Theory and application of gas drilling technology

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Abstract-Gas drilling began in the 1950s. The drilling process is implemented by injecting a mixture of air and water into the well with an air compressor. Field experiments have gradually proved that air drilling in hard rock can improve the ROP by 2 ~ 3 times, especially in reservoir protection. In this paper, the gas drilling technology is analyzed and discussed. The test results of gas drilling technology show that the drilling time is reduced and the mechanical ROP is greatly improved. Compared with mud drilling, the mechanical ROP of gas drilling in the same structure and well section is generally increased by 2 ~ 10 times, the production of oil and gas wells is relatively high and the economic benefit is remarkable.

1.IINTRODUCTION
Gas drilling technology is a new drilling technology with gas as circulating medium. Compared with conventional drilling, the advantages of gas drilling are mainly to discover and protect oil and gas reservoirs, reduce downhole complexity such as lost circulation, improve single well mechanical ROP and single well recovery. In recent years, gas drilling has developed rapidly in improving the ROP and protecting the reservoir. Compared with conventional drilling fluid drilling, the ROP is increased by 5 ~ 15 times and the drilling cycle is shortened. Practice shows that the influence of gas itself on borehole stability is not very serious [1]. For example, when gas drilling is used in loose sandstone formation, annulus plugging is rarely seen no matter how high the ROP is, because small-grained sandstone can smoothly pass through the key point on the upper part of the drill collar. Gas drilling is gradually becoming an important technical means to greatly improve the ROP, discover and protect oil and gas reservoirs, control serious lost circulation and reduce drilling costs. In the United States and Canada, underbalanced drilling accounts for about 40% of the total drilling workload, and the number of wells implementing gas drilling accounts for about 30% of the total underbalanced drilling workload [2].

Gas drilling has experienced two development stages in the United States. In 1953, eipaso natural gas company of the United States successfully drilled the first oil and gas well in Utah with air as drilling fluid for the first time. Until 1990, air drilling was widely used in engineering applications such as drilling speed increase, leakage prevention and control in non oil and gas bearing reservoirs. Since 1990, due to the needs of developing a large number of low-pressure and low-permeability oil and gas resources, coalbed methane, tight gas and other difficult to use oil and gas resources in the Midwest of the United States and Canada, inert gas drilling technology has been developed, especially the gas drilling technology combined with special orbital wells. China's gas drilling technology started almost at the same time as foreign countries, but its development is slow. It has experienced the early exploration stage (1950s ~ 1970s), the initial stage (late 1980s ~ 2004) and the development stage (2005 ~ now). With the rapid development of gas drilling in Sichuan basin after 2005, gas drilling shows the characteristics of revolutionary technological progress. Through the research in recent years, China's gas drilling technology and equipment have reduced the gap with foreign countries, reached the more
advanced level in the world, and realized large-scale application in Sichuan, Chongqing, Xinjiang, Jilin and other regions [3].

At present, foreign countries have mature downhole information transmission technologies such as wireline MWD, downhole storage measurement and electromagnetic MWD, as well as gas screw drilling tools and pneumatic hammers for horizontal wells, but China is still in the research stage in these aspects. Many domestic institutions have carried out EM-MWD research. The current MWD technology of Chuanqing drilling and production Institute has been tested to a well depth of 4300m, and mature products will be available soon. Many domestic institutions have gas screw drilling tools, but there are problems such as high speed, low torque, small load stall and short service life. The technology is imperfect and has not been popularized and applied in a large area. Chuanqing company has developed the guided air hammer, which is currently in the test stage [4]. The successful test of this product will promote the gas drilling horizontal well technology to a new level. Domestic Chuanqing gas drilling company has successfully carried out gas drilling tests of two wells in Guang'an area, Sichuan, with the longest horizontal section drilled to 537.9m, creating a domestic record of gas drilling horizontal wells.

According to the application at home and abroad, combined with the characteristics of gas drilling technology, the advantages are mainly manifested in discovering and protecting the reservoir, improving the ROP and reducing lost circulation. The main characteristics and mechanisms are as follows: (1) protecting and discovering the reservoir. Reservoir damage is irreversible [5]. As long as damage occurs around the wellbore, it will be difficult to eliminate these damage. In the process of gas drilling, the gas phase (mixed gas phase) is used as the circulating medium, and the bottom of the well is in an unbalanced state to prevent drilling fluid from entering the formation. Therefore, gas drilling can play an important role in discovering and protecting oil and gas reservoirs; (2) improve the mechanical ROP. The substantial reduction of fluid column pressure in gas drilling wellbore not only improves the rock breaking efficiency at the bottom of the well, but also helps to reduce the "holding effect", so that the bit can continue to cut new rock instead of rolling broken rock cuttings, so as to improve the mechanical ROP; (3) Reduce or avoid lost circulation. The problem of lost circulation greatly increases the cost of drilling engineering, and will cause serious losses caused by formation damage. Gas drilling can effectively eliminate the problem of lost circulation. The bottom hole equivalent density of gas drilling is 0.001 ~ 0.90g/cm3, the window range is large, and underbalanced drilling can be realized in various pressure formations, so gas drilling can eliminate lost circulation; (4) Extend bit life. During gas drilling, the bottom hole is under negative pressure, which is beneficial to blow the broken rock away from the bottom of the well, effectively prevent the repeated breaking of the rock, and prolong the service time of the bit; (5) Reduce complex situations such as sticking. Gas drilling machinery has high ROP, shortens drilling time and reduces the wear of drilling tools and centralizers; Reduce the drilling tool load and prolong its service life; At the same time, the vertical pressure of gas drilling is low, reducing the probability of penetration and leakage. Therefore, the occurrence of complex underground accidents is reduced; (6) Reduce well completion and stimulation measures. Due to the underbalanced drilling in the process of gas drilling, the solid particles and liquid phase can not enter the formation, so that the reservoir can be protected. Therefore, no further stimulation measures are required and the relevant costs are reduced.

2. FLOW PATTERN THEORY OF GAS DRILLING

The theory and technology of gas drilling technology are mainly based on the study of different fluid forms. Through experimental study, the flow pattern of gas-liquid two-phase flow in annulus tube is divided into five types by Caetano: bubble flow, slug flow, dispersed bubbly flow, annular flow and bubbling flow. Under normal temperature and normal pressure, the flow patterns of gas-liquid two-phase flow in annulus can be divided into four types: bubbly flow, slug flow, stirring flow and annular fog flow. The specific description is as follows: bubbly flow. The gas phase is distributed in the form of smaller discrete bubbles in the continuous liquid phase of the annular space, and the smaller spherical bubbles move upward in an approximate linear trajectory. In a fully eccentric annular tube, small bubbles tend to move to a larger annular space in the region of small annular gap; slug flow. The gas
phase mainly exists in the liquid phase in the form of large bubbles, namely Taylor bubbles. Bubbles are separated from each other by a liquid column containing small bubbles. The shape of Taylor bubble in annular tube is different from that in circular tube. It is wound on the outer wall of inner tube and occupies almost the whole section of annular tube; stirring flow. It is exhausted with slug flow, but it is very chaotic and unstable. The bubbles become very narrow and distorted into bubble flow; annular fog flow. There is a liquid film between the outer wall of the inner tube and the inner wall of the outer tube, and the annular space between the two films is occupied by the gas core containing small droplets. The four fluid forms are shown in Figure 1.

![Fig. 1 flow pattern of gas-liquid two-phase flow in vertical annulus](image)

Gas (including air or inert) drilling fluid is injected into the well at the same time to reduce the pressure of annulus fluid column. Inflatable drilling technology is a drilling circulating fluid with liquid phase as continuous phase and gas phase as dispersed phase. The bottom hole equivalent density can be adjusted by inflation and liquid injection. According to the different injection methods, it can be divided into riser injection, parasitic injection and concentric injection. The advantages of riser injection method are simple, do not affect the wellbore structure design, and can reduce the density of the whole circulation system. The disadvantage is that MWD and LWD measurement while drilling systems cannot be used, and the optimization of downhole motor parameters is limited due to the limitation of displacement. Parasitic pipe injection method and concentric string injection method are less used due to the disadvantages of high cost, complex process (special wellhead device is required), reduced wellbore (concentric string method), etc. According to the actual situation of Liaohe Oilfield, the riser (drill pipe) inflation injection method is selected as the nitrogen filling method. Therefore, the research and field test of aerated drilling are mainly aimed at this way. The process flow of aerated drilling is shown in Figure 2.

![Fig. 2 flow pattern of gas-liquid two-phase flow in vertical annulus](image)
3. PRINCIPLES OF PARAMETER DESIGN FOR AERATED DRILLING

The negative pressure value design of nitrogen filled drilling parameters must pay attention to the following problems:

1. The separation capacity of the surface separation equipment is greater than the fluid flow of the formation invading the wellbore. The greater the negative pressure difference during nitrogen filled drilling, the greater the oil and gas output. Therefore, the designed negative pressure difference cannot make the oil and gas output exceed the separation capacity of surface equipment, especially in high-yield reservoirs. The output of oil and gas can be estimated according to the production pressure difference and maximum initial production of adjacent wells.

2. The rated working pressure of wellhead equipment meets the requirements of safe drilling. The more oil and gas produced during nitrogen filled drilling, the higher the casing pressure controlled by the wellhead. In principle, the maximum allowable casing pressure shall not exceed the minimum of the rated working pressure of the wellhead device, the internal pressure resistance of the casing (calculated as 80%) and the formation fracture pressure. The influence of oil and gas production on casing pressure is very complex, which needs to be calculated by gas-liquid two-phase flow numerical simulation software.

3. Maintain wellbore stability. Sidewall stability is a major factor affecting the use of nitrogen filled drilling. Sidewall instability is mainly in mud shale formation, fracture zone and piedmont structural zone. Nitrogen filled drilling in Liaohe Oilfield is mainly Archean buried hill formation. The contact surface of this formation is unconformity ancient contact surface, mainly ancient buried hill weathering crust buried hill. There is fragmentation zone on the contact surface, so formation stability analysis should be carried out. Therefore, for underbalanced drilling in multiple layers, it is necessary to analyze the wellbore stability and determine the formation collapse pressure to determine the allowable maximum negative pressure difference.

4. Instability of gas-liquid two-phase flow. The instability of gas-liquid two-phase flow leads to periodic instantaneous positive pressure difference and production formation damage, which is an important problem in gas filled drilling through drill string. Due to the instability of gas-liquid two-phase flow, the negative pressure difference shall not be too small to avoid periodic instantaneous positive pressure difference caused by pressure fluctuation.

5. Optimization of gas injection rate. The relationship between bottom hole pressure and gas flow under a certain liquid flow rate. It can be divided into two areas: static pressure control area and friction control area. In the static pressure control area, hydrostatic pressure is dominant and the influence of gas flow is very sensitive; in the friction control area, the friction pressure drop is dominant, and the increase of gas flow has no obvious impact on the bottom hole pressure, which is relatively stable. In hydraulic design, the impact of formation gas should be fully considered to make the inflation volume the best.

4. EQUIVALENT DENSITY CONTROL METHOD FOR AERATED DRILLING

For conventional drilling, aerated drilling can adjust the bottom hole equivalent density by adjusting the gas-liquid ratio (liquid displacement, gas displacement) or casing pressure without changing the density of drilling fluid base fluid. In this way, the density of drilling fluid base fluid needs to be increased only when the bottom hole pressure is greater than the density of drilling fluid base fluid. It can be seen from Figure 3 that the density is affected by the displacement of drilling fluid. In the same case, changing the fluid injection volume can significantly affect the bottom hole equivalent density. The bottom hole equivalent density can be increased by increasing the drilling fluid flow. On the contrary, the bottom hole equivalent density can be reduced by reducing the drilling fluid flow. However, it should be noted that excessive displacement of drilling fluid will lead to excessive vertical pressure, and too small displacement of drilling fluid will affect the return of rock cuttings.
Fig. 3 Effect of adjusting liquid flow on bottom hole equivalent density

For the convenience of analysis and comparison, the data of pressure and well depth in the annulus and drill string in the wellbore are drawn in one diagram, as shown in Figure 4. The well depth at the turning point of the two curves is roughly the same, which is exactly the starting point of the drill collar tappet, that is, the position at the connection between the drill string and the drill collar. And the two curves are discontinuous, which is mainly due to the pressure drop caused by the air flow passing through the air hole of the bit.

Generally speaking, the annulus pressure increases gradually from the wellhead to the bottom of the well, and the curve slope decreases at the connection between the drill string and the drill collar, indicating that the pressure gradient increases rapidly, which shows that the pressure value increases rapidly. This is because the annular cross-sectional area at the junction of drill pipe and drill collar suddenly decreases, resulting in the rapid increase of flow rate and the increase of pressure loss, resulting in the sudden change of annular pressure in drill collar section and the sharp increase of pressure. The pressure in the drill string also increases gradually from the bottom of the well to the wellhead, which is similar to the distribution law of annular pressure. At the connection between the drill pipe and the drill collar, the inner diameter of the drill collar becomes smaller, which reduces the overflow cross-sectional area, and the pressure gradient increases rapidly, resulting in the rapid increase of pressure. Because the gas flow in the drill string is single-phase flow, and the fluid density is less than the density of the mixed fluid in the annulus, its pressure gradient is less than the pressure gradient in the annulus, making the pressure value change less. It can be seen from the above analysis that the sudden change of pressure gradient in the wellbore in gas drilling is at the intersection of drill pipe and drill collar, and the value of pressure gradient is large in the drill collar section, so the loss mainly occurs in the annulus drill collar section. Because the pressure gradient is closely related to the flow cross-sectional area, and the pressure gradient increases significantly with the decrease of the flow cross-sectional area. Therefore, where the cross-sectional area changes in gas drilling is the dangerous section where the pressure changes suddenly, and the pressure discontinuity in annulus and drill string is due to the pressure drop of bit.

Fig. 4 relation curve between wellbore pressure and well depth in gas drilling
5. CONCLUSION
The field test data show that the drilling rate of the gas injection designed according to the minimum kinetic energy method or the minimum rock cuttings carrying method gradually increases with the increase of the gas injection. The analysis shows that it is mainly due to the increase of the gas annulus return velocity, the decrease of the rock cuttings settlement speed, the cleaning better of the rock cuttings at the bottom of the well, the avoidance of repeated cutting of the rock cuttings, the improvement of the rock breaking efficiency of the bit, and the acceleration of the drilling speed. However, too much gas injection will greatly erode the wellbore and drilling tools. Therefore, appropriately increasing the injection gas is conducive to accelerating the drilling speed.

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