following boundary conditions y $= \delta/2, v_x = 0; y = -\delta/2, v_x = v_0$ we have

$$v_x = \frac{1}{2\mu}\frac{\Delta p}{l}\left[\left(\frac{\delta}{2}\right)^2 - y^2\right] \pm \frac{v_0(\frac{\delta}{2} - y)}{\delta}. \quad (8)$$

Fluid consumption for the plunger pair is

$$Q = \frac{B}{12l}\frac{\Delta p}{\mu}\delta^3 \pm \frac{v_0 B\delta}{2}, \quad (9)$$

where B is the width (circumference of the inner surface of the cylinder) of the gap, m; l is the length of the gap, m; δ is the plunger clearance, m; Δp o\is the pressure difference in the pump, Pa; v_0 – plunger movement velocity, m/sec.

Calculation results are presented in tables for selecting optimal design parameters of a plunger pair taking into account operating conditions of the well [5–8].

3. Experiment

Friction in the plunger pump pair affects the value of the maximum load at the suspension point of the rods. With an increasing friction force (a friction coefficient) load increases. The value of friction force depends on the speed of the plunger movement, properties of the pumped liquid, surface roughness, size of the plunger pair (length of the plunger), etc. [9, 10]. By reducing the plunger length by 2.5 ... 3 times, the friction force in the gap of the plunger pair decreases. At the beginning of 2016, two plungers were installed in the wells of different depths at the NGDU Krasnokholmskneft field. Their performance indicators are presented in Table 1.

Table 1. Performance of the wells with new plungers installed

Well parameters	Well No. 276	Well No. 1862
Well depth, m	1150	1168
Pump brand	NSN32	NSV38
Dynamic level in the well, m	485	526
Formation fluid density, kg/m^3	920	962

PR stroke length, m	2.65	2.95
Number of double PR strokes, min^{-1}	4.7	4.2
Kinematic fluid viscosity, m/sec^2	$1.96 \cdot 10^{-6}$	$2.01 \cdot 10^{-6}$
Average value of the feed rate of the pump (previous value)	0.738 (0.726)	0.712 (0.702)
Maximum load in the PR by the results of processing of dynamograms (previous value), kN	36.58 (36.61)	53.92 (54.21)

4. Conclusion

When installing new plungers, the operating conditions did not change. After using them for about 1 year (clogged valves, paraffin deposits, etc.) and comparing with previous operation, positive results were obtained. After lifting the pumps, a slight wear of the sealing rings in comparison with the previously used pumps was identified.

The obtained preliminary results on the commercial use of shortened plungers show the effectiveness of their use. They do no jam the plunger in the cylinder.

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