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Article

Study on the Equivalent Density Tool and Depressurization Mechanism of Suction-Type Depressurization Cycle

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Abstract: In order to further control the equivalent circulating density, a new type of annular pressure-reducing downhole tool for high temperature and high pressure wells-liquid-absorbing ECD tool is designed. Through this tool, the bottom hole pressure of the equivalent circulating drilling fluid can be close to its hydrostatic pressure, thereby achieving a deeper drilling depth. The tool is mainly composed of screw motor, vortex blade, annular seal, universal joint and drill string. Its working principle is mainly to use the liquid absorption effect of the tool and the hydraulic energy of the circulating fluid extracted by the screw motor to convert it into mechanical energy, and to generate suction force to improve the flow energy of the drilling fluid in the bottom hole annulus and reduce the equivalent circulation density. Based on ANSYS-FLUENT analysis and simulation, the change of pressure drop characteristics under different drilling fluid density, displacement and tool size was simulated. The simulation results show that the depressurization effect is 1.0MPa when the drilling fluid density is 1.2g/cm³. When the drilling fluid density is 1.5g/cm³, the depressurization is about 1.7MPa, and when the drilling fluid density is 1.8g/cm³, the depressurization is about 1.9MPa. When the drilling fluid density is 2.0g/cm³, the pressure drop is about 2.3MPa. When the flow rate is from 1500-2500L/min, the maximum pressure can be reduced by 2.3MPa. When the viscosity is 40mPa•S and 60mPa•S, the pressure drop almost does not change. The increase of viscosity has little effect on the pressure drop, and it is mainly affected by the flow rate under equal displacement.

Keywords: Cyclic equivalent density (ECD); Annular pressure reduction; depressurization tools; Suction-type ECD reduction tool; High temperature and high pressure

1. Introduction

With the continuous research and improvement of the world's drilling level, the drilling and research technology of deep oil and gas reservoirs has been greatly improved. There are more and more researches on high temperature and high pressure drilling at home and abroad, but most of the research principles and theories of high temperature and high pressure well drilling come from the extension and comparison of land drilling.

In 2008, Zheng Fenghui et al. [1] used the developed jet-type hydraulic depressurization simulation tool and its corresponding test bench to conduct an experimental study on a jet-type hydraulic depressurization method that effectively reduces bottomhole pressure under conventional drilling methods. In 2012, Yuan et al. [2] introduced in detail the structural characteristics, depressurization effect and research and application status of jet pump depressurization tools such as annular jet pump, jet depressurization sub and jet pump bit. In 2013, Zhu et al. [3] proposed a new

type of annular jet pump structure based on the principle of jet hydraulic depressurization technology. In 2016, Dokhani Vet al.[4]. developed a simulator for calculating wellbore temperature and pressure under cyclic and static conditions, and established a heat transfer mathematical model for offshore inclined well profiles. And verified. In 2016, Erge Oet al.[5] proposed a numerical model to accurately estimate the friction pressure loss in the annulus with and without inner tube rotation. The numerical model was verified by CFD software. In 2019, Abdelgawad et al.[6] developed artificial neural network (ANN) and adaptive neuro-fuzzy inference system (ANFIS). The ANN and ANFIS models were established to calculate ECD. In 2019, Huang Yi et al.[7] derived a risk assessment model based on the probability distribution of formation pressure and ECD, using the generalized stress and strength interference reliability theory. The calculation results are consistent with the actual risk in the field. In 2021, Chen Yuwei et al.[8] used the transient cuttings transport model to simulate the transient migration process of cuttings in the wellbore, and combined with the actual drilling data to analyze the influence of cuttings on ECD. In 2021, Huang Wei et al.[9] carried out a study on the calculation method of wellbore ECD in Changning shale gas horizontal well, and explored the calculation method of equivalent static density and equivalent cyclic density of drilling fluid under different temperature and pressure conditions. In 2022, Duan Hongzhi et al.[10] carried out high temperature and high pressure density experiments on oil-based drilling fluids commonly used in Xinjiang Oilfield, and established an accurate bottom hole ECD calculation model. In 2022, Foued B[11] et al. proposed a new model to predict ECD in vertical and inclined wells, which predicts cuttings concentration and equivalent cyclic density in vertical and inclined wells. In 2022, Gao Yongde et al.[12] established a wellbore temperature field model for subsea pressurization in order to solve the problem that ECD prediction of deepwater HTHP wells is difficult. In 2022, Wei et al.[13] discussed the check and control technology of high temperature and high pressure wells. Firstly, the development trend was discussed in combination with the current situation, and the key points of ECD check and control technology were summarized. In 2023, in order to improve the calculation accuracy of ECD, Li et al.[14] established a comprehensive calculation model of annular ECD in high temperature and high pressure slim hole horizontal wells by coupling the regression model of drilling fluid density and rheological parameters with the wellbore heat transfer model. In 2023, Okonkwo et al.[15] optimized four error indicators, namely correlation coefficient (R^2), mean square error (MSE), root mean square error (RMSE) and mean absolute percentage error (AAPE). The optimized ECD model has high prediction accuracy. In 2023, Mohammed et al.[16] developed two new models ECDeffc.m and MWeffc.m, which improved the calculation accuracy of ECD.

In this paper, a new pressure-reducing tool, the liquid-absorbing ECD-reducing tool, is used to reduce the ECD size in the wellbore. The suction pressure reducing tool is constructed by Solidworks physical model, and the pressure drop characteristics under different parameters are analyzed and simulated based on ANSYS-FLUENT.

2. The Structure of the Suction-Type Falling ECD Tool

2.1. Tool Structure and depressurization Principle

The traditional depressurization method is achieved by reducing the mud density, but in the case of a narrow density window, it may cause complex situations such as well kicks. Therefore, this paper designs a new type of ECD reduction tool-liquid absorption ECD reduction tool. The tool can reduce the equivalent circulation density of the bottom hole without reducing the mud density, and ensure the safety of operation under the narrow density window.

The tool mainly uses the liquid absorption effect, and the hydraulic energy of the circulating fluid is extracted by the screw pump to convert it into mechanical energy, and the suction force is generated to improve the flow energy of the drilling fluid in the bottom hole annulus and reduce the equivalent circulation density. The tool is mainly composed of screw motor, spiral blade, annular seal and drill string. Figure 1 (a,b,c,d) Its tool parts.

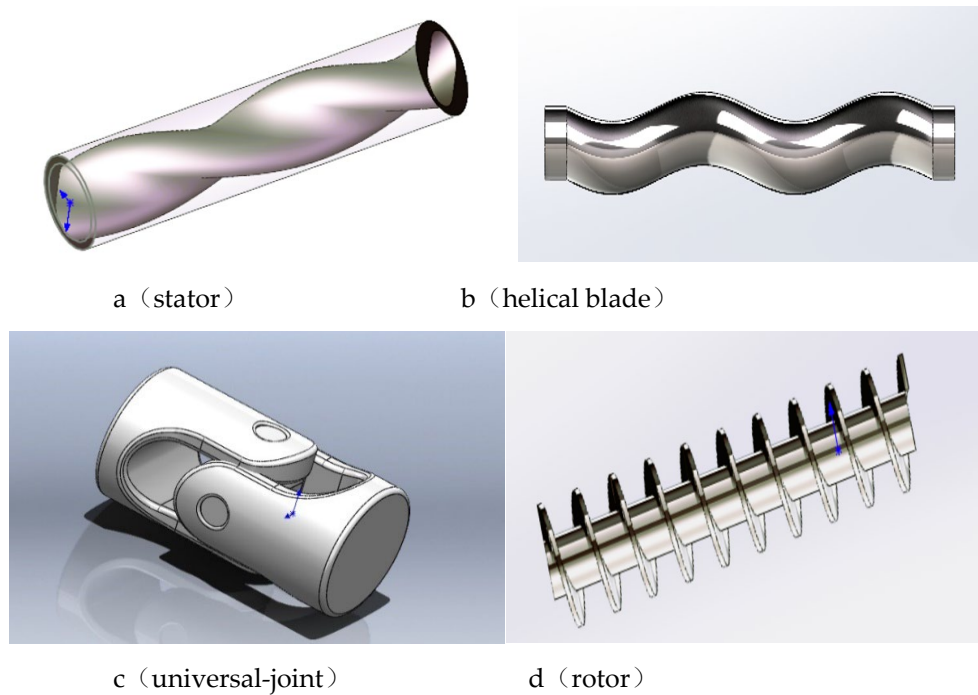


Figure 1. Structure diagram of parts of liquid-suction ECD reduction tool.

The top of the tool is a screw motor, which can convert the hydraulic energy generated by the circulating fluid and convert the hydraulic energy into mechanical energy. Then the screw drives the spiral blade to rotate. The backflow fluid replenishes energy and generates the required pressure difference in the annulus. In general, the screw pump is matched with the blade; therefore, there is no need to adjust the speed. The lower section of the liquid-absorbing ECD-reducing tool is composed of an annular seal to ensure that all flowback fluid and cuttings pass through the pump. The annular seal is always in contact with the casing and supported on the bearing, so that the annular seal does not rotate relative to the casing when the drill string rotates.

2.2. Parameters of Tools

Field applications have been carried out abroad, and there are few domestic applications. In addition, field applications have shown that there are significant differences in the magnitude of pressure reduction under different drilling parameters.

The liquid-absorbing ECD reduction tool is a self-activating tool powered by a circulating drilling fluid. When the drilling fluid is circulating, it starts automatically, and when the cycle stops, it stops running. The tool is used to process drilling fluids with a density of up to 1.8g/cm^3 . The current prototype has an outer diameter of 208.3mm, an inner diameter of 46mm, a casing size of 244.5mm-339.7mm, a length of about 9.15m, a top and bottom connection length of 114.3cm, and a maximum fluid circulation speed of 2.27L/min. The tool can handle a circulation rate of up to 2.27L/min.

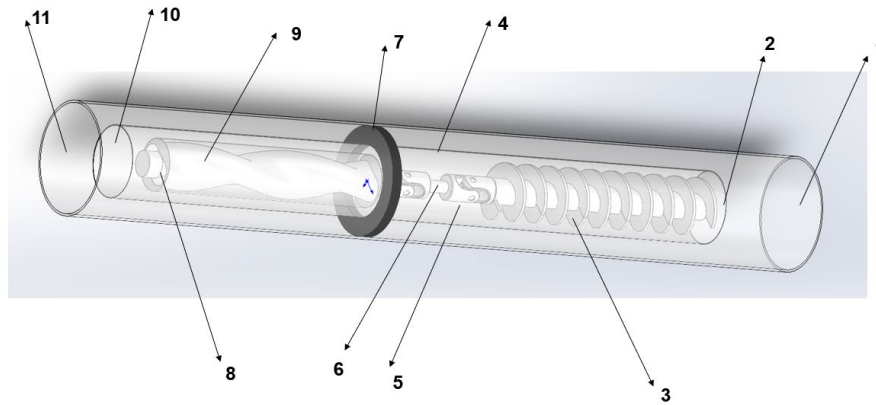


Figure 2. The overall structure of the liquid-absorbing ECD reduction tool. 1:Shaft inlet;2:Import of depressurization tools;3:Rotating blades;4:Tool jacket;5:Universal axis;6:Prevent the assembly;7:Sealing ring;8:Screw rotor;9:Screw stator;10:Tool export;11:Shaft outlet;

3. Numerical Simulation

In this paper, the pressure drop effect of the liquid-suction ECD reduction tool under different conditions is analyzed by numerical simulation. The liquid-absorbing ECD reduction tool is constructed by Solidworks physical model, and the pressure drop characteristics under different parameters are analyzed and simulated based on ANSYS-FLUENT.

3.1. The Simulation Pretreatment of the Liquid-Suction ECD reduction Tool Model

3.1.1. Computation Module

The equivalent circulating density(ECD)of drilling fluid can be defined as the sum of the equivalent static density of drilling fluid and the annulus pressure drop caused by drilling fluid flow. The expression of the equivalent cyclic density in the field case is shown in(1)[17]:

$$\rho_{ecd} = \rho_{esd} + \frac{\Delta P}{0.052h} \quad (1)$$

In the formula: ρ_{ecd} is the cyclic equivalent density; ρ_{esd} is the equivalent static density; ΔP is frictional pressure drop.

High temperature and high pressure drilling is closely related to the control of downhole pressure. The density and rheology of drilling fluid are the key problems. The equivalent density of drilling fluid equivalent circulation loop is an important parameter to control the bottom hole pressure. The ECD expression of the equivalent cyclic

density in the field case is shown in (2):

$$ECD = \rho(1 - C_a) + \rho_s C_a + \frac{\Delta p}{0.00981H} \quad (2)$$

In the formula: ρ is the drilling fluid density; ρ_s is the density of rock debris; C_a is the concentration of annular cuttings; Δp is the annular pressure loss;

The calculation formula of the annulus concentration of the annulus concentration calculation model (3):

$$C_a = \frac{v_a}{3600(v_c - v_s) \left(1 - \frac{d_0^2}{d^2}\right)} \quad (3)$$

In the formula : v_a is the drilling speed ; d_0 Is the outer diameter of the drill pipe ; d is the inner diameter of the wellbore ; v_c It is the annular return velocity of drilling fluid ; v_s It is the settling velocity of rock debris.

The annular pressure loss calculation model, when the flow pattern is turbulent, the calculation formula of the pressure loss of the annular section is as follows (4) :

$$\Delta P = \frac{2.04f \rho v_c^2 l}{d - d_0} \quad (4)$$

In the formula : ΔP is the annular pressure loss ; l is the length of drill pipe ; d_0 Is the outer diameter of the drill string ; d is the inner diameter of the wellbore ; v_c is the annular return velocity of drilling fluid ; f is the friction coefficient, dimensionless ; ρ Is the density of drilling fluid.

3.1.2. Meshing and Boundary Condition Setting

Based on the Solidworks modeling tool, the physical model of the suction-type falling ECD tool is constructed. The finite element analysis model of the tool is established by meshing the model through Meshing. In order to ensure a certain calculation accuracy and not to cause too long calculation time due to excessive calculation, a more detailed meshing of the key parts (blades) that are prone to fatigue damage is performed to improve the calculation accuracy, as shown in Figure 3.

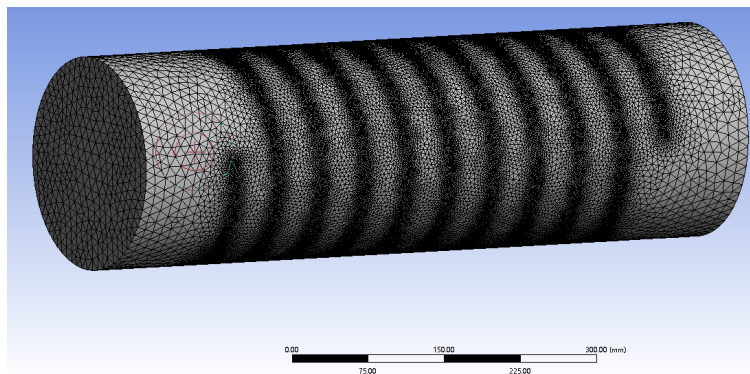


Figure 3. Grid division.

Relatively rough meshing is performed on other parts with simple and stable structures to improve computational efficiency, as shown in Figure 4

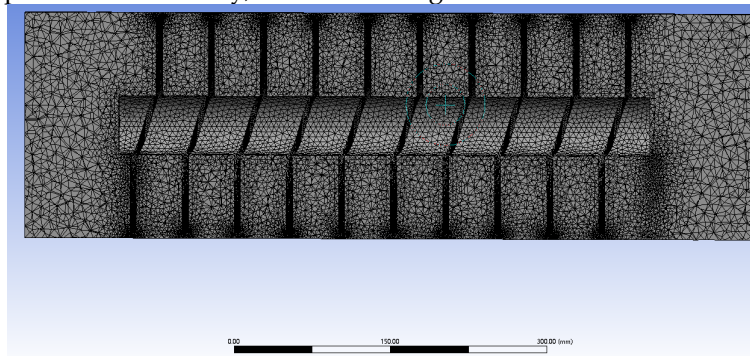


Figure 4. Tool grid partition section diagram.

Based on ANSYS-FLUENT, the boundary condition parameters of the tool are set as well depth 4275m, drilling fluid displacement 1500L/min-2500L/min, drilling fluid density 1.2-2.8g/cm³, inner diameter 9-5/8'in(244.5mm), wellbore diameter 190.5mm, tripping speed 0.25m/s, drilling fluid viscosity 20-60mPa•S.

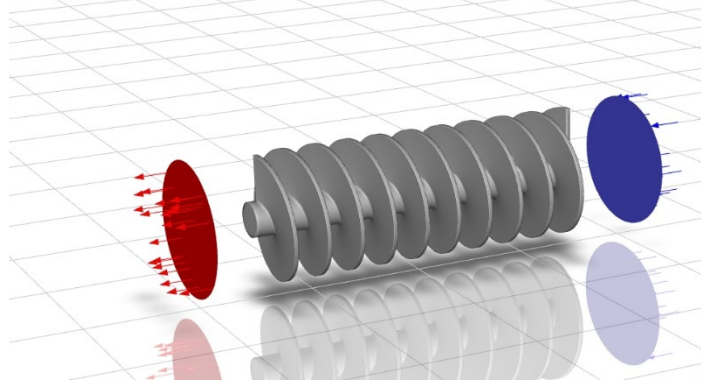


Figure 5. Tool simulation flow direction.

3.2. The Pressure Drop Distribution of the Liquid-Absorbing ECD-Reducing Tool when Drilling Fluid Flows with Different Densities

Based on ANSYS-FLUENT, the pressure drop distribution characteristics of drilling fluid density (1.2g/cm³, 1.5g/cm³, 1.8g/cm³, 2.0g/cm³) flowing through the liquid-absorbing ECD tool under different parameters are simulated (Figure 6). Among them a,b,c and d are the pressure drop distribution characteristics of drilling fluid density: 1.2g/cm³, 1.5g/cm³, 1.8g/cm³, 2.0g/cm³.

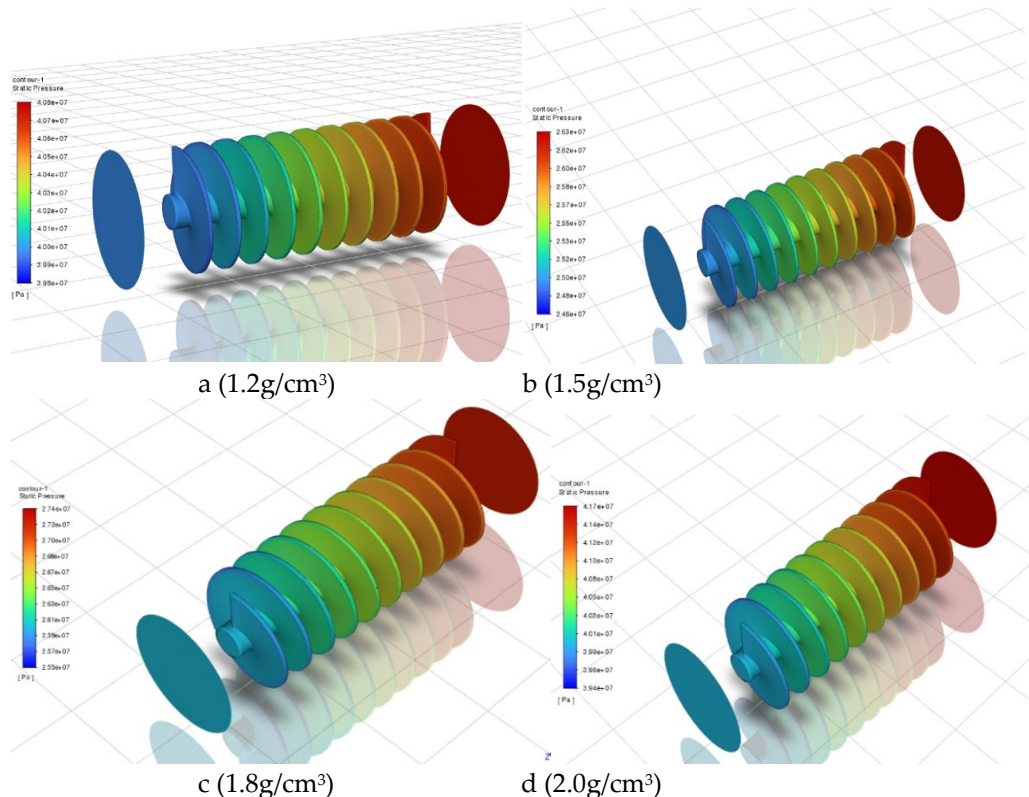
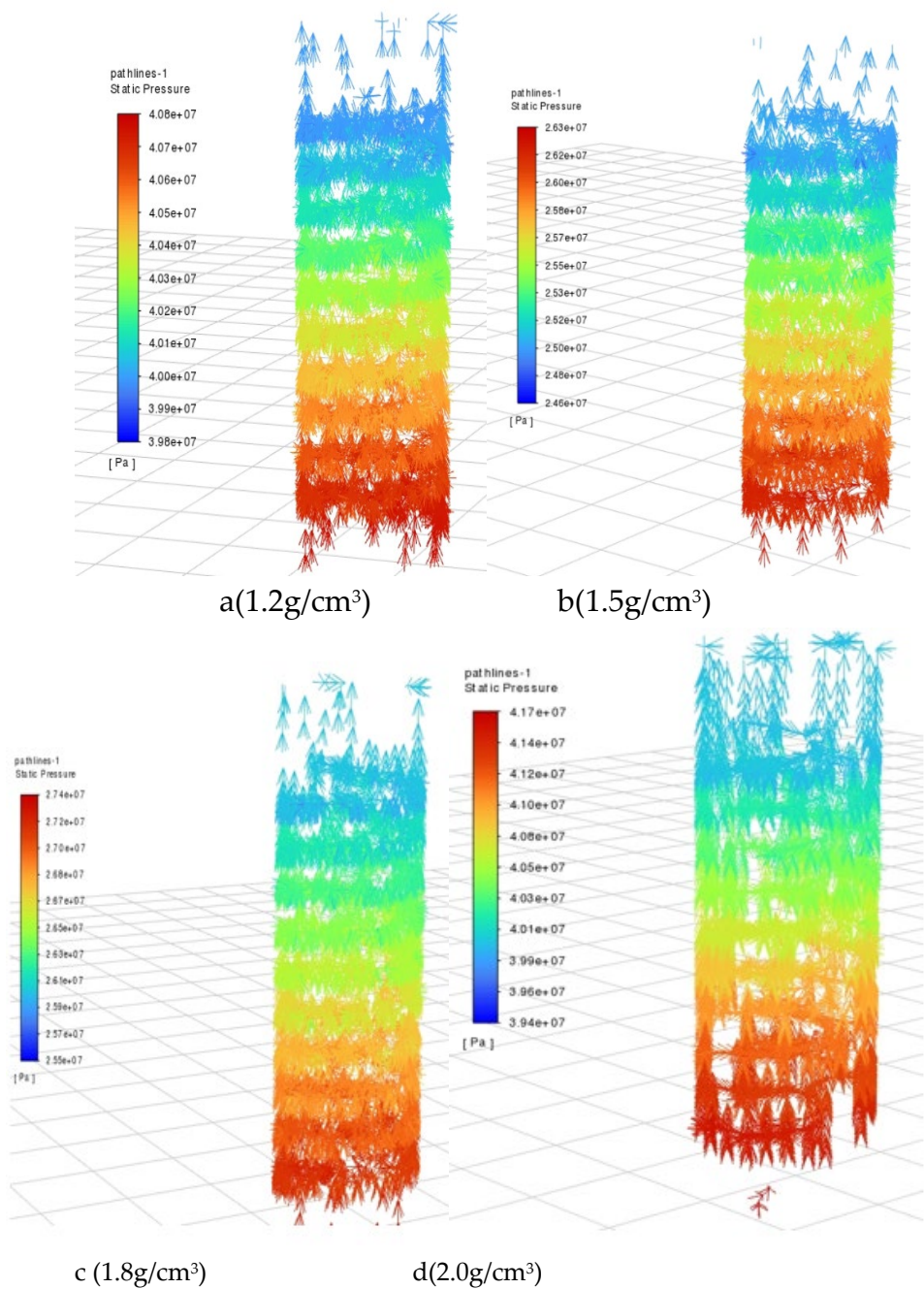


Figure 6. Pressure drop distribution of different drilling fluid density.

By analyzing Figure 6, when the drilling fluid density is 1.2g/cm³, the depressurization effect is only 1MPa. The depressurization effect is not obvious. When the drilling fluid density is 1.5g/cm³, the

depressurization is about 1.7MPa. When the drilling fluid density is 1.8g/cm³, the depressurization is about 1.9MPa. When the drilling fluid density is 2.0g/cm³, the depressurization is about 2.3MPa. From the simulation results, it can be obtained that with the increase of drilling fluid density, the pressure drop value will fluctuate obviously, and the pressure drop effect is more obvious. However, the density of drilling fluid should also be reasonably controlled. Too high density will make the pressure in the wellbore too large, resulting in increased risk of tool seal failure.

Figure 7 simulates the flow distribution characteristics of three different density fluids. It can be seen more intuitively that the pressure drop distribution characteristics and flow direction of the fluid. It can be seen from the fluid flow distribution that there are obvious pressure drop distributions under different density conditions, but the greater the density, the more obvious the pressure drop effect.



3.3. The Pressure Drop Distribution of the Liquid Absorption ECD Tool at Different Displacement

Based on ANSYS-FLUENT, the pressure drop distribution characteristics of three different parameters (1500L/min, 2000L/min, 2500L/min) flowing through the liquid-suction ECD tool were simulated (Figure 8). The flow rates of a, b and c are: 1500L/min, 2000L/min, 2500L/min.

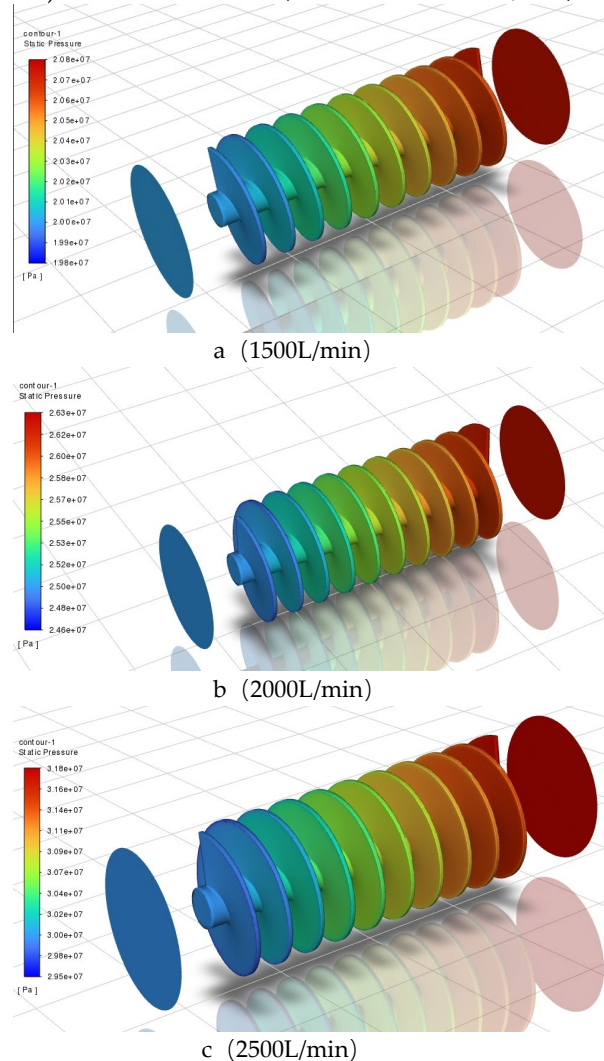


Figure 8. Pressure drop distribution characteristics and fluid flow distribution characteristics at different displacement.

By analyzing Figure 7, when the drilling fluid displacement is 1500L/min, the pressure is reduced by 1.1MPa; when the drilling fluid displacement is 2000L/min, the pressure is reduced by about 1.7MPa; when the drilling fluid displacement is 2500L/min, the pressure is reduced by about 2.3MPa. It can be seen that with the increase of drilling fluid displacement, the pressure drop value will fluctuate obviously, and the pressure drop effect is more obvious. With the increase of drilling fluid displacement, the depressurization effect will be improved, and the depressurization effect and diversion effect of the tool are not obvious when the displacement is small. Figure 9 shows the pressure drop distribution of the liquid-absorbing tool under different drilling fluid displacement. The simulation results show that the liquid-absorbing pressure drop tool has a more obvious effect on local pressure reduction.

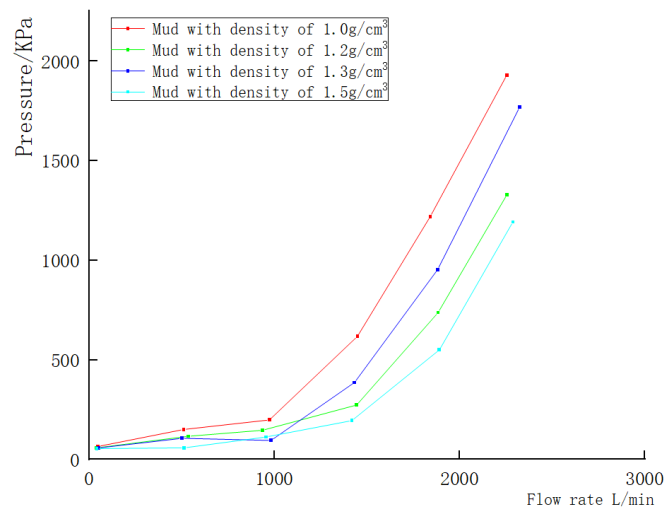


Figure 9. Pressure drop distribution of suction tool under different drilling fluid displacement.

3.4. The Pressure Drop Distribution of the Liquid-Absorbing ECD-Reducing Tool at Different Viscosities

Based on ANSYS-FLUENT, the pressure drop distribution characteristics of the liquid-absorbing ECD tool under two different parameters of viscosity 40mPa·S and 60mPa·S are simulated (Figure 10). The viscosity of a and b is:40mPa·S and 60mPa·S.

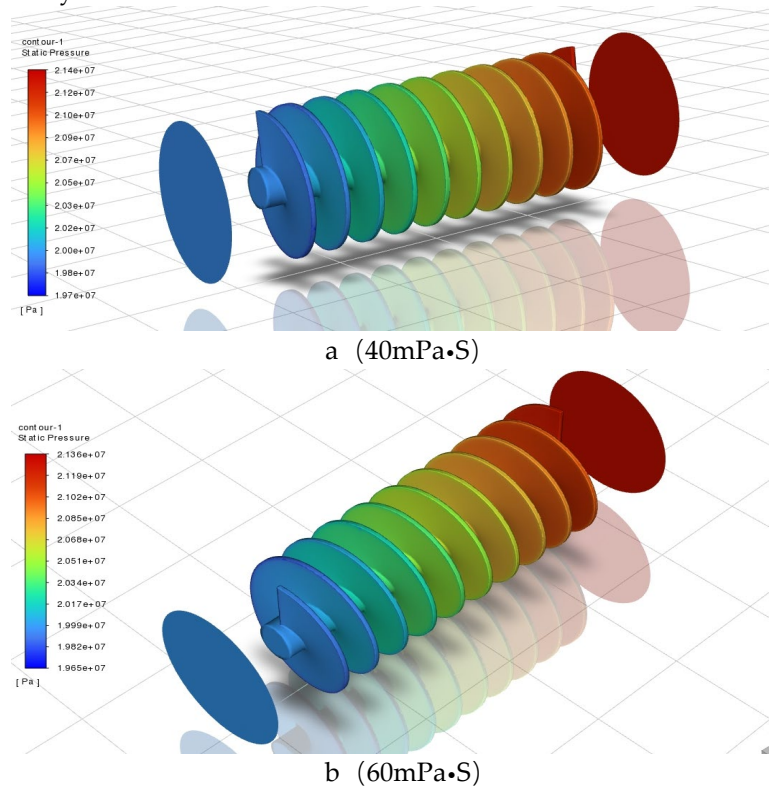


Figure 10. Pressure drop distribution characteristics of different viscosity.

By analyzing Figure 10, when the viscosity is 40mPa·S, the pressure drop is reduced by about 1.7MPa. When the viscosity is 60mPa·S, the pressure drop is reduced by about 1.71MPa. There is almost no change in the pressure drop under the two working conditions, indicating that the viscosity has little effect on the pressure drop of the suction tool, and the viscosity increases. The pressure drop effect is almost unchanged, and it is mainly affected by the flow rate under equal displacement.

4. Field test

According to the wellhead injection temperature and pressure are known, as a boundary condition, the data in this paper is based on the field data of Cao 8well in Jiangsu Caoshe Oilfield^[17], and tested in its field in the second half of 2023. Among them, the deepest measured well depth reaches 2600m, the drill bit adopts 6-1/2'in(165.1mm)PDC bit, the drilling fluid displacement is 1500L/min-2000L/min, the outer diameter of the casing is 9-5/8'in(244.5mm), the length of the drill pipe section is 10m, the wellbore diameter is 260.5mm, the tripping speed is 0.25m/s, the viscosity of the drilling fluid is 40mPa•S, the friction coefficient is 0.029, the surface temperature is 288.15K, and the geothermal gradient is 0.03K/m.

The inner diameter of the test tool is 7-1/2'in(190.5mm), the outer diameter is 9-5/8'in(244.5mm), the drilling fluid density is 1.5g/cm³, and the tool is installed at a distance of 800m from the wellhead. After field testing, the pressure reduction effect of the tool can be about 2MPa, reaching its target pressure reduction value. Table 4 contains the pressure change table of the depressurization tool.

Table 1. includes pressure change table of depressurization tool.

Well depth/m	Normal drilling pressure/MPa	Contains pressure relief tool pressure/MPa	Depressurization value /MPa
800	11.76	10.08	1.68
1000	14.70	12.96	1.74
1200	17.64	15.98	1.66
1400	20.58	18.81	1.77
1600	23.52	21.70	1.82
1800	26.46	24.87	1.59
2000	29.40	27.48	1.92
2200	32.34	30.32	2.02
2400	35.28	33.39	1.89
2600	38.22	36.23	1.99

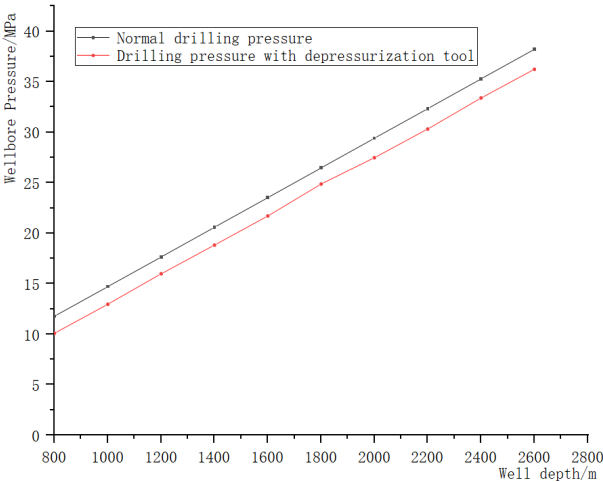


Figure 11. Wellbore pressure with depressurization tool.

It can be seen from Figure 11 that the pressure value has obvious fluctuation in the case of containing depressurization tools in the wellbore, and the pressure is reduced by about 1.7 MPa, which meets the requirements of on-site depressurization.

5. Conclusion

Based on ANSYS-FLUENT to simulate the pressure drop characteristics under different parameters, we can get the following conclusions.

(1) The traditional solution has been difficult to solve the problem of efficient and rapid drilling of complex wells such as narrow density window. It must be fundamentally improved, relying on the change of equipment and drilling methods to solve the complex situation in the drilling process.

(2) With the increase of drilling fluid density ($1.2\text{--}2.0\text{g/cm}^3$), the depressurization effect increases gradually, and the pressure drop effect is more obvious, and the depressurization value is up to 2.3MPa ; however, the density of drilling fluid should also be reasonably controlled. Too high density will make the pressure in the wellbore too large, resulting in increased risk of tool seal failure.

(3) With the increase of drilling fluid displacement ($1500\text{--}2500\text{L/min}$), the pressure drop value will fluctuate obviously, and the pressure drop effect is more obvious, up to about 2MPa . With the increase of drilling fluid displacement, the depressurization effect will be improved, and the depressurization effect and diversion effect of the tool are not obvious when the displacement is small.

(4) When the viscosity is $40\text{mPa}\cdot\text{s}$, the pressure drop is about 1.7MPa , and when the viscosity is $60\text{mPa}\cdot\text{s}$, the pressure drop is about 1.71MPa . There is almost no change in the pressure drop under the two working conditions. The viscosity has little effect on the pressure drop of the suction tool, and it is mainly affected by the flow rate under equal displacement.

Author Contributions: Ren Meipeng put forward innovative ideas and grasped the research direction.; Zhang Xingquan is responsible for the analysis of step-down algorithm; Xie Renjun is responsible for the software simulation of the step-down tool; Wang Junyan is responsible for the construction of the physical model of the step-down tool; Zhu Zhaopeng is responsible for the physical construction of depressurization tools; Cheng Xuebin is responsible for the test site of depressurization tools; Dou Liangbin provides financial assistance.

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Data Availability Statement: As the project is in the development stage, the data is temporarily confidential.

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