Application of Gas Lift Technology in High-deviated Well in NanPu Oilfield

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Abstract. At present, the gas lift production technology used in conventional vertical Wells is basically maturing, but its adaptability of application is poor in high-deviated wells. The paper mainly aims at the technique challenges of gas lift production applied in high-deviated well, and the researches on some aspects such as the design optimization of gas lift, the mechanics analysis of downhole strings, the optimization of completion strings, and the research and development of completion tools and wire dropping& fishing tools. Finally, a set of gas lift production technology suitable for the application of high-deviated wells has been formed. This technology has been applied in 93 high-deviated wells in Nanpu 1-3 artificial island of Jidong oilfield with the design of gas lift coincidence rate 92%, string success rate 97% and success rate of gas lift put into production 100%. And gas lift production has been successfully realized in high-deviated and horizontal well in China.

1. Foreword

Nanpu 1-3 artificial island belongs to complex dissolved gas flooding reservoir composed of sandstone, carbonate rock and volcanic rock, with burial depth (2250~3050m). Gas oil is relatively high (100~200m³/t). Oilfield adopts directional wells with small spacing of 3.3m for centralized development, and build-up point of oil well 400~800m, and well inclination 40°~60°among them (the maximum 70°). Through initial research and optimization on oil production methods, the analysis results show that the lifting methods such as rod pump and electric pump are not so suitable for high gas-oil ratio and sand-producing oil wells with some problems such as low pump efficiency and broken stem easily often, and the result of short inspection cycle of pump inspection, and low efficiency of oil well production comes out which causes short inspection cycle of pump inspection and low efficiency of oil well production, which has a great impact on the efficient production of oil reservoirs. The comparative study shows that the structure of the gas lift oil production completion string is relatively simple, without moving parts, and has stronger adaptability to sand production and
high gas-oil ratio oil wells which can extend the life of the string and can be applied to various types of reservoirs and complex well conditions\cite{1}. Therefore, gas lift oil production has become the best artificial lift method for oil well development of Nanpu 1-3 artificial island.

2. Difficulties in gas lift production in high-deviated oil well

Gas lift oil production technology has some technical difficulties that need to be overcome in high-deviated well, mainly in the following three aspects:

The first One is the design of gas lift oil production technology, in which the important working parameters of the gas lift valve, such as the lowering stages of the gas lift valve, the depth of the gas lift valve in the well, the hole size of the gas lift valve, and the starting pressure of the gas lift valve. These factors directly determine the design of gas lift oil production and the test of gas lift valve. If it simply adopts the equal pressure drop design, there may be interference between the valves, resulting in abnormal operating conditions during oil well production, or the design depth of the valve in oil well becomes shallower, which cannot meet the requirements of oil well production.

Second, the wellbore trajectory of high-deviated well is complex, so the completion string and the tool are close to the casing wall, which increases the friction resistance between the string, the tool and the pipe wall. The transmission efficiency of the axial force of the string is low, which increases the pulling resistance of the string, and increases the risk of string sticking.

The third is that the gas lift string requires the packer to achieve gas sealing, and it can be safely relieved out after 5 years of service life.

Fourth, gas lift dropping& fishing is rarely used in high-deviated well, and its applicability conditions are not mature.

3. Technical and optimization measures

In order to ensure the successful test of gas lift oil production technology in high-deviated well of Nanpu 1-3 artificial island, these have been carried out that optimization studies of gas lift oil production completion technology in high-deviated well from gas lift technology optimization, string stress analysis, string optimization, to research and development of well completion and wire dropping &fishing tools, etc. Optimize the current gas lift oil production technology design plan; research and develop gas lift completion strings suitable for high-deviated wells; perform force calculations on string structure, analyze the lifting load of the string of gas lift oil production technology, and complete the gas lift string lowering security research. Through the optimized design of the completion string for high-deviated wells, the Y455-115 hydraulic packer, matching set tools and stab-in pipe of well completion suitable for the setting in high-deviated wells were developed. The wire dropping& fishing tool string suitable for the gas lift completion string in high-deviated wells was studied, and the complete set of gas lift oil production technology matching for high-deviated wells was upgraded and improved.

3.1. Selection of completion string type

Usually, the continuous gas lift oil production technology is designed into three conventional downhole string types according to different tools of the gas lift completion string, including open, semi-closed and closed strings. The liquid supply level of the production well and the safety of the gas lift production string are the main basis for selection. Because of the open string does not make-up a packer, it completely relies on the formation liquid supply capacity to balance the gas injection pressure to maintain the dynamic liquid level in the well at a certain height, so it is suitable for oil wells with good formation liquid supply capacity. The semi-closed string has a packer installed at a certain position under the working valve on the basis of the open string, and the function of the packer is to separate the annulus between the tubing and casing and the intermediate casing. Although the semi-closed string is slightly higher at cost than the open string, it can avoid problems such as the injection of gas at the bottom of the string, the unloading process when the well is restarted, and back pressure contaminating formation caused by the gas injection pressure higher than the formation
pressure. The closed string is based on the semi-closed string. The fixed valve is installed at the bottom of the string, and the fixed valve is used to prevent the pressure in the string from acting on the formation directly. This string is mainly used for intermittent gas lift Well production. Nanpu 1-3 artificial island belongs to complex dissolved gas flooding reservoir composed of sandstone, carbonate rock and volcanic rock, Oil well production is medium and factor such as the decline in oilfield development capacity is involved, therefore, a semi-closed gas lift production string is selected.

3.2. Design of completion string

Generally, the completion string of a continuous gas lift well is composed of a bell mouth + a setting stub + a packer + a wire operation sliding sleeve+ a multi-stage eccentric work cylinder and a gas lift valve, as shown in Figure 1. In oil wells with high well inclination, due to the long disturbance of the gas lift string, the outer wall of the string is closely attached to the inner wall of the casing, which increases the friction between the string and the casing, the transmission efficiency of the axial force is lowered, and the running resistance of the string is larger. In order to make the string run smoothly into hole, at the same time, the string can realize the safe and higher efficient of gas lift function, in the design of the gas lift string in high-deviated well, many improvements have been made on the basis of the gas lift completion string of the vertical well. Firstly, the lowermost bell mouth of the string is designed as a beveled end face, which has the function of guiding the string RIH through the build-up section smoothly, Then the Y455 packer is connected with the matching stab-in pipe, the Y445 packer is set with a hydraulic setting tool, and the sealed stab-in pipe is inserted to complete the well. The operation requires two consecutive strings to be completed for completion. During the construction process, the size of the best matching tools must be strictly selected, and the design of the gas lift production string should be optimized to avoid the risk of stuck. Finally, a rounded design is used at the lower part of the sealed stab-in pipe, which reduces the friction coefficient between the pipe walls. The improved gas lift completion string is shown in Figure 2.

![Schematic diagram of conventional gas lift completion string](image1)

**Figure 1. Schematic diagram of conventional gas lift completion string**

1- tubing; 2, 4, 6- side pocket mandrel; 3, 5, 7- retrievable gas lift valve; 8- wire operated sliding sleeve; 9- packer; 10- setting nipple; 1- bell mouth; 12- oil reservoir; 13- casing.

![Schematic diagram of improved gas lift completion string](image2)

**Figure 2. Schematic diagram of improved gas lift completion string**

1- tubing; 2- fixed mandrel; 3- fixed gas lift valve; 4, 6- side pocket mandrel; 5, 7- retrievable gas lift valve; 8- steel wire operated sliding sleeve; 9, 12- slide centralizer; 10- sealing stab-in pipe; 11- drillable & retrievable packer; 13- setting nipple; 14- bell mouth; 15- oil formation; 16- casing.
3.2.1. Mechanical analysis on string. Due to the large deviation, the working load of the gas lift string is complex and changeable in the process of RIH, which makes the string deform under stress. Especially when the well deviation exceeds 30°, the downhole tools will be stuck, which is easy to cause downhole accidents such as tool damage and packer unsealing. The structural mechanics calculation of gas lift string is carried out to provide theoretical basis for tripping operation of gas lift string\(^2\).

Assumptions: ① The borehole curvature of the calculated unit section is constant. ② During trip of string operation, the string load changes with the change of the hook, and the gas lift string can be safely and stably tripped. ③ The cross-section shear caused by the string operation is ignored, and the stiffness collision between the inner wall of the pipe is ignored, that is, the energy loss of the collision is not recorded. ④ The curvature of the wellbore section where the string contacts the casing is the same as that of the borehole. ⑤ The calculated element is considered to have the same rigidity change, and the force model in Figure 3 is established.

![Figure 3. Pipeline research section](image)

According to the mechanical equilibrium conditions, the equations are listed and the mechanical expression of the string plane model (1) is established.

\[
\begin{align*}
\frac{dF}{d\alpha} &= \pm \mu F(\alpha) + gALWpR \times (\sin \alpha - \mu \cos \alpha) \\
N &= gWpAL\cos \alpha - F(\alpha)/R
\end{align*}
\]  

(1)

The force formula (1) of theoretical analysis is multiplied by differential fork, and the formula (2) is projected in every direction.

\[
\begin{align*}
T - gW_b AL \cos \theta + F_r &= 0 \\
N - gW_b AL \sin \theta &= 0 \\
F &= \mu N
\end{align*}
\]  

(2)

The mathematical model of the theoretical formula is established by Matlab / Simulink\(^3\), and the verification calculation of well Np13-x1052 in Jidong Oilfield is carried out. The results are shown in Table 1. The hook load can be obtained when the string is tripped at different depths and different inclination. The change of the inclination has a great influence on the hook load. During the pulling-up and RIH process, the self-weight of the tubing is sometimes the resistance and sometimes the power. The existing workover equipment of the operation team can meet the requirements of the construction.

| Well depth (m) | Well declination angle (°) | Azimuth (°) | Lifting hook load (N) | Lower hook load (KN) |
|---------------|---------------------------|-------------|-----------------------|----------------------|
| 330           | 2.10                      | 216.72      | 36.16                 | 34.38                |
| 600           | 21.00                     | 216.72      | 67.22                 | 54.52                |
| 1020          | 50.40                     | 216.72      | 112.3                 | 70.54                |
2400  50.64  216.72  200.32  157.39  
2520  50.64  216.72  265.57  224.51  
3570  49.80  216.72  274.85  228.83  
3852  40.80  216.72  304.96  233.44

3.2.2 Tool safety analysis. Due to the different characteristics of the working environment in deep well, the string is mainly subjected to axial force, bending stress of tubing following the wellbore and tangential force caused by the pressure in each direction. During the tripping operation of the string with the gas lift tool, mainly check the working conditions of the gas lift mandrel at the bottom of the well[4-5].

(1) Tensile and compressive stress
The reservoir is buried deep, the formation temperature is high, and the pressure is high. So, there are high requirements for the temperature resistance and pressure resistance of the string and supporting tools. The condition to ensure that the tool can run into hole smoothly is that the tool will not be stretched or compressed under the axial load.

\[ \sigma_t = \frac{T_t}{A} \]  

(2) Bending stress
It is assumed that there will be no bending deformation due to the short time when the tools on the string pass through the high deviated well section. However, when the bending stress reaches the allowable stress of steel for a long time, the string will produce large bending stress, which is easy to cause damage or permanent deformation of the string. The axial pressure on the string should be controlled below the critical yield load of the string. Here, the bending stress caused by borehole and tubing bending should be checked[6-7].

\[ \sigma_b = \frac{Ek\Delta L}{ILrT_t} \]
\[ \sigma_{bc} = \frac{2I}{6LrT_t} \]
\[ I_P = \frac{\pi d_k^4(1-d_k^2)}{64} \]  

(3) Tangential shearing stress

\[ \tau_P = \frac{M_k \cdot r}{J_P} \]
\[ J_P = \frac{\pi (d_k^4-d_t^4)}{32} \]  

Using Matlab / Simulink model and stress formula, the mechanical characteristics of string and tool under different well deviation conditions can be analyzed, which has a guiding role in the design of gas lift string[8].

3.3. Research & Development of supporting tools for gas lift production

In order to reduce the number of workover operations, achieve three to five years of immobile string, and improve the production efficiency of oil well, the retrievable gas lift completion tools are selected. Meanwhile, the drillable & retrievable Y455 packer and its setting tools, completion stab-in pipe and high impulse integral fishing tool string are developed.

3.3.1. Selection of gas lift valve and Optimization of technology design. In continuous gas lift production, the oil pressure gas lift valve and the casing pressure gas lift valve can meet the production requirements. The opening and closing of the gas lift valve is controlled by the oil pressure, and the gas injection rate is adjusted according to the oil pressure. If the oil well is short of liquid supply or the design condition is different from the actual production condition, intermittent production is easy to occur. Under the same design parameters, in order to achieve the same depth of injection, the stage of oil pressure gas lift valve is more than that of casing pressure gas lift valve by 2-3 valves. The characteristic of the casing pressure gas lift valve is that it is opened and closed by the high-pressure
gas injected into the annulus between casing & tubing, and the working stability is better than other types of valves. It can be judged from the change of the gas injection pressure that which valve is working. Therefore, the gas injection pressure-operated valve is preferred.

According to the different treatment methods for the oil pressure, the gas lift design is divided into the equal pressure drop method and the variable pressure drop method. In the gas lift design of high deviated wells, if the design of equal pressure drop is adopted, one is that the interference between valves may occur, and the working condition of oil well is abnormal; the other is that the depth of valve becomes shallow, which can not satisfy the production allocation of oil well. The variable pressure drop design can well eliminate the interference between valves, improve the normal rate of oil well working conditions and the utilization rate of high-pressure process gas, increase the depth of gas injection, and improve the lifting efficiency of oil wells. Therefore, the variable pressure drop design method to improve the safety factor of anti-interference between valves is adopted in the gas lift design of high deviated wells.

Under the conditions of vertical wells, Y211 packer is mostly used for gas lift string. However, due to the large deviation of high deviated wells, the setting difficulty of Y211 packer is increased. Therefore, Y455 drillable & retrievable packer was developed, as the Figure 4. The Y455 packer is connected with the tubing string and reaches a predetermined depth according to the process design. Hydraulic setting or cable setting can be used to insert the matching sealing stab-in pipe to seal the annulus between casing & tubing.

Conventional released packers use shear pins or release rings to achieve both connection and release, which will cause the possibility of releasing during the process of RIH or sealing, which cannot guarantee the safe sealing of the packer. The sealing stab-in pipe of Y455-115 packer is shown in the Figure 5, slip connection is used to effectively avoid the phenomenon of midway release. The release process is as follows: first, drop the ball and press to cut the shear pin, the lock is retracted, the slip moves downward under the tension; Then, lower the stab-in pipe, the slip moves upward relatively; Finally, lift the stab-in pipe, the slip shrinks, the limit ring moves downward, the slip loses support and is released. Ensure the safety of packer setting and releasing.

3.3.2. Development of high-impact steel wire dropping & fishing tool assembly. Due to the large deviation of high deviated wells, the tool assembly is difficult to run into hole and drop &fish, and the transmission of impact force is limited. A high-impact dropping &fishing tool assembly has been developed as Figure 6, and multiple pulleys centralizer are installed on the tool assembly to reduce friction with the well wall. The pulley centralizer has the advantages of flexible rolling ball, small friction force and no damage to tubing; At the same time, hydraulic jar and pipe jar are used together to increase the impact force and reduce the sticking risk of string; In addition, the overall length of the tool string is shortened for passing through the build-up section smoothly.
4. Application effects
The gas lift level of 63 wells have been built in Nanpu 1-3 artificial island oilfield and 93 wells have been tested and applied. The average daily oil production of gas lift well is 895t/D, the highest average daily oil production of single well is 25.1t/d, and the built production capacity is 310, 000t/A.

5. Conclusions and Cognitions
(1) The gas lift well has achieved rapid liquid backload and unloading start, and the oil well start-up time is shortened, which meets the needs of rapid production of oil wells and improves the production efficiency of oil wells.

(2) A set of gas lift production technology suitable for high deviated well of Nanpu 1-3 artificial island has been formed, including the design method of gas lift technology, production string and supporting tools. The theory and application of gas lift technology in high deviated wells have been improved and developed, which fills the gap of gas lift technology in China.

(3) It has been applied in 93 wells of Nanpu 1-3 artificial island, the coincidence rate of gas lift design 92%, the success rate of string 96%, and the success rate of gas lift production 100%. It is the first time to realize gas lift production in highly deviated wells in China, which has a good guiding significance for the gas lift development of Nanpu 1-3 artificial island.

At the same time, it provides an efficient and low-cost artificial lifting method for the oil fields development in directional wells and highly deviated wells at home and abroad.

Acknowledgments
From the topic selection to the completion of this paper, we have always been inseparable from the enthusiastic help of colleagues and friends. Here we would like to express my most sincere gratitude to Rendong Feng, Lifang Ding, and other people for their hard work.

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