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Research on plunger dynamic model and wellbore profile

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Abstract

Plunger gas lift is one of the effective technologies to solve the problem of low formation energy and serious water outflow in the late stage of gas well development.In order to ensure the normal production of gas well, it is necessary to establish the plunger gas lift production system reasonably. At present, the plunger gas lift model equation is mainly established to solve the optimal production system according to the model.Its advantage is that it can predict the lifting characteristics of the plunger and provide a calculating way for the optimization of the plunger gas lift.However, the drawback is that it requires comprehensive analysis of parameters such as casing pressure, liquid accumulation height, shut-in time and plunger running speed, and the calculation process is complex.Therefore, it is necessary to establish a model of the relationship between real-time position and temperature and pressure during plunger operation.

Keywords

Plunger gas lift;Production system;Real time position; Temperature and Pressure.

1. Introduction

With the development of gas field in China, the formation pressure decreases, the bottom hole has serious fluid accumulation, and the gas flow rate decreases, which leads to the failure of the liquid to remove the wellbore in time, which affects the normal exploitation of the gas well[1]. Plunger gas lift technology is a drainage gas recovery method, which accumulates energy by intermittently opening and closing wells, so as to push the plunger in the tubing up and down, discharge wellbore fluid and carry out natural gas development[2], it can effectively reduce liquid leakage and improve gas lift efficiency[3,4]. The working process of plunger can be divided into four stages as shown in Fig. 1.

a) Wellbore closing phase:Close the wellhead and the plunger will decrease under its own gravity;

b) Bottom hole energy recovery stage:Most of the gas enters the annulus of the oil sleeve, the liquid in the oil pipe rises, and the pressure of the oil sleeve rises;

c) Well opening stage:When the bottom hole energy is enough to bring the plunger and upper liquid out of the wellhead, open the wellhead;

d) Liquid drainage and gas recovery stage:The liquid is discharged from the wellbore, and the plunger stays in the wellhead blowout preventer to produce gas.

In actual production, the wellhead is controlled to open and close by setting a good working system. However, the adjustment of the current production system lacks systematic theoretical guidance. It is difficult and inefficient to analyze and adjust the production system only by manual work. In order to optimize the drainage gas recovery system, it is necessary to analyze the factors affecting the production efficiency of plunger gas lift[5].

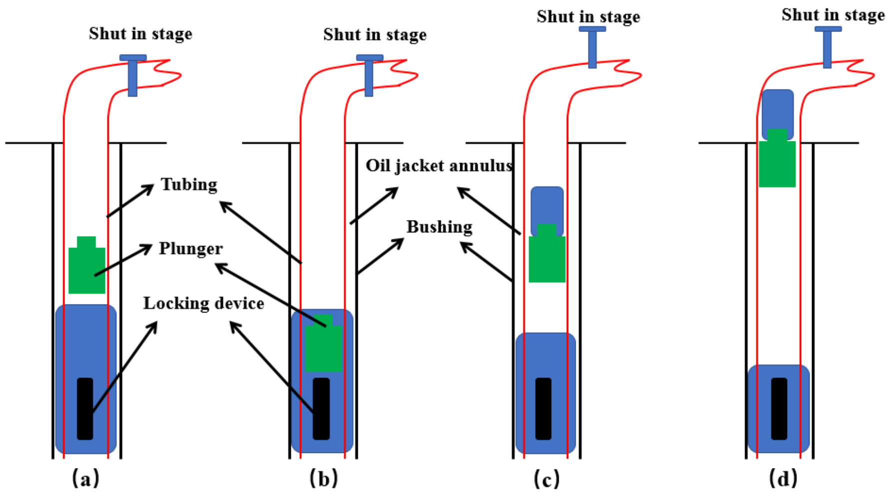

Fig. 1 Working process of plunger gas lift[2]

a) Dynamic factors:Gas production, liquid production and productivity recovery capacity of gas wells;

b) Gas well factors: The situation of the gas well's fluid accumulation, well body design parameters, external pipeline manifold, wellbore condition, etc;

c) Equipment factors: plunger selection, setting depth and plunger equipment operation status;

d) System factor: the establishment and adjustment of production system.

The establishment and solution of the relationship model between plunger real-time position and pressure, temperature, etc. can establish the theoretical basis for the subsequent plunger drainage gas recovery process influencing factor analysis, optimization design and well selection conditions. The dynamic simulation of the plunger model reflects the periodic characteristics of the plunger gas lift process, so as to predict the variation of the key parameters and the dynamic characteristics of the system in the lifting process, analyze the factors influencing the lifting efficiency of the process and their internal relationship, and finally achieve the goal of improving the lifting efficiency through the optimization design. This paper will be carried out from three aspects: plunger dynamic modeling method, wellbore profile analysis and development trend.

2. Dynamic modeling of plunger

2.1. Dynamic modeling method of plunger

The dynamic model of plunger has been studied abroad for a long time, FOSS and Gaul first proposed the most widely used authoritative plunger gas lift process design method [6], The model uses a large number of data of gas-liquid ratio plunger gas lift wells to predict important gas lift parameters, such as average casing pressure, oil pressure, etc. the predicted results are in good agreement with the actual situation. Hacksma successfully introduced the concept of optimum gas-liquid ratio into plunger gas lift process design [7], the model is used to simulate and analyze the gas volume of the lifting plunger and its upper liquid section. It is found that under the optimal gas-liquid ratio, the plunger does not need to wait for pressure recovery at the bottom of the well, and the formation has sufficient energy to lift the plunger and its upper liquid section again.Until J.F.lea analyzed and studied, the dynamic model of conventional plunger lifting technology was proposed for the first time, and some numerical algorithms for key parameters were proposed [8], however, the problems of liquid falling back and gas slippage are not considered.Maggard[9] made a theoretical study on the technology of drainage gas recovery using plunger gas lift in tight gas wells, and established a new plunger gas lift performance model suitable for tight gas wells.Gasfarri and Wiggins have studied the dynamic

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model of plunger gas and the working method of improving lifting efficiency considering the influence of the pressure of the ground oil pipeline [10].

With the continuous improvement of underground monitoring system, in 2008, chava[11] and others proposed a new method to simulate plunger lifting. The method uses intelligent plunger to obtain pressure and temperature data, then replaces the obtained pressure and temperature data into the basic mass, momentum and energy conservation equation of the control plunger dynamics to predict the change of other parameters. This method can reflect the actual dynamic of the plunger more accurately, but it can not predict the dynamic process of plunger lifting, but can only be adjusted and optimized after installation.

With the development of computational fluid dynamics and finite element technology, Neil[12] and others carried out CFD Simulation Research on horizontal well plunger gas lift. They used CFD to predict the decline speed of various plunger, and compared with the actual test results, it was found that the decline error of CFD prediction was less than 8%, and the reliability was very high.

In 1994, Yu Rong et al.[13] and others analyzed the relationship between pressure build-up and shut in time by studying different working systems of plunger gas lift test wells, and proposed to optimize the shut in time.

In 2005, He Shunli et al.[14,15] pointed out that the early static equation of plunger gas lift had large errors in practical application, while the established dynamic model of plunger gas lift was mainly aimed at specific gas fields and could not be applied on a large scale. Starting from the basic working principle, the movement process of plunger gas lift was divided into three stages, and the dynamic model of plunger gas lift was established. The plunger gas production process is as follows: the gas flows from the formation to the annulus of oil and casing, then enters the oil pipe and pushes the plunger to make the liquid rise to the wellhead gas nozzle (membrane valve), and then enters the separator through the surface pipeline and the gas nozzle of gas gathering station (as shown in Fig. 2).

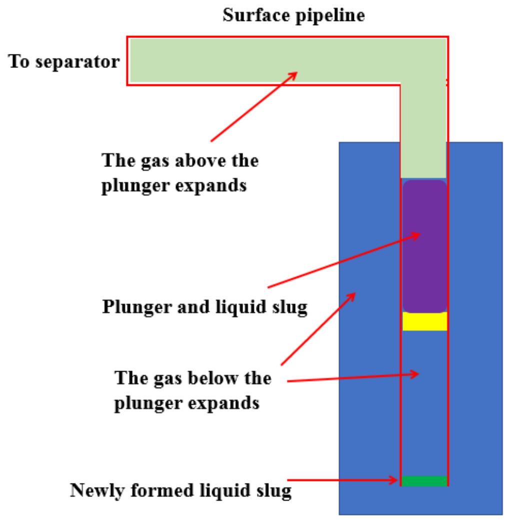


Fig. 2 Schematic diagram of plunger air lift model[15]

Feng Xiaoya[16] used the law of conservation of mass and other methods to study the whole process of plunger gas lift movement in highly deviated wells and horizontal wells, and established its dynamic lift model, considering the well deviation angle, plunger running state and stress. In order to improve the integrity and accuracy of the simulation of the dynamic process of plunger gas lift, the inflow performance of the formation is studied and analyzed in detail.

According to the current research and development direction of the plunger structure, the resistance of the plunger is small when it goes down and the sealing is good when it goes up.

However, the structure of the plunger designed based on this principle is relatively complex, and in the actual production process of oil and gas wells, the fluid in the wellbore often has strong turbulence, which can not be designed by using the classical theory. This problem can be optimized by physical experiments, but the cost of physical experiments is high, and the test process is easily affected by the accuracy of the instrument and external factors. Zhou Qingqiang[17] used CFD method to analyze the force of the plunger in the process of movement, and calculated the pressure and velocity distribution of the flow field in the downward and upward process of the plunger, providing reference data for the plunger structure and analysis of the plunger process.

2.2. Establishment of dynamic model of plunger

In the upward stage of the plunger, the gas at the bottom of the plunger is the driving force for the upward movement of the plunger, while the gas pressure at the upper part is the resistance to prevent the movement of the plunger. In this stage, the friction resistance between the plunger and the liquid section and the oil pipe wall is regarded as the friction resistance between the liquid section and the oil pipe wall of the same length. The force analysis of the plunger liquid section is carried out, and the force analysis diagram of the plunger liquid section is obtained, as shown in Figure 3.

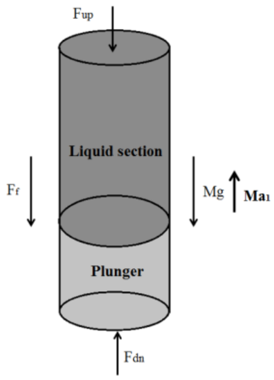


Fig. 3 Analysis of upward force of plunger liquid section in tubing[2]

According to Newton's second law, the equilibrium equation is established.

$$F_{dn} - F_{up} - Mg - F_f = Ma_1 \quad (1)$$

Where: M, total mass of plunger liquid section, kg; g, Acceleration of gravity,m/s^2;a_1, Upward acceleration of plunger liquid section, m/s^2; F_{dn}, Lower thrust, N; F_{up}, Downward pressure of upper gas, N; F_f, The friction force in the liquid section of the plunger, N.

The pressure on the upper end of the liquid section of the plunger, P_{up} can be obtained from the following equation (2),

$$\begin{aligned} P_{up} &= \rho_{gup} g\left(H - h_{zy} - s\right) + \lambda_{gup}\rho_{gup}\frac{H - h_{zy} - s}{2d_{oc}}v_{up}^2 + p_0 \\ v_{up} &= \frac{ds}{dt} = s' \end{aligned} \quad (2)$$

Where, ρ_{gup} average density of gas above liquid section of plunger, kg/m^3; H, the depth of wellhead to bottom of well, m; h_{zy}, The depth of plunger and its upper liquid section, m; s, Plunger up distance, m; λ_{gup}, The average friction coefficient of gas in the upper part of plunger; d_{oc}, Inner diameter of tubing, mm; v_{up}, Up speed of plunger, m/s; P_o, Wellhead oil pressure, MPa.

The pressure P_{dn} on the lower end face of the plunger can be obtained from equation (3).

$$P_{dn}=\rho_{gc}gH-\lambda_{gc}\bar{\rho}_{gc}\frac{H}{2\left(d_{oc}-d_{oc}\right)}v_c^2-\rho_{gdn}gs-\lambda_{gdn}gs$$
$$-\lambda_{gdn}\rho_{gdn}\frac{s}{2d_{oc}}v_{up}^2-\rho_1 gh_1 \quad (3)$$

Where, ρ_{gc}, the average gas density in the annulus of oil jacket, kg/m^3; λ_{gc}, average friction of the annulus gas in oil jacket; v_c, the velocity of the gas in the annulus of the oil jacket, m/s; ρ_{gdn}, average density of gas in the lower part of plunger, kg/m^3; λ_{gdn}, the average friction of the gas in the lower part of the liquid section of the plunger; ρ_1, density of produced liquid, kg/m^3; h_1, new liquid height in wellbore, m;

Finally, the second order ordinary differential equation is obtained,

$$s''=B_1 ss'^2+B_2 s'^2+B_3 s+B_4 \quad (4)$$

Where,

$$B_1=\frac{A_{oc}\lambda_{gup}\rho_{gup}}{2d_{oc}M}$$
$$B_2=\left[\lambda_{gup}\rho_{gup}\left(H-h_{zy}\right)-\lambda_l\rho_l h_{zy}\right]\frac{A_{oc}}{2d_{oc}M}$$
$$B_3=\frac{A_{oc}\rho_{gup}g}{M} \quad (5)$$
$$B_4=\left[P_{dn}-P_o-\rho_{gup}g\left(H-h_{zy}\right)\right]\frac{A_{oc}}{M}-g$$

Where, A_{oc}, cross sectional area of tubing, mm^2; $M=M_p+\rho_1 gh_{yd}$, the weight of the liquid section of the plunger, kg, the liquid leakage is not considered; λ_l, the friction coefficient of liquid.

3. Solution of wellbore pressure profile

The sensor is installed inside the plunger to obtain the acceleration of the plunger, the temperature and pressure of the wellbore during the operation of the plunger, and the data is transmitted by wireless transmission. According to the data of pressure, temperature and acceleration, we can get the graph as shown inFig. 4. From the graph, we can judge the time period when the plunger goes up and down, and solve the real-time position of the plunger in the two stages of the plunger.

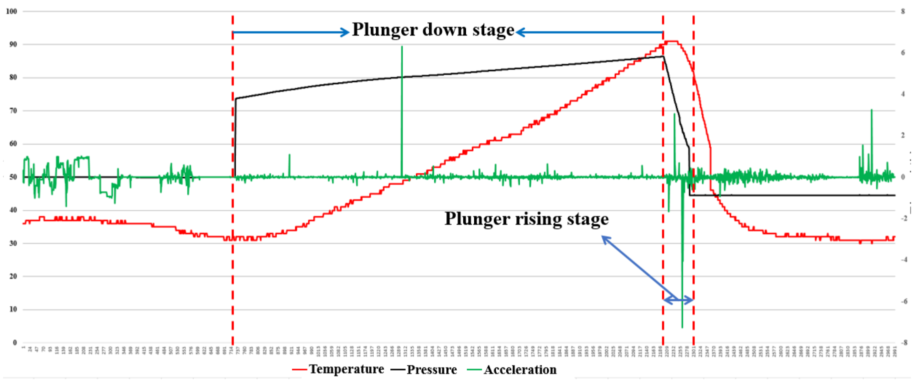
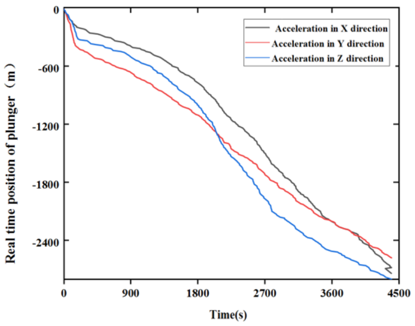


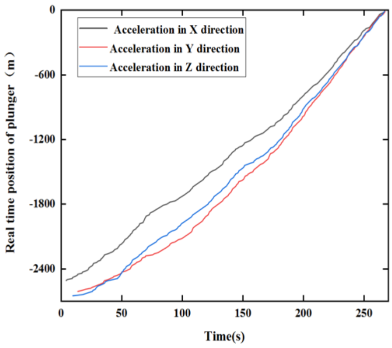
Fig. 4 Pressure, temperature and acceleration curves

3.1. Real time position solution of plunger

When the plunger passes through the coupling, the acceleration will change dramatically, and the distance between each coupling is 10m. Therefore, the real-time position of the plunger can be roughly obtained by selecting the point where the plunger acceleration changes dramatically and corresponding to the tubing coupling. Using matlab program to screen out the point where the acceleration of the plunger changes dramatically, take the wellhead as the origin, and finally solve the real-time position of the plunger according to the three acceleration directions of the plunger, as shown in Fig. 5.



(a)



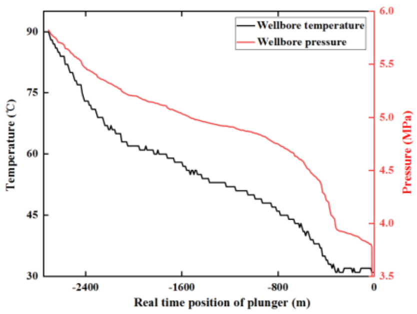
(b)

Fig. 5 Real time position curve of plunger, (a) plunger descending stage, (b) plunger rising stage

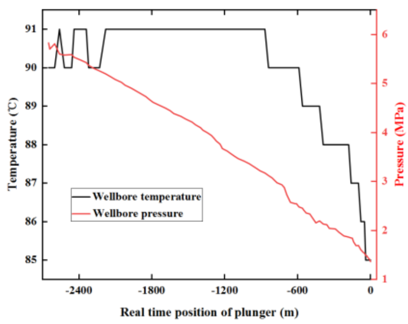
It can be seen from Fig. 5 that the plunger position curves solved in the three acceleration directions have roughly the same trend, but there are differences between the curves. This is because the acceleration changes in the three directions are different when the plunger passes through the coupling, and the plunger often collides with the inner wall of the tubing during wellbore operation, resulting in acceleration changes, thus affecting the selection of points.

3.2. Analysis of wellbore temperature and pressure profile

The acceleration data of plunger can be connected with wellbore pressure and temperature through time nodes. When the curve of plunger position and time is obtained, the data of plunger position, pressure and temperature at the same time can be selected by compiling matlab program, and the curve is drawn with plunger position as abscissa and pressure and temperature as ordinate, as shown in Fig. 6.



(a)



(b)

Fig. 6 Wellbore pressure and temperature profile analysis, (a) plunger down stage, (b) plunger up stage

It can be seen from Fig. 6 that the pressure and temperature in the wellbore increase with the increase of the well depth. The pressure and temperature data measured in the plunger falling stage are more accurate. In the rising stage, due to the speed of the upward process of the plunger is relatively fast and the temperature sensor measurement has a certain delay, there is a large error in the temperature data. Therefore, when the temperature and pressure profile is used for the wellbore analysis, Data when the plunger is lowered should be used.

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4. Development trend

At present, the research on plunger lift has been carried out at home and abroad, and it has been widely used in low-pressure and low-yield gas fields. However, there are still some limitations in the establishment and solution of the dynamic model of plunger lift:

1) The parameters calculated by the plunger gas lift mechanism model are only applicable to certain production conditions;

2) Some important parameters of the mechanism model are taken from the test wells with specific conditions, which is not universal;

3) There are many assumptions in solving the dynamic model of plunger, which leads to the error between the calculated results and the actual results.

In view of the limitations of the above plunger gas lift research, it is necessary to combine the massive production data of plunger gas lift wells in the gas field in the future, and apply the plunger gas lift model to design the parameters of new wells. At the same time, the matching model is used to study the production system of the well that has been put into production in the plunger gas lift technology, so as to find the specific scheme to optimize the production system.

In order to give full play to the working efficiency of plunger gas lift process, it is necessary to optimize the design of the process to ensure the normal operation of the process and give full play to its working efficiency, and finally improve the natural gas recovery. Before the parameter optimization design, it is necessary to study the factors that affect the lifting efficiency in the process according to the results of the dynamic analysis of the plunger gas lift process, so as to have pertinence in the process parameter optimization and tool optimization design. Based on the analysis of the influencing factors, the application conditions of the plunger gas lift well can be obtained. According to the formation pressure calculation of gas well effusion, the optimization algorithm of plunger gas lift is established, and then the optimization software is compiled to realize the optimization of plunger gas lift drainage gas production system, which is developing towards the intelligent research of plunger operation.

5. Conclusion

1) Plunger gas lift is a kind of intermittent oil production method which uses the energy of gas well to promote fluid accumulation in tubing. To optimize the working system of plunger gas lift, the dynamic model of plunger in tubing should be established, and the influence of formation pressure, gas production of gas reservoir, gas-liquid ratio and other factors on the dynamic model of plunger should be considered;

2) According to the dynamic analysis of the running process of the plunger, the lifting model of the plunger in each stage is established. The initial value is solved by Runge Kutta method, and then the dynamic model is solved by the modified Miline-Hamming prediction correction method. The velocity and displacement of the plunger in the wellbore as well as the pressure and temperature corresponding to the position can be predicted;

3) The real-time position of the plunger is calculated by the measured data of the plunger, and the curves of the wellbore position with temperature and pressure are drawn. Finally, it is recommended to use the measured data when the plunger drops to analyze the wellbore pressure and temperature profile.

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