SIMULATION AND ANALYSIS OF WELLBORE STABILITY FOR DRILLING WELLS IN DEEP AND COMPLEX FORMATIONS

by

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Deep and ultra-deep drilling has become the key direction of oil and gas exploration and development research at the present stage. The density window of deep and complex formations is narrow, and most of the wells drilled are high temperature and high pressure wells, which have a large impact on the density and rheological parameters of drilling fluids and further affect the stabilization state of the wall of the well after the intrusion of drilling fluids into the formation. Therefore, this paper comprehensively applies the knowledge of heat transfer, applied mathematics, and computer science to analyze the temperature change of the whole well section and the change of physical properties parameters of drilling fluids in deep formations, and judging the degree of wall instability by introducing the wellbore yield state parameter, and carrying out the simulation and analysis of wall stability in drilling wells of deep and complex formations, and optimizing the design of the selection of the performance parameters of drilling fluids in the subsequent wells.

Key words*: deep formation, high temperature and pressure, wellbore stability, optimized design*

Introduction

With the rapid development of drilling technology, oil drilling and development is gradually shifting to deep, high temperature, and high pressure formations, and drilling wells in deep and complex areas are facing two difficult problems: one is the high temperature and pressure at the bottom of the well, and this high temperature and high pressure environment further affects the density and rheology of the drilling fluid, and the other is the unknown degree of wall destabilization after the circulating drilling fluid intrudes into the formation [1]. In the process of calculating the temperature and pressure of the well section of a conventional well, the temperature of the well section is often calculated by using the gradient of the ground temperature of the block, and the static column pressure of the well section is calculated by using conventional mathematical formulas [2]. This calculation method has little error in the conventional well section, but it will cause large errors for complex well sections such as deep wells and ultra-deep wells, which in turn affects the drilling efficiency.

In this study, numerical methods are used to calculate the temperature and pressure profiles in the wellbore, taking into account the characteristics of drilling fluid properties with

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downhole temperature changes, drilling column eccentricity, rotation, changes in drilling tool combinations, and the effects of temperature changes on along-stream pressure consumption, combining knowledge of heat transfer with the finite difference method, and utilizing MATLAB + COMSOL Multiphysics to simulate and analyze the well wall stability of deep, high temperature, high pressure, and complex drilling wells in deep, high pressure formations, taking into account the changes in the drilling fluid properties parameters.

Modelling principles and assumptions

In the heat transfer process in the wellbore, the fluid-flow and the heat transfer between the formations take place simultaneously. Therefore, the temperature and pressure in the wellbore are coupled with each other. Both are governed by a number of parameters, such as the viscosity of drilling fluid, thermal conductivity, specific heat capacity*, etc.* and in turn, affect these parameters. In the process of establishing the circulation model, corresponding assumptions should be made to simplify the problem. The assumptions made in this paper are as [3-5]:
– drilling fluid in the wellbore is a 1-D transient heat transfer,
– the formation is a non-stationary heat transfer,
– the formation, drilling column, drilling fluid, the specific heat and thermal conductivity does not change with the temperature and pressure, and
– do not take into account the effect of the rock cuttings on the flow of the wellbore.

Results and discussion

Temperature field distribution of drill pipe and annulus

When the depth of the well is 5980 m, the temperature profiles of the drilling fluid in the drilling column and the circulating temperature in the annulus obtained after circulating for 1 hour, 3 hours, 5 hours, and 7 hours, respectively, are shown in fig. 1. The temperature of the drilling fluid in the drill pipe is higher than the formation temperature. This is due to the fact that when the drilling fluid is first injected into the drill pipe, the lower temperature of the drilling fluid in the drill pipe exchanges heat with the higher temperature of the drilling fluid returning from the annulus, which results in the temperature of the drilling fluid in the drill pipe being slightly higher than that of the formation temperature in the initial section, *i.e.*, there is an *inflection point*. Similarly, in the process of circulating upward in the annulus, the temperature of the drilling fluid is first lower than the formation temperature and then higher than the formation temperature, which is due to the fact that the drilling fluid with a lower temperature will be added to the drilling column all the time, which leads to heat exchange between the drilling fluid in the drilling column and the annulus at the bottom of the well. The temperature at the beginning of the circulating upward in the annulus is lower than the temperature profile of the formation, *i.e.*, there is another *inflection point*.

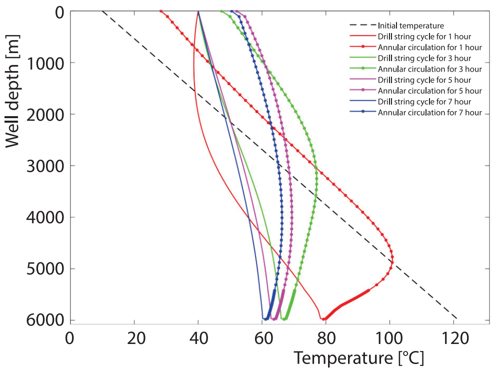

Figure 1. Variation of circulating temperature profile in the drill string and annulus with time

Changes in physical parameters of wellbore drilling fluids during circulation

With the increasing depth of the well, the temperature and pressure in the wellbore are increasing, which makes the drilling fluid's physical parameters also undergo further changes; using the model to simulate the changes in the density and rheological parameters of the drilling fluid with the depth of the well and the circulation time, in which the changes in the drilling fluid density (ESD) are shown in fig. 2.

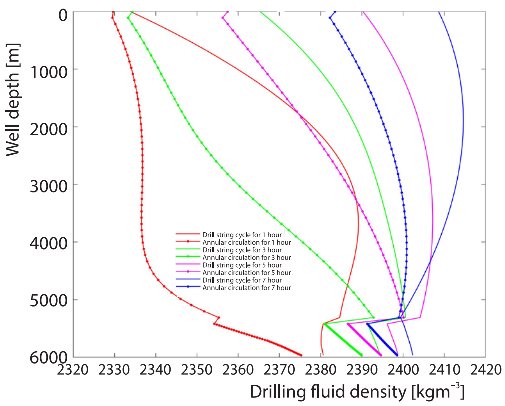

Figure 2. Density field distribution of drilling fluid

From the figure, it can be obtained that the temperature of the annulus is higher than the temperature inside the drill column, resulting in the drilling fluid density inside the annulus being lower than the drilling fluid density inside the drill column, which will lead to an error if the ESD inside the annulus is equated to that inside the drill column [6, 7]. At the wellhead, as the lower-temperature drilling fluid has been added to the column, the heat exchange rate between the annulus and the column increases the wellhead, the temperature of the annulus fluid plummets, and the density of the drilling fluid increases abruptly, resulting in an *inflection point*.

At 5420 m, due to the reduction of the borehole section area when drilling the fourth open hole section, the annulus area decreases, the flow rate increases, and the temperature suddenly increases. Thus, the density of drilling fluid in the annulus suddenly decreases, and an *inflection point* occurs. In the drilling column, due to the increase in the temperature of the annulus, the heat exchange rate between the annulus and the drilling column increases, and the temperature inside the drilling column also increases, resulting in a sudden drop in the density of the drilling fluid and an *inflection point.* At the bottom of the well at 5980 m, due to the pressure drop of the drill bit, the pressure inside the drill column to the annulus dropped suddenly, resulting in a decrease in the density of the drilling fluid.

The variation of drilling fluid rheology is shown in figs. 3 and 4, from which it can be seen that the viscosity of the drilling fluid in both the drilling column and the annulus becomes smaller and smaller with the increase of the well depth. The variation of the viscosity of the drilling fluid in the drilling column is higher than that in the annulus.

Assessment of changes in the degree of well-wall destabilization

The data obtained from Matlab calculations were imported into COMSOL to analyze the change of well wall instability parameters with the circulation time. It can be seen from fig. 5 that, under the action of differential pressure, the plastic-yielding region around the well wall is small at the early stage of the intrusion of drilling fluid (1 hour). However, with the continuous intrusion of drilling fluid, the increase of water content leads to the occurrence of hydration expansion and hydration dispersion phenomenon in the formation rock, which greatly reduces the mechanical strength of the formation. Then the reservoir starts to yield, and the area increases, and after circulating for 7 hours, almost all the area around the wall yields, which seriously jeopardizes the safety of well control in drilling wells [8, 9].

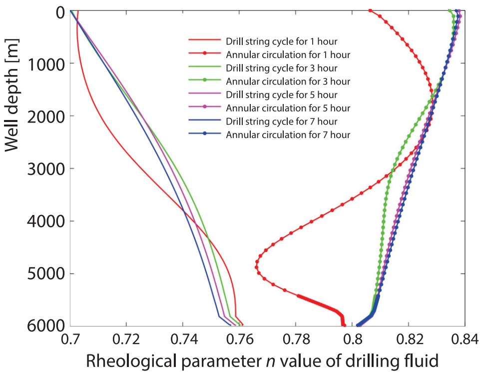

Figure 3. Variation of *n* values of drilling fluid rheological parameters

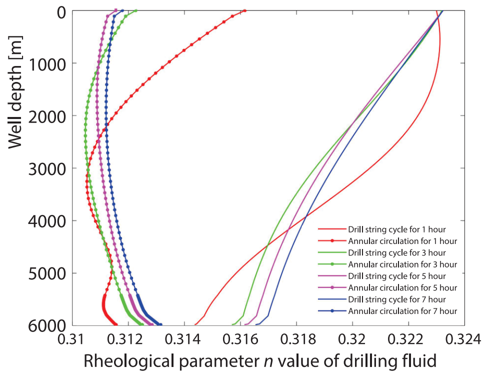

Figure 4. Variation of *k* values of drilling fluid rheological parameters

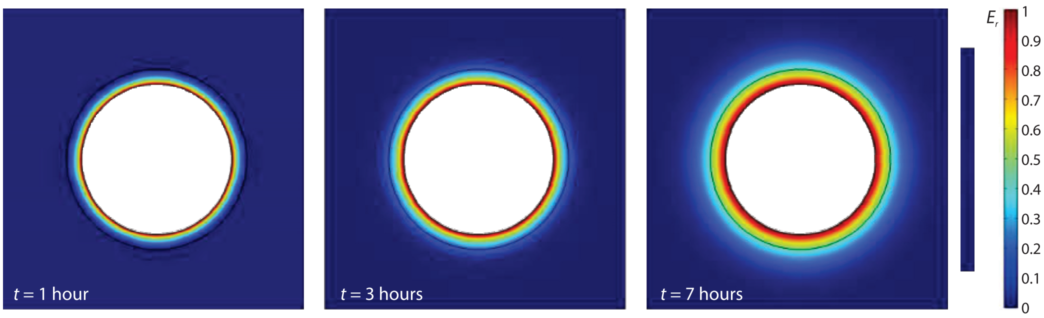

Figure 5. Plot of well wall destabilization parameters *vs.* cycle time

In order to maintain the stability of the well wall, the drilling fluid parameters should be adjusted, such as adjusting the density of the drilling fluid to match the density of the formation or adding a drilling fluid mass transfer blocker or water activity regulator to reduce the degree of intrusion of the drilling fluid, or taking immediate measures to complete the well, passing through the unstable layer quickly, and completing the cementing of the well within the best time.

Conclusions

In this work, the physical properties of drilling fluid are considered to be affected by temperature and pressure in the deep HPHT well section. A well wall stability model is established based on the law of energy conservation, which visually describes the coupling changes between the drilling fluid and drilling column, annulus, and stratum and provides a relevant theoretical basis for the subsequent optimization design of deep ultra-deep drilling. The conclusions are as follows.

- During circulation, the temperature in the annulus is always higher than that in the drilling column. It is not equal to the formation temperature, which results in the density and viscosity of the drilling fluid in the annulus always being lower than that in the drilling column.
- The temperature distribution between the wellbore and the formation is relatively uniform. The formation is heated at the wellhead and cooled at the bottom of the well during circu-

lation. The temperature distribution of the two varies with the change in the radial distance from the formation in the opposite direction.

- Drilling fluid intrusion will increase the water content of the formation, which in turn will reduce the mechanical strength of the formation, and the risk of well wall destabilization of the formation will increase with the increase of circulation time. Therefore, the drilling fluid parameters should be selected to match the formation, to reduce the degree of drilling fluid intrusion into the formation, or to take immediate completion measures to pass through the unstable layer quickly and to complete the cementing in the optimal time.

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