Research on ECD Distribution Law under Managed Pressure

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Abstract. By analyzing the basic theories and technical principles of managed pressure drilling, this paper establishes the cyclic pressure loss check and ECD calculation model under managed pressure conditions. The model is used to calculate and analyze the distribution of equivalent density curves in the wellbore under different drilling fluid densities and different pressure control conditions, and to analyze the distribution of ECD curves in pressure profiles at the same depth. Analyze the density range of the safe use of drilling fluid.

Keywords: software programming, managed pressure drilling, ECD, cyclic pressure loss, pressure profile.

1. Introduction
Managed Pressure Drilling technology [1] precisely controls the pressure in the wellbore through the following methods: through comprehensive control of wellhead backpressure, drilling fluid rheology, annulus fluid level, drilling fluid density, friction along the way, and wellbore geometric dimensions, etc. The pressure of the drilling fluid column in the wellbore is between the formation pore pressure and the formation fracture pressure [2-3], reaching near-equilibrium pressure or even pressure for drilling. It can be seen that this technology has a lot of application space in formations with a narrow window of formation pore pressure and formation fracture pressure. Therefore, the purpose of this article is to study the distribution of ECD curves in pressure profiles [4-5] under managed pressure drilling conditions and determine the density range of drilling fluids.

2. Establishment of annulus ECD calculation model

2.1. Calculation of annulus pressure loss
The calculation method of pressure loss along axial laminar flow in concentric annulus based on trough flow model[6-7]: In actual engineering, the average annulus flow velocity is often substituted into the flow calculation formula to obtain the pressure loss method. The following focuses on the calculation method of annulus pressure loss based on the trough flow model in the Hertz-Barr rheological model[8-9].

The calculation formula for the pressure loss of the Hertz-Barr fluid annulus structure flow is as follows:

\[
\Delta \rho = \frac{4K \rho_L}{\eta y} \left( \frac{2n + 1}{3n} \frac{\eta y}{\eta y} \right)^n + \frac{2n + 1}{n + 1} \frac{4\tau_0 L}{\eta y} 
\]

(2-1)

The calculation formula for the annulus pressure loss per unit length obtained from the empirical formula is as follows:

\[
\frac{\Delta \rho}{L} = \frac{4K \rho_L}{\eta y} \left( \frac{2n + 1}{3n} \frac{\eta y}{\eta y} \right)^n + \frac{2n + 1}{n + 1} \frac{4\tau_0}{\eta y} 
\]

(2-2)

In the formula, \( \Delta \rho \) is the annular pressure loss, Pa; \( \tau_0 \) is the yield strength (also called dynamic shear force/yield value); \( K \) is the consistency coefficient Pa\( \cdot \)g\( ^n \); \( n \) is the fluidity index, dimensionless; \( \eta y \) is the annular hydraulic diameter, m; \( v \) is the average flow velocity in the annulus, m/s; \( L \) is the well depth, m;

2.2. ECD calculation

ECD is the sum of the equivalent value of hydrostatic pressure and the equivalent value of the pressure loss produced by the fluid circulating flow. Here, the equivalent value of hydrostatic pressure is also called Equivalent Circulating Density (ESD), the pressure loss generated in the flow The equivalent value is also called the additional equivalent circulating density (Additional Equivalent Circulating Density, referred to as AECD)[10]

The specific expressions of ESD and ECD are as follows:

ESD at a certain moment:

\[
ESD = \frac{1}{H} \int_0^H \rho_L dz + \frac{p_0}{gH} 
\]

(2-3)

In the same way, the corresponding ECD at a certain moment will be obtained:
\[ ECD = ESD + \frac{\Delta p_{\text{af}}}{gH} = \frac{1}{H} \int_0^H \left( \rho_f + \frac{dp_{\text{af}}}{gdz} \right) dz + \frac{p_0}{gH} \]  

(2-4)

In the formula, \( H \) is the vertical depth, m; \( \Delta p_{\text{af}} \) is the annulus pressure loss, Pa; ESD is the equivalent static density, \( \text{kg/m}^3 \); ECD is the equivalent circulating density, \( \text{kg/m}^3 \); \( p_0 \) is the wellhead pressure (atmospheric pressure), Pa; \( \rho_f \) is the fluid density value, \( \text{kg/m}^3 \).

3. Software programming

3.1. Software introduction

The calculation methods of cyclic pressure loss and ECD under different rheological modes have been discussed above. Based on the established hydraulic calculation model, this article uses matlab and vb to program[10]. The main functions of the program are introduced below.

3.2. The program can achieve the following functions

(1) The software mainly includes operating parameters, rheological model analysis, cyclic pressure loss check calculation, ECD analysis, etc.

(2) Input the operating parameters of each well, including data of well depth and drilling tool assembly.

(3) To check the circulation pressure loss, the required parameters include displacement, pump pressure, and nozzle flow coefficient. And choose different rheological models to check, to ensure that the relative error is as small as possible.

(4) ECD analysis interface enters the pump pressure and section length to get the ECD curve distribution.
4. Case Analysis

According to the wellbore structure of a deep-water well in the South China Sea, the pressure profiles of the 3675-3959m interval were found, and the ECD curve analyzed by the software was put into the pressure profile of the same depth to analyze the law.

(1) Establish the pressure profile and wellbore structure of a well in the deepwater of the South China Sea, and analyze the distribution of ECD under different suppression by applying backpressure.

(2) According to the specific analysis of the wellbore structure, the ECD under conventional drilling and the distribution of ECD curves with different drilling fluid densities and different back pressure values in this interval.
Fig. 3 ECD distribution under managed pressure and well structure

Fig. 4 Conventional drilling 3675-3959m interval ECD curve distribution
According to the four diagrams, the ECD curve can be found on the pressure profile at the same depth. Fig.4 can pass the pressure profile under conventional drilling, and Fig.5 uses ECD analysis software to adjust the drilling fluid under pressure control drilling. The ECD curve of the drilling fluid density with different density passes through the pressure profile normally, and the control range for the safe use of the drilling fluid is obtained. The drilling fluid density range that can be used in the 3675-3959m interval is 1.6-1.7g/cm³. The Fig.6 is the distribution of the ECD curve in the 3675-3959m interval under the adjusted backpressure value. It can be concluded that by adjusting the
backpressure to change the ECD curve in this interval, the casing depth can be increased. The usable backpressure value in the 3675-3959m layer is 1-3Mpa.

5. Conclusion
The article uses the calculation method of the annular pressure loss based on the trough flow model under the Hertz-Barr rheological model, and also uses the calculation formula of ECD. Use matlab, vb, and other software to program to obtain the ECD distribution curve, and place the ECD curve of the same depth in the established pressure profile to analyze whether it can effectively pass through the pressure window under managed pressure drilling conditions. Through the research of this article, it is found that adjusting the density of drilling fluid and backpressure value through managed pressure drilling technology can make the ECD curve pass through the pressure profile normally, and determine the range of the density and back pressure value of the safe use of drilling fluid. By adjusting the backpressure value to increase the casing depth, it provides a basis for the control of wellbore pressure and ECD under the condition of the subsequent narrow density window, and the optimization of wellbore structure.

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