Design of Parameters Optimization System for Screw Pump Well

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Abstract — In the oil field applications, screw pump often affects the well production capacity. On the other hand, the screw pump's efficiency is usually low, which affects the screw pump well's energy-saving and stable production. In this paper, we made a dynamic analysis for the well inflow, and gave the design method of submergence depth and pump setting depth. In order to meet the requirements of optimizing oil well productivity, we selected the type of screw pump and set a certain speed and other operating parameters. Afterwards, we analyzed and calculated the torsion load and axial force of sucker rod string. Furthermore, according to the fourth intensity theory, we derived the intensity condition of sucker rod string. Finally, by using the C# language, we developed the production parameters optimization platform for the screw pump well. The real application shows that the designed platform can easily be operated without special knowledge and skills, which improves the productivity efficiency.

Keywords - Screw pump well; Parameters optimization; Fourth intensity theory

I. INTRODUCTION

Screw pump is a new way of artificial lift, and has important significance in oilfield production. Furthermore, screw pump plays a leading role in the mid-late oil field production. However, there are still many defects in the screw pump production [1,2]. The exploitation of oil is a dynamic process, and production parameters need the estimation of the professionals. Therefore, there exists a paradox: real-time change of production status cannot match with the adjustment of production parameters [3,4,5,6]. It greatly reduces the production efficiency. Therefore, we developed the oil parameters optimization system. This system adjusts production parameters without professional knowledge. We just need to input the changing parameter into system, then we can get the reasonable parameters setup. Using this method, we can save the labor cost and improve the utilization.

The organization of this paper is as follows: we briefly describe the range of submergence depth in section 2. Section 3 presents inflow performance of the oil well. We design sucker rod according to the fourth intensity theory in section 4. Section 5 presents production system parameters optimization design of screw pump well .The conclusion is drawn in Section 6.

II. ANALYSIS ON THE SUBMERGENCE DEPTH RANGE

In the screw pump production, submergence depth is an important parameter of screw pump system. If the submergence depth is too low, there will be two negative consequences. One is to heat the screw pump stator rubber, increasing frictional resistance between stator and rotor, which makes operating condition of the pumping system even worse and accelerates the rate of deforestation of the stator. The other one is to decrease the pump efficiency. When the pump efficiency drops to a relatively low value, friction heat dissipation cannot go out to the temperature rise, and long-term operation will burn the pump [7,8]. If the submergence is too high, oil well flow pressure will increase. When it is more than a reasonable limit, compared with thin and poor reservoirs, because of the low permeability and low formation pressure, the layer will be inhibited and there will be not a liquid, and there will be the contradiction in the well liquid producing interlayer. Moreover, when the submergence depth exceeds the reasonable value, the production of oil well will not increase any more, the system efficiency will be in decline. Therefore, it is necessary to determine the best submergence of screw pump system.

The best volumetric efficiency of screw pump is at about 60%. According to the special changes of the situation, it can also be set at around 40% to 80%. Equation (1) to equation (3) are used to calculate the range of submergence depth.

$$H_c = \left(P_{in} - P_c\right)/r \tag{1}$$

$$P_{in} = P_o - \sqrt{\frac{100-\eta_v}{2}} \tag{2}$$

$$r = r_0\left(1 - f_w\right) + r_w f_w \tag{3}$$

Where H_c, P_{in}, P_o, η_v, r, r_w, r_o and f_w indicate submergence depth, inlet pressure, casing pressure, modulus values, volumetric efficiency, bulk density of well fluid, bulk density of water, bulk density of crude oil and moisture content, respectively.

III. ANALYSIS ON INFLOW PERFORMANCE OF THE OIL WELL

Inflow performance of the oil well is the relationship between liquid production of oil well and bottom hole flowing pressure. It shows the capability of oil supply by the oil reservoir to the oil wells. Analysis of inflow performance of oil well is the theoretical basis for design of oil well lifting system. Once the productivity and the corresponding changes are determined, we can build the single well production target, select the type of pump, design the speed, match the rod, and install the power of motor and driving device etc. The accurate prediction for fluid production of oil well is one of the most important aspects for screw pump wells production optimization system [9,10].

A. Inflow Performance Relationship for Single Phase Flow

1) Inflow performance relationship for linear seepage flow patterns

When the production of oil well is very low, it accords with the linear seepage law near the bottom. The relationship between production of oil well and flowing pressure follow the productivity index equation. The equation is:

$$q_o = J_o\left(P_r - P_{wf}\right) \tag{4}$$

Where

$$J_o = \frac{q_{o(test)}}{P_r - P_{wf(test)}} \tag{5}$$

Where q_o , $q_{o(test)}$, P_r , P_{wf} , $P_{wf(test)}$ and J_o indicate production of oil well, production of test point, formation pressure, bottom hole flowing pressure and bottom hole flowing pressure of test point, respectively.

2) Inflow performance relationship for nonlinear seepage flow patterns

When the production of oil well is very high, it does not accord with the linear seepage law near the bottom. According to the nonlinear percolation binomial percolation mechanics, we can formulate the relationship between well liquid production rate and bottom hole flowing pressure. The equation is:

$$q_o = \frac{\sqrt{A^2 + 4B\left(P_r - P_{wf}\right)} - A}{2B} \tag{6}$$

We draw the relationship curve of production and bottom hole flowing pressure, as shown in Fig. (1).

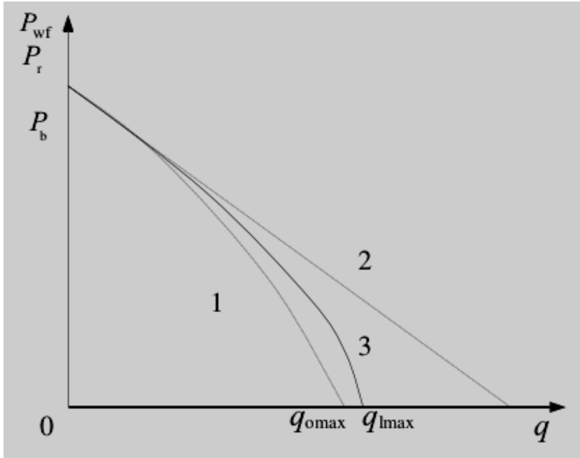

Fig.1 Inflow Performance Relationship Curve

The slope is B, and the intercept is A .After get the A and B, we can calculate production by equation(6).

B. Inflow Performance Relationship for Oil and Gas Two-phase Flow

1) Inflow performance of Vogel type

When the formation pressure is lower than saturation pressure, oil will release the dissolved gas. The reservoir belongs to gas, liquid two-phase flow and is called dissolved gas drive reservoirs. The equation is:

$$q_0 = q_{o\max}\left[1 - 0.2\frac{P_{wf}}{P_r} - 0.8\left(\frac{P_{wf}}{P_r}\right)^2\right] \tag{7}$$

$$q_{0\max} = \frac{q_{(test)}}{1 - 0.2\frac{P_{wf}}{P_r} - 0.8\left(\frac{P_{wf}}{P_r}\right)^2} \tag{8}$$

Where $q_{0\max}$ indicates the maximum production of oil gas two-phase flow.

2) The inflow performance of mixed type

When the formation pressure is higher than saturation pressure, and the bottom hole flowing pressure is lower than saturation pressure, there will be the single-phase flow of oil and gas oil two-phase flow at the same time. IPR curve will be a straight line when the formation pressure is higher than saturation pressure, which is in the single phase flow region. When the bottom hole flowing pressure is lower than saturation pressure, it will be a curve. This curve can be gotten by Vogel type equation. Mixed type inflow performance relationship curve should be continuous.

(A) The part of single phase oil flow

When the bottom hole flowing pressure is higher than the saturation pressure, all the fluid reservoir will be the single phase flow of oil, the inflow performance of oil well can be expressed as

$$q_0 = J_0 (P_r - P_{wf}) \tag{9}$$

Productivity index can be calculated by equation (10). The equation is

$$J_0 = \frac{q_{(test)}}{P_r - P_{wf(test)}} \tag{10}$$

When the bottom hole flowing pressure is equal to the saturation pressure, the pump's production can be expressed as

$$q_b = J_0 (P_r - P_b) \tag{11}$$

(B) The part of two - phase flow

When the bottom hole flowing pressure is lower than saturation pressure, two-phase flow in reservoir will appear. Inflow performance relationship changes from straight line to curve. At this point, the pump's production can be expressed as

$$q_0 = q_b + q_c \left[1 - 0.2 \frac{P_{wf}}{P_b} - 0.8 \left(\frac{P_{wf}}{P_b} \right)^2 \right] \tag{12}$$

After a series of derivation, q_c can be expressed as

$$q_c = \frac{q_b}{1.8 \left(\frac{p_r}{p_b} - 1 \right)} \tag{13}$$

To calculate the productivity index, we use the following equation (14)

$$J_0 = \frac{P_{(test)}}{P_r - P_b + q_c \left[1 - 0.2 \frac{P_{wf}}{P_b} - 0.8 \left(\frac{P_{wf}}{P_b} \right)^2 \right]} \tag{14}$$

3) The inflow performance of Fetkovich type

When the bottom hole flowing pressure is lower than saturation pressure, the pump's production can be expressed as

$$q_0 = q_{o\max} \left[1 - \left(\frac{P_{wf}}{P_r} \right)^2 \right] \tag{15}$$

or

$$q_0 = J_0 \left(P_r^2 - P_{wf}^2 \right) \tag{16}$$

To calculate the productivity index, we use the following equation (17)

$$J_0 = \frac{q_{(test)}}{P_r^2 - P_{wf}^2} \tag{17}$$

When the bottom hole flowing pressure is equal to 0, $q_{0\max}$ can be expressed as

$$q_{0\max} = J_0 P_r^2 \tag{18}$$

C. Inflow Performance Relationship for Three-phase Flow

When the bottom hole flowing pressure is higher than saturation pressure, the well will be two-phase flow; When the bottom hole flowing pressure is lower than saturation pressure, the well will be three-phase flow. As shown in Figure 1. In the case of $f_w = 0$, inflow performance relationship is curve 1; In the case of, $f_w = 100\%$, inflow performance relationship is curve 2; In the cases of other moisture contents, inflow performance relationship is curve 3.

1) Calculation of productivity index

(A) When the saturation pressure is lower than bottom hole flowing pressure of the test point, J_1 can be expressed as

$$J_1 = \frac{q_{(test)}}{P_r - P_{wf(text)}} \tag{19}$$

(B) When the saturation pressure is higher than bottom hole flowing pressure of the test point, J_1 can be expressed as

$$J_1 = \frac{q_{(test)}}{(1-f_w)\left(P_r - P_b + \frac{P_b}{1.8}\left(1 - 0.2\frac{P_{wf(test)}}{P_b} - 0.8\left(\frac{P_{wf(test)}}{P_b}\right)^2\right)\right) + f_w\left(P_r - P_{wf(text)}\right)} \tag{20}$$

2) While the pump's production is known, we can calculate bottom hole flowing pressure.

(A) if $0 < q < q_b$, bottom hole flowing pressure can be expressed as

$$P_{wf} = P_r - \frac{q}{J_1} \tag{21}$$

(B) if $q_b < q < q_{o\max}$, bottom hole flowing pressure can be expressed as

$$P_{wf} = (1 - f_w) P_{wf(o)} + f_w P_{wf(w)} \tag{22}$$

We can also express bottom hole flowing pressure as follow.

$$P_{wf} = f_w \left(P_r - \frac{q}{J_1} \right) + 0.125 P_b \left[-1 + \sqrt{81 - 80 \left(\frac{q - q_b}{q_c} \right)} \right] \tag{23}$$

(C) If $q_{o\max} < q < q_{t\max}$, the bottom hole flowing pressure can be expressed as

$$P_{wf} = f_w\left(P_r - \frac{q_{o\max}}{J_1}\right) + \frac{(q - q_{o\max})(8f_w - 9)}{J_1} \quad (24)$$

In this case, $q_{t\max}$ can be expressed as

$$q_{t\max} = q_{o\max} + f_w\left(P_r - \frac{q_{o\max}}{J_1}\right)\frac{J_1}{9 - 8f_w} \quad (25)$$

IV. DESIGN OF SUCKER ROD

According to the fourth intensity theory, intensity condition of sucker rod string was calculated and analyzed [11,12,13,14]. The thought of the design of multi-stage of the rod string of screw pump were put forward. Equal strength design method of multi-stage compounding rod string was obtained, and the diameter and length of different rods were calculated according to the demand and the standard.

A. Calculation of Polished Rod Torque

The torque can be calculated by

$$M = \frac{2eDT\Delta P}{\pi}\times 10^6 + \sum_{i=1}^{n}\frac{\pi^2 \mu n d_t^{\,2} d^2 l_i}{30\left(d_t^{\,2} - d^2\right)} + 1.02\times\left(0.0913\delta_0 - n^{0.45}\right) \quad (26)$$

Where e, μ, d, D, T, ΔP and δ_0 indicate eccentricity, viscosity of crude oil ,diameter of sucker rod, section diameter of rotor, the pressure between the pump exit and entrance ,stator lead and initial magnitude of interference, respectively.

B. The Calculation of Axial Load of Sucker Rod

The axial load can be calculated by

$$P = \sum\frac{\pi}{4}d^2 l_i \rho_s g + \left(\pi r^2 + 16er\right)\Delta P - \rho_y g\pi\left(\frac{d}{2}\right)^2 l_i \quad (27)$$

Where r and ρ_y indicate section radius of rotor and drilling fluid density, respectively.

C. Static Strength Condition

By the mechanical analysis of sucker rod section, the dangerous point is two dimensional stress states. According to the fourth strength theory, the strength conditions of sucker rod is

$$\sigma = \sqrt{\left(F_t / A\right)^2 + 3\left(T / (\frac{\pi dr^3}{16})\right)^{2\ldots}} \le [\sigma] \quad (28)$$

Where A, $[\sigma]$, F_t and σ indicate sectional area, allowable strength of sucker rod , axial force on the section and compound stress on the section.

D. Design Method of Rod String

In case of satisfying ultimate strength of rod, we try to choose sucker rod with a small diameter to reduce waste. According to the principle of equal strength, those of all levels of rod string whose complex stress are equal and stress utilization rate are less than 1. Stress utilization rate can be expressed by

$$B_i = \frac{\sigma_i}{[\sigma]} \quad (29)$$

Minimum diameter is $d \ge \sqrt[3]{\dfrac{32eDT\Delta P}{\pi^2[\tau]}}\times 10^4$.

When the utilization value is equal to the specified value, the length is the length of the first designed rod string. If the length is greater than the pump depth, we just use first grade rod. Otherwise, we turn to the next step.

The diameter of second grade sucker rod is greater than the first one, so the difference is one specification. We can design the rod by

$$\left[\frac{P_{\mathrm{I}}}{A_{\mathrm{I}}}\right]^2 + 3\left[\frac{M_{\mathrm{I}}}{W_{n\mathrm{I}}}\right]^2 = \left[\frac{P_{\Pi}}{A_{\Pi}}\right]^2 + 3\left[\frac{M_{\Pi}}{W_{n\Pi}}\right]^2 \quad (30)$$

If the conditions of equation (30) and B_2 are met, we finish the design of rod. Otherwise, we need to design the rod of the third level.

The design method of the third grade sucker rod is same to that of the second grade sucker rod.

V. DESIGN OF PRODUCTION PARAMETERS OPTIMIZATION SYSTEM FOR SCREW PUMP WELL

According to the inflow performance relationship curve and design principle of the rod, we exploited Microsoft Visual Studio 2008 platform as the development tool, SQL Server 2005 as the database, C# as the development language, and developed the optimization software platform.

A. Design Thought of System

(1) Based on the volume efficiency range, compute the range of submergence through equations (1)-(3).

(2) Select the maximum production by inflow performance relationship curve.

(3) Calculate the head. We can use $H = \frac{\Delta P}{r}$.

(4) Select the pump type according to the production and head.

(5) Calculation of rotation rate. We can use $n = \frac{q}{5760eDT}$.

(6) Select the electrical machinery. The power of driving head is $N_q = \frac{1}{86.4}\eta_q q \Delta P$, and the power of the electrical machinery is $N_e = \eta_p N_p, \eta_q = 85\%, \eta_p = 80\%$.

(7) Design the rod.

B. The operation interface

(1) At first, enter the interface to select the well in Fig. (2).

Fig.2 Interface of Selecting Well

(2)Press the “Next” button to enter the next interface, as shown in Fig. (3). To determine the range of submergence, input the range of volumetric efficiency. Then we can get the range of submergence.

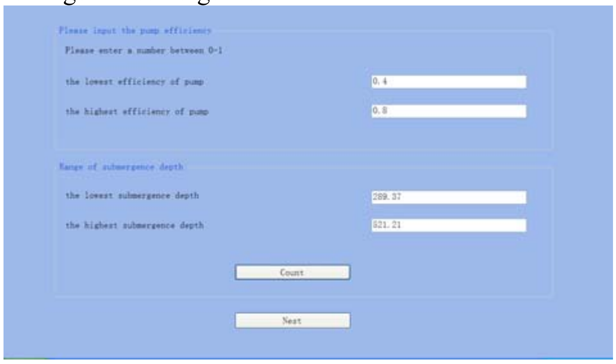

Fig.3 Interface of Computing the Submergence Depth

(3) As shown in Fig. (4), we can get the productivity index ,the picture of IPR curve and down hole pump depth.

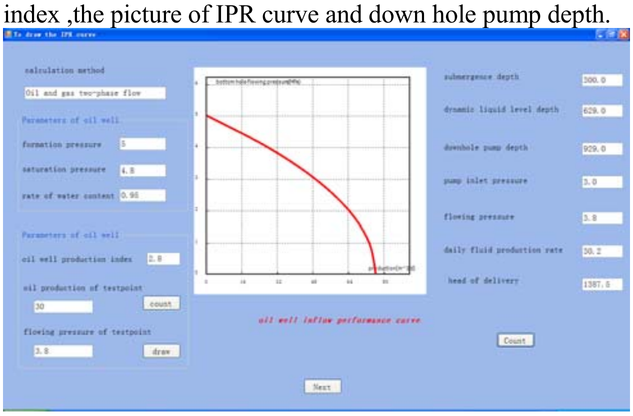

Fig.4 Interface of Computing the Productivity Index

(4) As shown in Fig. (5), select the type of the pump and the rotation rate.

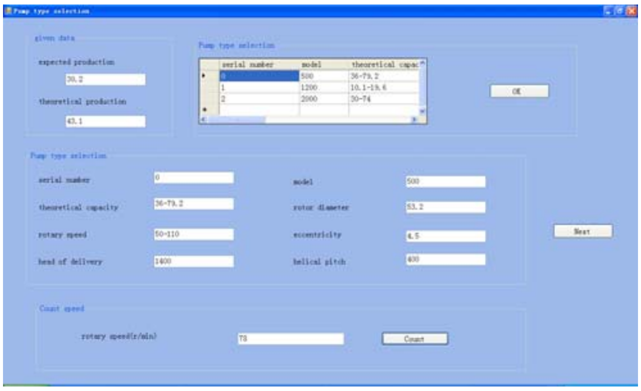

Fig.5 Interface of Selecting the Type of the Pump

(5) As shown in Fig. (6), select the type of motor.

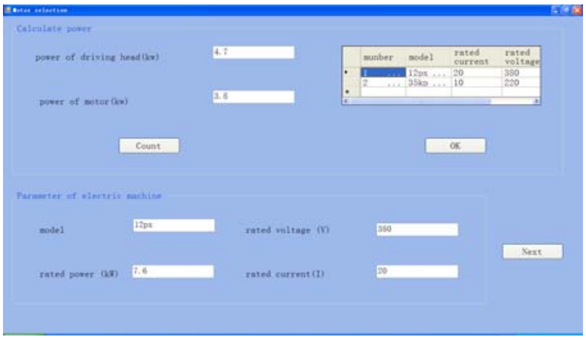

Fig.6 Interface of Selecting the Type of Motor

(6) As shown in Fig. (7), the diameter and length of different rods are calculated.

Fig.7 Interface of Computing the Diameter

(7) Finally, the results are shown in Fig. (8).

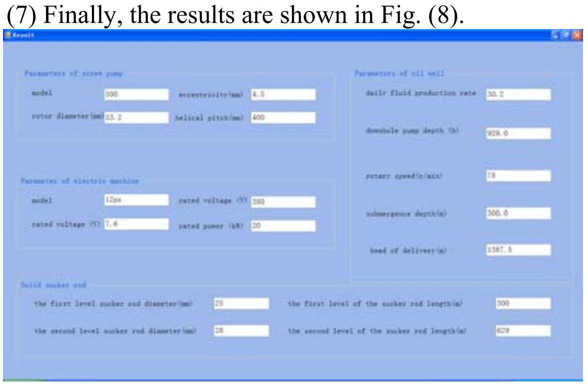

Fig.8 Interface of Displaying the Results

VI. CONCLUSION

Inflow performance of the oil well was analyzed in this paper. We gave the method of computing the range of submergence depth and the method of designing the sucker rod. Finally, we design the parameters optimization system using the C# language. The system is simple and easy to operate without relevant expertise. The real application in oil-field verifies that the computation results of the platform are accurate, which improve the efficiency of operation greatly.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflicts of interest.

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