Optimization design of gas sand deflector for reverse circulation drilling

Biao Liu1,2,5, Lei Wang3, Shukai Chen4, Dongsen Zhang4, Caibao Wang4, Hao Wang1 and Yufan Zhou4

1 Research Institute of Petroleum Engineering, Sinopec Northwest Oilfield Company
2 Sinopec Key Laboratory for Enhanced Recovery (EOR) in Fractured and Cavernous Reservoirs
3 Sinopec Research Institute of Petroleum Engineering
4 School of Petroleum Engineering, Changzhou University
5 E-mail: liubiaodri@126.com

Abstract. Gas reverse circulation drilling which has a wide application prospect in complex strata of deep and ultra-deep wells can effectively improve drilling speed, protect the environment, reduce costs, and reduce downhole accidents, but its string structure is different from that of conventional drilling. In this paper, the design of integral and splitter head-in to side-out rotary sand deflecting device consists of rotating inner tube and non-rotating outer deflecting chamber, so that it can be effectively connected to the double-wall drill pipe system to ensure the normal sand deflecting of the gas reverse circulation drilling system. At the same time, the test well was verified and analyzed, and the sand-carrying efficiency was close to 92.53%. After drilling, there was no sand-settling at the bottom of the well. The average carrying rock diameter is about 10-15mm, and the maximum can be up to 30-40mm, indicating that the top-injection side-exit gas sand guide can be used for gas reverse-circulation drilling.

1. Introduction
With the gradual improvement of gas drilling technology, gas drilling technology has been rapidly developed in the petroleum industry due to its advantages of improving mechanical drilling speed, controlling lost circulation, effective discovery and protection of reservoirs. Compared with conventional liquid phase drilling technology, gas drilling technology can effectively avoid or reduce lost circulation accidents. Greatly increase the drilling speed of hard and brittle formations, thereby reducing drilling costs and shortening the period of well construction. Effectively protect low-permeability reservoirs from drilling fluids and improve the oil and gas recovery rate and production of a single well because of the reduction of the drilling fluid column holding effect, it is also easier to find and improve the drilling rate of low-pressure and low-permeability reservoirs, and to realize the evaluation of the reservoir while drilling. In addition, because its circulating medium is gas, it saves a lot of drilling fluid costs. It also protects the environment. Therefore, this technology has many advantages unmatched by other technologies [1-5]. In the deep drilling process, due to the complexity and change of the formation, there are often formations with the same layer of collapse and leakage, and a negative safety density window. The gas reverse circulation drilling technology can effectively solve such problems. The gas demand for gas reverse circulation drilling is only 1/5 ~ 1/6 of the positive circulation gas demand, and there are few repeated cuttings of rock fragments during drilling.
The degree is 3 to 4 times that of conventional PDC drilling. Especially when the diameter of the well is increased, the drilling cost can be reduced by 1/3 year-on-year. The cuttings are discharged from the inner pipe, and the upward return speed is not affected by the diameter of the well, which is beneficial to reduce downhole complexity. There is no loss of fluid medium, and drilling or encountering karst caves or large cracks will not stop drilling due to gas leakage. Therefore, gas reverse circulation drilling technology can greatly reduce application costs, effectively increase drilling speed, ensure drilling safety, and improve economy benefit [6-8]. The specific process is shown in Figure 1 [9].

However, the existing gas reverse circulation drilling technology is mostly used in underground mining systems, and it has two sand removal methods. One is the use of drilling rig hoses and risers to remove sand. The disadvantage is that the pressure level decreases after the pipeline wears, which controls the drilling well. It poses a safety hazard; the second is to use the crane to place the sand discharge hose directly and discharge the cuttings near the drilling rig, but this method does not meet the standard requirements of gas drilling [10]. The reverse circulation drilling system of the existing mines mostly uses power head drilling, the method of gas injection and sand return mostly adopts the method of gas faucet, as shown in Figure 2.

Figure 1. Gas reverse circulation drilling technology.  

Figure 2. Gas faucet structure.

It can be seen from Figure 2 that gas enters from the side of the gas faucet, and the circulating sand particles are returned in the vertical tube. However, the sand return channel of the gas reverse circulation drilling requires two inner tubes, and the gas is injected from the outer inner tube. Since the pipe returns to sand, it is necessary to design a better supporting gas reverse circulation drilling technology to meet the sand drainage and diversion device for drilling well control and drilling safety in the field of oil drilling.

2. Development of top injection side-out rotary gas sand deflector device

2.1. Design requirements and principles

Unlike conventional liquid drainage and sand removal devices, gas injection and sand removal equipment suitable for gas reverse circulation drilling needs to be able to overcome the occurrence of large sand deposits in the downhole blocker or serious block drop in the upper well section. The problem can deal with the complex conditions downhole that occurs at this time; at the same time, it is necessary to complete the killing operation of shallow gas encountered; and when the drilling cannot be started, this equipment can realize rapid conversion on the double-wall drilling tool.

In order to make the flow of backflow drilling fluid in the sand deflector smooth and reduce the hydraulic loss of the deflector, the effective connection of the front and rear outlets must be fully considered when designing the size of the deflector. The design steps of the structure are as follows:
1. The parameter size of the rotating gas sand deflector is determined, and the front and rear ends are exported;  
2. The direction of the flow channel of the rotary gas sand deflector should be radial fluid flow as much as possible during the mining process to reduce wear;  
3. According to the structural size of the rotating gas sand deflector, calculate the sand return speed, etc., and continue to adjust the size before it reaches better hydraulic performance;  
4. The development and experiment of the rotary deflector were carried out to verify the performance of the developed rotary gas sand deflector.  

The particle sedimentation formula is used in the optimization process of the rotary gas sand deflector. In this paper, the concentration correction method is used to obtain the particle sedimentation formula:

$$\frac{u_0}{u} = (1 - S_v)^m$$

$$m = \left[ 2.4 + \frac{2.5}{1 + 5d^2} \right] \cdot \left[ S_v - 0.2 \right]^{-0.1}$$ (1)

In the formula, $u$—single particle settling velocity; $u_0$—Particles interfere with sedimentation speed; $S_v$—Particle volume concentration; $m$—index related to concentration and particle size.

At the same time, the average flow rate of the liquid is also closely related to the sand-carrying efficiency, which is proportional to the specific surface area of the flow channel. Therefore, in order to achieve a better sand-carrying effect, it is not only related to the particle size of the particles, but also to ensure the internal surface area of the sand return deflector is large, and the turbulence effect is generated as little as possible. At the same time, it must meet the size of the inlet and outlet.

Based on the above principles, combined with the on-site working conditions, this article designed integrated special top and split injection side outlet of sand deflector.

2.2. Integrated dedicated top injection side out gas sand deflector

The traditional top injection side-out gas sand deflector is difficult to match most drilling rigs, which makes the gas reverse circulation drilling installation process too complicated. Therefore, in order to meet the needs of gas reverse circulation drilling, a new type of injection sand return device needs to be developed. It meets the diversion function of the top injection side, and is convenient to connect with the rig injection system, and can realize the function of connecting the rotation of the double-wall drill.

Figures 3 and 4 are the front view and rear view of the designed dedicated top injection side-out rotating structure, as well as the processed solid prototype diagram. It can be seen from the figure that gas can be injected into the wellbore along the outer diversion chamber to produce an inner annulus, during the reverse cycle, the gas carries the sand into the rotatable cavity and sprays the sand from the side, thereby achieving the goal of top injection side.

Table 1. Rotate inner tube parameters.

| parameter | Upper buckle type | Lower button | Inside | Rotary bearing | Inner diameter of inner tube of lower double-wall drill pipe (mm) | Diameter of side opening (mm) |
|-----------|------------------|--------------|--------|----------------|---------------------------------------------------------------|-----------------------------|
| Size model | 6 5/8 "reg (631 counter) | NC50=4 1/2"IF (410) | Connect the female buckle | Tapered Roller Bearings | 76 | 50-60 |
Table 2. Parameters of external guide chamber.

| Parameter               | Height (mm) | Outer diameter of sand guide cavity (mm) | Sand guide cavity inner diameter (mm) | Outlet flange |
|-------------------------|-------------|----------------------------------------|---------------------------------------|---------------|
| Size model              | 720         | 590                                    | 550                                   | 3             |
|                         |             |                                        |                                       | 1/8” DN80 (API)|

Therefore, the top injection side flow deflector for gas reverse circulation drilling mainly includes two parts that can be connected to the double-wall drill pipe. It is composed of a rotating inner tube and a non-rotating outer deflector cavity (Figure 5). According to the requirements of double-wall drill pipe gas reverse circulation drilling conditions, the specific parameters are shown in Tables 1 and 2.

2.3. Split-type top injection side-out gas sand deflector
In the actual design process, in order to prolong the life of the bearing and improve the overall pressure bearing capacity. Based on the principle of convenient maintenance and cost saving, this paper proposes another structure of the top injection side outlet gas sand deflector (Figures 6, 7), which mainly includes bearing and seal structure, anti-rotation device, diversion pressure bearing body, etc., that can be installed separately during operation. The parameters of the inner tube and the diversion chamber are basically the same as the integrated structure.

The main problem of the split structure is that the seal ability and pressure bearing capacity are weak, so it is necessary to measure whether the pressure bearing performance of the device meets the
After the split type has passed the indoor static pressure test and assembled the experimental equipment, the constant oil temperature is at the specified temperature. Then the sealing rubber tube is set, the sealing force is 5t, and the sealing distance is recorded (Figure 8). Next, after separately pressing and stabilizing for a period of time, it is found that the range of the sealing distance is within the scope of the engineering requirements, and the equipment is well under pressure.

3. Field test and effect analysis

3.1. Field test design
The test well is a production well located at the high part of the sand body in the gentle slope structure zone. The test well section is the surface casing and cemented sweep plug, the wellbore diameter is 273.1mm, the wellbore steel grade is J55, and the wall thickness is 8.89mm. The inner diameter of the tube is 255.32mm, and the cement returns to the ground. According to the parameters of the field test well and the engineering reality, the parameters of the main equipment for the test are shown in Table 3, and the equipment used for the test is shown in Figure 9.

Based on the purpose of verifying the sand return performance of the top injection side-out rotary gas sand deflector, the following experiments and experimental procedures were designed, the connection method of the sand discharge pipe is: top side row device → suspended hose on the drill floor → suspended hose in the direction of the gate → ground hose → ground sand discharge pipe.
Table 3. Main equipment parameters of reverse cycle test.

| Device name                  | Specifications                  | Quantity | length |
|------------------------------|---------------------------------|----------|--------|
| Air compressor               | 32.5Nm³/min                     | 1 set    |        |
| Double-wall hexagonal        | Φ152.4mm/Φ65mm                  | 1        | 12.25m |
| drill pipe                   |                                 |          |        |
| Double Wall Drill            | Φ228.6mm/Φ65mm                  | 2 roots  | 18.52m |
| Collar                       |                                 |          |        |
| Double wall drill pipe       | Φ127mm/Φ65mm                    | 15 roots | 145.85m|
| Conventional drill collar    | Φ203.2mm                       | 3 roots  | 26.7m  |
| Side sand deflector          |                                 | 1        |        |
| Shunt blocker                | Φ250mm                          | 1        |        |
| Gas manifold                 | Φ50.8mm                         | 1 set    | 30m    |
| Sand discharge manifold      | Φ76.2mm, Φ177.8mm               | 1 set    | 20m, 16m |

3.2. Test effect and conclusion

The overall test effect of this test is good, the test task is successfully completed, the designed sand return deflector has good rock carrying effect, and the bottom is basically free of sediment after drilling. The effective footage is 42.73m, and the average drilling speed is 20.57m / h, drilling weight 2-6t, turntable speed: 30-40 rpm, riser pressure: 1.1-1.38MPa; gas injection volume is 30m³ / min, compared with conventional gas drilling, it saves more than 66.7% gas volume.

The gas reverse circulation has good sand carrying effect, and the efficiency is close to 92.53%. There is no sand sedimentation at the bottom of the well after drilling. The average particle size of the rock carrying is about 10-15mm, and the maximum can reach 30-40mm. Further increase the mechanical drilling speed of drilling. Gas reverse circulation drilling has a strong ability to carry water and respond to formation water, which is expected to further expand the application range of gas reverse circulation drilling.

Figure 10. Sand return normal condition.

The top injection side gas outlet sand deflector is developed in this paper achieves an efficient connection with the rig (Figure 10), which can effectively replace the conventional reverse circulation drilling riser sand return method, and realizes the top injection side row type sand return method that is more in line with oil well control standards.

4. Conclusions

(1) The split top injection side outflow gas sand deflector is more suitable for engineering practice, with extended bearing life and overall pressure bearing capacity, and convenient maintenance and cost savings.

(2) The reverse circulation of the gas injected from the top injection side developed in this paper has a good effect and high efficiency. There is no sand sedimentation at the bottom of the well after
drilling, and the particle size of the rock is large, which can greatly reduce repeated crushing and can further improve drilling. The speed of drilling.

Acknowledgement
National key project of science and technology (No. 2017ZX05005-005): project "key engineering technology of ultra-deep oil and gas Wells in Marine carbonate rocks" of "development of large oil and gas fields and coalbed methane".

References
[1] Zhang Xiaodong, Wu Chende, Zhang Yuan, et al. 2008 Analysis of gas drilling technology and research prospects[J]. Petroleum Machinery 36(6) 75-78
[2] Huang Tao, Li Jun, Song Xuefeng, et al. 2019 Research on ReelWell drilling reverse jet suction technology and tools[J]. Petroleum Machinery 47(2) 8-13
[3] Chen Yingjie, Yang Youheng, WangPing, et al. 2011 Simulation study on annulus drilling fluid flow of double-wall drill pipe in rdm technology[J]. Petroleum Machinery 39(5) 20-22+33
[4] Yang Guang, Ji Shenglong, Bai Liye, et al. 2013 Double-wall drill pipe drilling technology and applicability analysis[J]. Westward Exploration Engineering 25(3) 80-82
[5] Deng Ke, Deng Hu and Li Gang 2018 Application of aerated continuous circulation drilling technology in deep leaky formations[J]. Drilling and Production Technology 41(2) 108-109
[6] Li Yonghe 2007 Low-pressure drilling technology of double-wall drill pipe[J]. Petroleum Drilling Technology 35(2) 1-4
[7] Deng S, Fan H, Liu Y, et al. 2017 Two innovative pore pressure calculation methods for shallow deep-water formations[J]. Journal of Applied Geophysics 146 208-213
[8] Deng S, Fan H, Shen W, et al. 2016 An Optimization Method of Top Tension in Drilling Riser–Conductor System[J]. Arabian Journal for Science & Engineering 41(7) 2707-2714
[9] Wang Zhongsheng and Liao Bing 2008 Analysis and calculation of reverse circulation air drilling cycle parameters of double-wall drill pipe[J]. Drilling and Production Technology 31(3) 1-4
[10] Yang Huwei 2020 Development of reverse circulation drilling double-wall drilling tools for large-diameter reaming[J]. Coal Mine Machinery 41(01) 157-159