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Research Article

Study on Determination Method of Inter Well Pumping System for Liquid Supply Shortage Well

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Abstract:

In the grim situation of low oil prices, the oil exploration and production companies have to reduce costs and increase benefits. The wells with deficient-liquid supply account for 20%-30% for all production wells, the proportion of the oil field in the long production time is greater. Intermittent production is an effective way to reduce the cost and increase the efficiency of the oil supply shortage. The purpose of intermittent production is to increase production and reduce cost. The key is determining a reasonable intermittent pumping system, which means develop a proper close time and open time. The author studies the dynamic liquid level variation, uses electrical power curve to solve the dynamometer card, through changing in the diagram to determine the dynamic liquid level decline rule, and then get the time of open well; through analyzing the relationship between the inflow performance of oil wells and the submergence to determine the close time.

Introduction

With the severe situation of low oil price, most of oil field take actions to reduce the expenditure and improve the benefit. There are a lot of shortage supply wells in China, and the intermittent method is an effective way to operation for these wells[1,2]. The intermittent method means that opening well to produce oil for some time, when liquid in the annulus is plenty; then shut-in the well for some time, when the liquid in the annulus decreased till the well can't work normally. The intermittent can reduce the energy consumption, improve the pump efficiency and alleviate the abrasion of pump and casing. The key of intermittent is to determine the open time and shut-in time, a reasonable intermittent regime can maximize the profile. There are four ways to determine the intermittent regime so far, which are the way of liquid curve, the way of production declination, the way of economical limitation and analytical method.

Jiang yan et al used the liquid recovery way to optimize intermittent system of liquid shortage wells[3]. Zhang maiyun et al used the annulus flow pressure distribution theory and pressure recovery well test theory to determine the intermittent system, according to the porosity and production of liquid shortage wells[4]. Lei qun pointed that the appropriate intermittent system can make the production tend to stable, and can largely improve the economic benefit[5]. Yu xiaoming concludes that most of intermittent system is unchangeable, which are easy to handle but also are not the best intermittent system[6]. Because the ability of liquid supply is different for each well at different periods, which means the intermittent system should be changed every once in a while. Guan ning used matter balance equation to get an exponential relationship between the shut-in time and production[7]. Zhou daiyu et al use the balance theory and break-even analysis to determine an economical limitation for each well, and build an intermittent model for liquid shortage wells[8]. Liu haitao study the principles of selecting well and the characteristics of the recovery curve for liquid shortage wells, and find the suitable open time and shut-in time[9]. According to the production test and theory analysis, Yan qingyu et al determine the intermittent time by using the variation rate of casing pressure[10]. Meng xiaoling et al define a reduced pressure and develop an initial intermittent system[11]. Based on the initial system, they build a model on annulus liquid height variation, which connected with the time, and got the liquid recover line, finally gave an intermittent system for liquid shortage wells.

These ways all needs sound wave to observe the dynamic liquid depth. However, the sound wave was tested by human, and gathered the data for a period, which means it can't gather the data constantly. In this paper, we propose a new way to get the intermittent regime. First, we can draw the ground dynamometer card through the electrical parameters, which are gathered in real time; second, the dynamic liquid depth can be solved by the pump dynamometer card, which can be converted from the ground dynamometer card, and which can draw the variation curve of dynamic liquid depth during operation period; third, analyzing the relationship between the inflow performance of oil wells and the submergence to draw the recover curve during the shut-in period. Finally, the intermittent regime can be solved by the slope method.

2. Method: The determination of intermittent time

2.1 Using power curve to get the ground dynamometer card

There are all kinds of behaviors, when pumping unit is working[1]. The power of pumping unit is electricity. Electrical energy is input into the motor at the entrance, then the motor drives the donkey head movement through the belt reducer and four bar linkage. The electrical energy is converted into mechanical energy[12,13]. If the stress of suspension point is big, then the more power is needed. For example, if the pump is struck or the viscosity of oil is large, the stress of suspension point will increase, and correspondingly the input power will increase too. On the contrary, if there exists pump loss and blowing, the pumping unit need less power. Therefore, the power curve can also represent the well behavior. We set a mathematical model for loading and electrical power, through studying the relationship of power, torque and loading, which are as follows:

$$E = 9549\frac{N_r \eta i}{n_m} \tag{1}$$

$$E = [\frac{a}{b}\text{P} - \frac{c}{b}\text{W}_b(\cos\theta - \frac{c}{a}\frac{a_A}{g})]\frac{r\sin a}{\sin\beta} - W_c^{'} r\sin\varphi \tag{2}$$

Where E is torque of crankshaft, N.m; N_r is motor power, KW; n_m is motor revolution, r/min; η is driving efficiency; I is driving ratio; R is balancing radius, which represents the distance from the core of crank balancer to crank shaft, m; P is the loading of suspension center, kN; a,b is the length of before and after beam arm, m; c is distance from the core of beam balancer to beam pivot,m; W_b is the weight of beam, kN; W_c'is the balance weight of crank radius after converting; a_A is the acceleration of suspension center, θ is the beam angel ,which is started from the horizontal position; β is the angel between after arm of beam and pitman. The figure 1 is the geometry size of pumping unit:

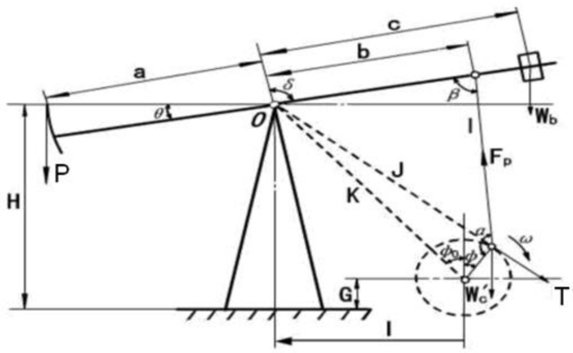

Figure 1. *Geometry size of pumping unit*

We can get the relationship between power and loading from above two formulas:

$$P = f(\text{N}_\text{r}) \tag{3}$$

The displacement curve can be solved from the crank angel, and the ground dynamometer card can be obtain from the electrical power curve.

2.2 Getting dynamic liquid level from ground dynamometer card

The pump dynamometer card can be obtain from ground dynamometer card through using Gibbs equation[12]. The dynamic liquid level is defined as the height of liquid in the annulus between tubing and casing[1]. The corresponding loading difference is the loading difference of liquid height between annulus and tubing. When the pumping unit at the bottom dead center, the stress of suspension (F_d) can be express as the following equation:

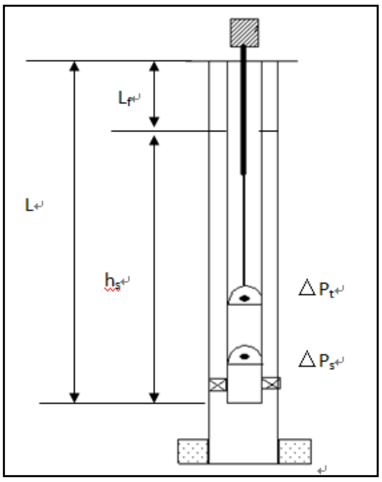

Figure 2. *The location of the static and dynamic level*

$$F_d = [h_s \rho_l g + (P_c - \Delta p_s) * 10^6] A_p \qquad (4)$$

When the pumping unit at the top dead center, the stress of suspension (F_u) can be express as the following equation:

$$F_u = [L \rho_l g + (P_t + \Delta p_t) * 10^6] A_p \qquad (5)$$

$$L_f = L - h_s \qquad (6)$$

$$\Delta p_t = \Delta p_s = \Delta p = \frac{\rho_l v_f^2}{2\xi^2} \qquad (7)$$

We can get the following formula from above equations:

$$L_f = \frac{(F_u - F_d) - 10^6 (P_t - P_c) A_p}{A_p \rho_l g} - \frac{10^6 v_f^2}{\xi^2 g} \qquad (8)$$

Which also can be expressed as the following equation :

$$L_f = \frac{\Delta W - 10^6 (P_t - P_c) A_p}{A_p \rho_l g} - \frac{10^6 v_f^2}{\xi^2 g} \qquad (9)$$

Where L is pump depth,m; ρ_l is the density of liquid in the well bore, g/cm^3 ; P_c is casing pressure, MPa ; ΔP_t is the resistance of travel valve , MPa ; P_t is the tubing pressure, ; ΔPs is the resistance of affix valve, MPa ; A_p is the area of plunger, m^2 ; h_s is the distance from pump depth to dynamic liquid depth, m ; v_f is the velocity when the liquid flow through the valve, m/s ; L_f is the dynamic liquid depth, m ; ξ is the coefficient of valve flow rate, which is the function of valve diameter, viscosity and flow rate; ΔW is the loading difference between bottom dead center and top dead center of pump dynamometer card.

2.3 Changing rule of the submergence depth

(1) Decline law of the submergence depth

The submergence depth means the depth of pump in the well bore, which equals the value of pump depth minus the dynamic liquid depth. The pumping unit can start working, when the dynamic liquid depth of well annulus arrives a certain position. At this time, the dynamic liquid depth, submergence depth and the liquid in the pump is high. So, when pump starts sucking liquid, the decline rate is fast. When the submergence depth decline a certain level, the liquid in the pump is becoming less and less, the coefficient of fullness of pump is start decreasing, until it arrives a certain value.

（2）Increasing law of the submergence depth

During the shut-in period, because of pressure difference between layer and bottom hole, the fluid flow into the bottom of the well, and the fluid in the annulus becomes higher and higher, which means the submergence depth improves[14]. The higher of dynamic fluid depth , the higher of bottom hole flowing pressure, and corresponding to the less pressure difference between layer and bottom hole, which leads to less fluid flow into bottom of the well. In this period, the liquid in the annulus rises slowly, and the submergence also varies slowly. It turns out that the longer shut-in time, the higher dynamic liquid level, the less cumulative production. For liquid shortage wells, the submergence first decline fast, then tend to a stable position.

2.4 Determination of open well time

According to the actual situation, we pick up the suit interval, test the electrical curve in every stable time, turn to the submergence depth, and draw the submergence decline curve. We can get the slope of curve in every interval, if the interval less than the certain value, then shut-in the well, and record the working time T_1.

Detail: we pick up N points, and record the two adjacent points coordinates, then get the slope. If the slop is small than a certain value, then shut-in the well, the mathematics equation is $\left|\frac{h_2 - h_1}{t_2 - t_1}\right| \le \varepsilon_1$. The open point is this point, record as T_1. The determination of ε_1 can be gotten from the truth condition or former experience.

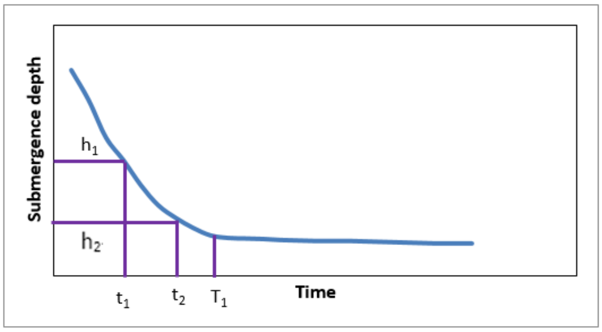

Figure 3. *Curve of submergence descent*

2.5 Determination of shut-in time

We can get the liquid depth backup law from the bottom hole inflow performance. There are three-phase in the late production period, which is oil, gas and water, so we use Petrobras way to get the production equation.

$$dp_{wf} = \rho g dh \tag{10}$$

$$dh = \frac{Qdt}{s} \tag{11}$$

We can get the following equation from the above equations:

$$\frac{dp_{wf}}{Q} = \frac{\rho g}{s} dt \tag{12}$$

Besides:

$$q_{oil} = q_b + (q_{omax} - q_b)[1 - 0.2(\frac{p_{wf}}{p_b}) - 0.8(\frac{p_{wf}}{p_b})^2] \tag{13}$$

$$J_1 = \frac{q_b}{p_r - p_b} \tag{14}$$

$$q_{water} = J_1(p_r - p_{wf}) \tag{15}$$

$$Q = (1 - f_w) q_{oil} + f_w q_{water} \tag{16}$$

Finally we get the follow equation from the above five equation

$$-Bdt = \frac{dp_{wf}}{Wp_{wf}^2 + Yp_{wf} + Z} \tag{17}$$

Where

$$B = \frac{\rho g}{s}$$

$$W = \frac{0.8(1 - f_w)(q_{omax} - q_b)}{p_r^2}$$

$$Y = \frac{0.2(1 - f_w)(q_{omax} - q_b)}{p_r} + f_w \frac{q_b}{p_r - p_b}$$

$$Z = -[(1 - f_w) q_b + f_w \frac{q_b}{p_r - p_b} p_r]$$

And then

$$p_{wf} = \frac{\frac{2M}{1 + e^{-M(Bt+C)}} - Y - M}{2W} \tag{18}$$

$$M = \sqrt{Y^2 - 4WZ}$$

The C in the equation can be gotten when the t=0 and the corresponding submergence depth in the shut-in time.

Therefore, the relationship between submergence and time is as follows:

$$H = \frac{p_{wf}}{\rho g} + H_{pump} - H_0 \tag{19}$$

$$H = \frac{\frac{2M}{1 + e^{-M(Bt+C)}} - Y - M}{2W\rho g} + H_{pump} - H_0 \tag{20}$$

$$M = \sqrt{Y^2 - 4WZ}$$

Where B,M,W,Y,Z is inter variation, which have no physical meanings; H is the submergence depth; h is dynamic liquid value; H_{pump} is pump value; H_0 is the middle depth of formation.

According to the submergence backup curve, we pick up N points, record the two adjacent point coordinates, and get the slope of two points, if the slop less than a certain value, then shut-in the well. The mathematics equation is $\left|\frac{h_3 - h_4}{t_3 - t_4}\right| \le \varepsilon_2$. The shut-in point is this point, record as T_2. The determination of ε_2 can be gotten from the truth condition or former experience.

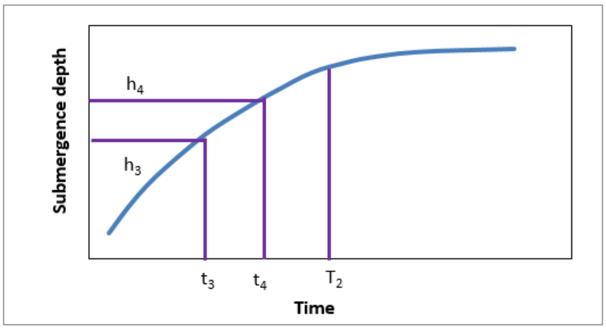

Figure 4. *Curve of submergence rising*

3. Conclusion

We studied the intermittent system for liquid shortage wells, and realized the importance of intermittent for oil operation. We also studied the variation law of annulus dynamic liquid depth, and got the ground dynamometer card from electrical power curve, finally solved the open and shut-in time. We conclude several conclusions, which are as follows:

(1) By using the relationship between electrical power, torque and loading, we draw the dynamometer card from electrical power curve, which can calculate the dynamic liquid depth.
(2) During the open and shut-in period, both of the decrease and rise speed of submergence depth are first quick back slow, the inflection point can determine the open and shut-in time.
(3) The determination of shut-in time can be solved by the mathematics relationship between inflow performance and submergence variation law.

Nomenclature

E is torque of crankshaft, N.m;
N_r is motor power, KW;
n_m is motor revolution, r/min;
η is driving efficiency;
I is driving ratio;
R is balancing radius, which represents the distance from the core of crank balancer to crank shaft, m;
P is the loading of suspension center, kN;
a,b is the length of before and after beam arm, m;
c is distance from the core of beam balancer to beam pivot,m;
W_b is the weight of beam, kN;
W_c'is the balance weight of crank radius after converting;
a_A is the acceleration of suspension center,
θ is the beam angel ,which is started from the horizontal position;
β is the angel between after arm of beam and pitman.
L is pump depth,m;
ρ_l is the density of liquid in the well bore, g/cm^3；
P_c is casing pressure, MPa；
ΔP_t is the resistance of travel valve， MPa；
P_t is the tubing pressure,MPa ；
ΔPs is the resistance of affix valve, MPa；
A_p is the area of plunger, m^2；
h_s is the distance from pump depth to dynamic liquid depth, m；
v_f is the velocity when the liquid flow through the valve, m/s；
L_f is the dynamic liquid depth, m；
ξ is the coefficient of valve flow rate, which is the function of valve diameter, viscosity and flow rate;
ΔW is the loading difference between bottom dead center and top dead center of pump dynamometer card
B,M,W,Y,Z is inter variation, which have no physical meanings;
H is the submergence depth;
h is dynamic liquid value;
H_{pump} is pump value;
H_0 is the middle depth of formation.

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