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Research Article

Configuration Research of Centering Device Effected by Viscoelastic Fluid

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Abstract: The polymer flooding can improve the oil production at the late stage of oilfield development but this viscoelastic behavior of the polymer solution will cause sucker rods eccentric wear and break off., which can shorten the cycle of pump inspection. In this paper, we studied the influence of those stress factors on the rod according to the force analysis of rod during down stroke, established mechanical model, and finded out advisable interspacing that centering device should be arranged by using MATLAB to program and calculate. In this way can extend the cycle of pump inspection, and can lay a foundation for further investigation.
Keywords: polymer flooding, normal force, centering device, anti-eccentric, viscoelasticity, MATLAB

INTRODUCTION

With oilfield development has gone into middle and final stages, In order to meet the requirements of oil well production, most oil field are using the oil production technology of polymer flooding, which obtained better displacement characteristics. But it also brought some new problems that polymer flooding during oil recovery process, such as compared with water flooding, the property of polymer solution is complicated. The maximum difference of polished rod load is increased, the loading condition on rod is deteriorated, the eccentric wear on rod is serious, all that will shorten the cycle of pump inspection, affect the oil production, and increase the operation cost, even cause a series of engineering problems[1]. Therefore, studying the force conditions of rod in polymer flooding oil wells, preventing pumping rod and oil tube from eccentric wear will be of great importance in achieving oil fieled high and stable yield and improving the whole benefit.

It discovers that the rational distribution of centering device is one of the most effective way to slow down eccentric wearing according to field application. It directly affects the applications whether the laying position of centering device is reasonable. There are some problems in the current application, the position and spacing of centering device is in general determined by experience. Many domestic and overseas scholars conducted a significant amount of studies on technological theories of preventing pumping rod and oil tube from eccentric wear. But since the force conditions of rod in polymer flooding oil wells are very complex, there is less research about this area. So in this paper based on the consideration of normal force caused by viscoelastic fluid, synthesizes other stress factors, establishes mechanics analysis model, we obtain advisable interspacing that centering device should be arranged under different oil well parameters by means of programming in MATLAB, which can increase the life of oil tube and pumping rod, and extend the cycle of pump inspection, so it can bring immeasurable economic benefits to the long-term development of the oilfield.

FORCE ANALYSIS

During down stroke, the standing valve of the pump is off, travel valve is on. The sucker rod string is influenced by longitudinal bending concentrated load and axial uniformly distributed load, the upper of it is in tension and lower under pressure, thus at a certain depth position exist a balance between tension and pressure, that is neutral point. The sucker rod string can be considered slender bar, it will become local bending-buckling below the neutral point of a sucker rod string. Due to the restriction of oil tube to radius of buckling, rod string will generate bending stress, resulting eccentric wear[2].

(1) P_w ,the axial concentrated load at the bottom of the rod string, consists of semi-dry friction, P_f that forces on the pump barrel and plunger piston, hydraulic resistance , P_v that generated by well fluid flowing through the travel valve, and liquid differential pressure, P_y that acting on the upper and lower surfaces of pump plunger in the tubing[3].

①P_f ,semi-dry friction between pump barrel and plunger piston:

$$P_f = 0.94\frac{D_p}{\delta} - 140 \tag{1-1}$$

Where, D_p —Pump plunger diameter, mm.

δ —Fit clearance between piston and liner, mm.

②P_v ,hydraulic resistance that generated by well fluid flowing through the travel valve:

$$P_v = \frac{1.5n_k}{729\mu^2} \cdot \frac{A_p^{\ 3}\left(1 - \frac{A_0}{A_p}\right)}{A_0^{\ 2}} (s \cdot n)^2 \cdot \rho_L \tag{1-2}$$

Where, n_k —The number of travel valve.

μ —Coefficient of flow, can obtain by following calculation formula:(if $R_e \le 3\times10^4$) $\mu = 0.28$,(if $\mu = 0.28$) $\mu = 0.37 - \ln R_e - 1.38$. There into, R_e is Reynolds number, calculating formula is $R_e = 52.36 \cdot n \cdot s \cdot \rho_L \cdot \frac{D_p^2}{d_0 \cdot \mu_c}$,there d_0 is traveling valve diameter, mm, μ_c is well fluid viscosity, $Pa \cdot s$.

A_P , A_0 —Sectional area of pump plunger, traveling valve hole, m^2 .

s —Stroke, m .

n —Times of stroke, $\min^{-1}$.

ρ_L —Well fluid density, $\mathrm{kg/m^3}$.

③P_y ,liquid differential pressure that acting on the upper and lower surfaces of pump plunger:

$$P_y = A_r \cdot L_p \cdot \rho_L \cdot g \tag{1-3}$$

Where, A_r —Cross-sectional area of sucker rod, m^2 .

L_p —Depth of plunger, m.

g —Acceleration of gravity, $\mathrm{m/s^2}$.

From the foregoing, longitudinal bending concentrated load of the bottom of the pump is:

$$P_w = P_f + P_v + P_y \tag{1-4}$$

(2) Axial uniformly distributed load that act in body of rod, q_x include q_g that self-weight of sucker rod, q_f that buoyancy of rod in well fluid, q_v that oil drag, and q_I that inertial force generated during the rod movements, etc.

①Self-weight of sucker rod q_g :

$$q_g = A_r \rho_r g \tag{1-5}$$

Where, ρ_L —Rod density, $\mathrm{kg/m^3}$.

②Buoyancy of rod in well fluid q_f :

$$q_f = A_r \rho_L g \tag{1-6}$$

③The friction between rod and well fluid q_v :

$$q_v = 2\pi\mu_c \frac{m^2 - 1}{\left(m^2+1\right)\ln m - \left(m^2 - 1\right)} v_{\max} \tag{1-7}$$

Where, m —Tubing inside diameter to Rod diameter ratio, that is $m = \frac{d_t}{d_r}$,of which d_t is tubing inside diameter, mm. d_r is rod diameter, mm.

v_{max} —Maximum operating speed of pump plunger, when consider suspension center as simple harmonic motion, $v_{max} = \frac{s}{2}\omega = \frac{\pi s n}{60}$, m/s.

④Inertial force generated during the rod movements q_I:

$$q_I = \frac{\pi d_r^{\,2}}{4} \cdot \rho_r \cdot \frac{s}{2}\left(\frac{2\pi n}{60}\right)^2 \qquad (1\text{-}8)$$

(3) Horizontal uniformly distributed load generated during the rod movements, which main caused by polymer solution.

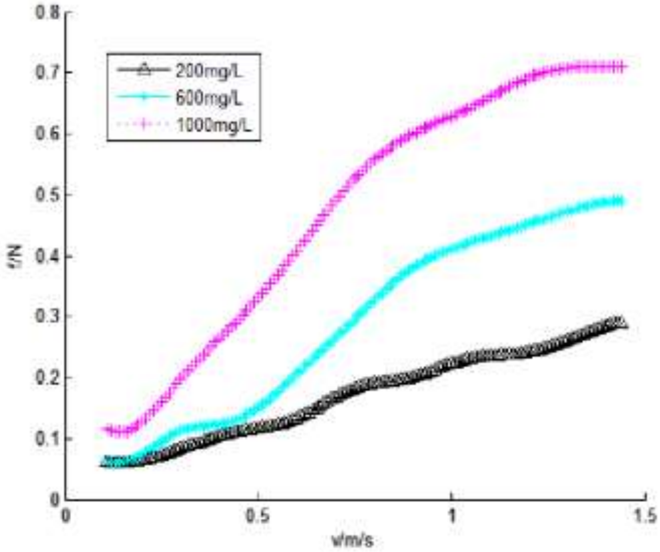

Fig-1: The impact of different concentration polymer solution on normal force at different flow velocity

Polymer solution blongs viscoelastic fluid, it has both the viscosity and elastic properties, which lead to a normal force always on the rod during the movements, this force is one of the reason that rod string bending and abrasion. But since the complexity of viscoelastic fluid,it is difficult to obtain the relationships of movement rule for normal force by creating a mathematical equations. Thus, in this paper, though establishing pump simulated experimental equipment in the laboratory, and simulating the actual working conditions in oil wells. We have prepared respectively polymer solution of 200mg/L,600mg/L, and 1000mg/L to study the impact of different concentration polymer solution on normal force, ignoring the impact of rod initial eccentricity, Figure 1 shows the variation of normal force measured at different flow velocity, changing curves are fitted by using cubic spline interpolation, which can determine the magnitude of normal force of different concentration polymer solution at different flow velocity.

MECHANICAL MODEL

Ignoring the effect of polymer concentration

During down stroke, rods below the neutral point always under pressure, we will build the simple beam model by treating both ends of rod as articulated arm joint, ignoring the effects of axial uniformly distributed load and polymer solution. To prevent rods become deformed lack of stability, we adopt the principle of columns, from the bottom of the pump, the critical span that rods buckling deformation could be calculated from known critical load by formula (1-9), iterate step by step to neutral point.

$$L_i = \sqrt{\frac{\pi^2 EI}{P_i}} \qquad (1\text{-}9)$$

Where, E —Rod elastic modelling quantity, approximately equals 2.1×10^{11} Pa.

I —Polar moment of inertia of rod between adjacent centraliser, m^4.

P_i —Critical bucking load of the ith simple beam, N.

Considering the effect of polymer concentration

Build the simple beam model, take any span of simple beam analysis, as shown in figure 2.

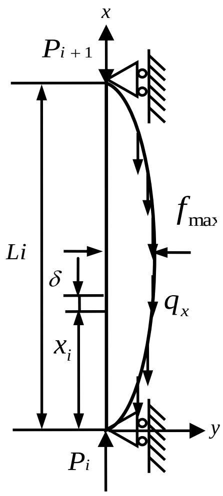

Fig-2:The vertical well simple beam model considering the effect of uniformly distributed load and normal force

Set the approximlately flexure line equation of rod in the model is:

$$y_i = \sum_{n=1}^{\infty} A_n \sin \frac{n\pi x_i}{L_i} \qquad (1\text{-}10)$$

Conclude destablization equation adjacent centraliser according to elasticity stability theory:

$$\frac{8q_y L_i^4}{2\pi^5 EI - 2\pi^3 P_i L_i^2 - \pi^3 q_x L_i^3} - \frac{d_t - d_r}{2} = 0 \qquad (1\text{-}11)$$

Where, q_x —Axial uniformly distributed load, $q_x = q_g - q_f - q_v - q_I$, N/m.

q_y —horizontal uniformly distributed load, which is related to liquid producing capacity and polymer concentration, $q_y = f$, N/m.

SOLUTION METHOD

(1) Take the bottom of pump as the fundamental point, set initial value i=1,then $P_1 = P_w$, plug P_1 into the equation (1-11), and obtain the distance L_1 of the laying position that first centering device from the bottom of pump by solving the equation.

(2) By analyzing the rod force condition from the ith simple beam,we find out the (i+1)th mechanical calculation meet the formula $P(i+1) = P(i) - q_x \times L(i)$,and plug that into the equation (1-11) will get the other simple beams axial load P_i and length L_i by means of successive iteration.

(3)We stop calculating when $P_i \le 0$,that is $\sum_{i=1}^{n} L_i \ge L_x$, indicates that the force on rods has reach the location L_x of neutral point, rods above it is always in tension, there can be no problem of instability.

(4) On the basis of above preliminary calculation results, considering the effect of well fluid on way resistance as well as local resistance caused by Installing centralizer, change the lower load P_w of pump, repeat the above steps to recalculate and optimize the calculational results of arrangement distance of centering device, that computational solutions are rounded to the integers, L_i=2m if 2m≤Li<3m, L_i=3m if 3m≤Li<4m, And by this analogy, get the final reasonable arrangement interval.

CALCULATIONAL EXAMPLES

The research method of this paper is using Matlab to program and calculate, import the fundamental parameters of each well into Matlab software in MAT format, and run the computer program, the value of each variable can be viewed in the workspace of Matlab software. Three wells parameter of the oilfield as shown in table 1.

Table 1 original fundamental parameter of oil wells

Well	Pipe	Rod	Pump	Depth of	Water	Stroke	Times	Liquid	Polymer

No.	Diameter /mm	Diameter /mm	Diameter /mm	Plunger /m	Percentage /%	/m	of Stroke /min^{-1}	Producing Capacity /m^3/d	Concentration /mg/L
J1	62	22	44	800	90	3	6	34	200
J2	62	22	44	800	90	3	9	68	1000
J3	62	22	57	1000	90	3	6	110	200

The reasonable arrangement interval of centering device for each well as shown in table 2 and table 3.

Table 2 The arrangement interval of centering device Ignoring the effect of polymer concentration

Well No.	Interval /2m	Interval /3m	Interval /4m	Interval /5m	Interval /9m	Number of Centralizer
J1	17	13	5	4	2	41
J2	21	13	5	4	2	45
J3	35	13	5	4	2	59

Table 3 The arrangement interval of centering device considering the effect of polymer concentration

Well No.	Interval /2m	Interval /3m	Interval /4m	Interval /5m	Interval /9m	Number of Centralizer
J1	19	15	6	11	1	52
J2	23	20	12	8	1	64
J3	38	16	5	5	5	69

CONLUSIONS

At present, most of the oil fileds take a method that a rod is placed one centraliser according to operation experience, and we can see the problem of eccentric wear at the position of 20 rods from the bottom of pump remains serious. Therefore, in this paper, we put forward a method based on the column buckling theory, considering the object matter that rod in the polymer solution might be affected by radial and axial uniformly distributed load, and its results are more aligned with the status in the field. It can be concluded from above computational solution of three wells:

(1) Closer arrangement distance of centraliser near the bottom of the pump, the interval increasing close to the neutral point, there is no need to install centraliser because of rod always in rension above neutral point.

(2) The results of two methods were similar, by comparing the analysis, it requires more centraliser while considering the effect of polymer concentration.

(3) Depth of plunger, times of stroke, liquid producing capacity, and polymer concentration, which are suggested that it have a great impact on force condition from computational data, those are significant considerations in study of preventing pumping rod and oil tube from eccentric wear.

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