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Analyzing of Multi Field Coupling Borehole Collapse Time for Shale

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Abstract

Based on the theory of semi-permeable diaphragm equivalent pore pressure, the fluid-chemistry coupling diffusivity equation of pore pressure is deduced, and then fluid-solid-chemistry coupling model for porous media is founded. Based on theory deduction and laboratory experiment, a new model which represents the relation between the pore pressure and the rock intensive parameters (cohesion stress and angle of internal friction) is founded. A new model which can calculate the collapse time for shale is developed by using the Coulomb-Mohr failure criteria, and then the finite element simulation program is developed by using the software of FEPG. According to the research, the drilling fluid of low activity can inhabit the increasing trend of pore pressure nearby the borehole effectively, and the drilling fluid of low activity can also inhabit the decreasing trend of cohesion stress effectively under the influence of chemical field and seeping field, which favors the borehole stability. The lithological character and drilling fluid performance should be considered in the process of evaluation and forecast of collapse time, and the drilling fluid can be optimized by using this multi field coupling model.

Key words: Porous media; Multi field coupling; Pore pressure; collapse time

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INTRODUCTION

Theories and experiments plays proved that the drilling fluid's chemical nature has a great role on the wellbore stability of shale.[1-2] At present many scholars at home and abroad provide some mechanics-chemical coupling models that researched with coupling mechanics and chemical factors without too many uncertainly parameters and considering the change of rock intensity while set up models.[3-4] For better research on the coupling effect and law of seeping field and chemical potential field and stress field, the author establishes the conductive model of pore pressure and the parameter model of rock intensity under multi-field coupling and develop relevant finite element soft using FEPG soft. The study shows the evaluation of collapse cycle size should be comprehensive consideration for lithology and drilling fluid performance. The establishment of evaluation method has great referred value to maintain the wellbore stability while field drilling operation.

1. THE ESTABLISHMENT OF FORECAST MODEL OF COLLAPSE CYCLE UNDER MULTI-FIELD COUPLE

1.1 The Establishment of Coupling Model for Seeping Field, Chemical Potential Field and Stress Field

1.1.1 The Conductive Equation of Seeping Field's Pore Pressure

Mody and Hale apply the theory of semi-permeable diaphragm equivalent pore pressure on shale and water base drilling fluid which assume that semi-permeable diaphragm but not ideal occur on the surface of shale and water base drilling fluid thus insert the coefficient I_m of not ideal semi-permeable diaphragm (to ideal semi-permeable diaphragm, I_m=1), where $I_m=\Delta P_{\text{observation value}}/\Delta P_{\text{theoretical value}}$

Thus, the computer equation of equivalent pore pressure under chemical potential energy difference can be revised as:

$$I_m \frac{RT}{V}\ln\left(\frac{a_{sh}}{a_{df}}\right) = P - P_0 . \tag{1}$$

Where a_{sh} and a_{df} are formation water salinity and drilling fluid salinity of shale respectively, R, T and V are gas constant (J/mol/K) and absolute temperature (K) and molar volume of pure wate r (m^3/mol).

The difference of hydraulic pressure and chemical potential are mainly factors which lead to the change of pore pressure, thus the volumetric rate which flow through haploid as:

$$J = \frac{k}{\mu}\frac{1}{\Delta x}\left(\Delta P - I_m\left(\frac{RT}{\overline{V}_w}\ln\left(\frac{a_{sh}}{a_{df}}\right)\right)\right). \tag{2}$$

Where J is the volumetric rate (cm^3/s), K and$\mu$are penetration of rock (md) and fluid viscosity(cp).

Deduced from equilibrium equation:

$$\frac{1}{r}\frac{\partial}{\partial r}[r\rho J] + \frac{\partial}{\partial t}(\phi\rho) = 0. \tag{3}$$

Simplified the equation from (2) and (3) as:

$$\nabla^2 P + I_m \frac{RT}{V}\nabla^2 a = \frac{\phi\mu C}{k}\frac{\partial P}{\partial t}. \tag{4}$$

Where C is fluid compressibility ($1/Pa$), Φ and μ are porosity and fluid viscosity (cp) respectively, α is chemical potential energy activity.

1.1.2 The Conductive Equation of Activity For Chemical Potential Energy Field

The activity α on the conductive equation of pore pressure should meet the diffusion equation:

$$\frac{\partial a}{\partial t} - D\nabla^2 a = 0 . \tag{5}$$

Where D is diffusion coefficient of activity (Dm^2/s).

1.1.3 The Computer Equation of Stress Field

The computer equation of stress field as follows:

$$\frac{\partial \sigma_{ij}}{\partial x_j} + \alpha\frac{\partial P}{\partial x_i} + f_i = 0. \tag{6}$$

Where σ_{ij} is effective stress component (Pa), α is Biot coefficient, f_i is volume force component, P is pore pressure (Pa).

The compute stress field should use geometric equations and constitutive equations except the equilibrium equation which can be referred from previous documents.[5] While computing with above three coupling fields should use border condition and primary condition of every field. To seeping field and chemical potential energy field, the relevant border condition and primary condition as follows:

$$\begin{cases} t = 0, r_w \le r \le \infty, a = a_{sh}, P = P_0 \\ t > 0, r = r_w, a = a_{df}, P = P_w \\ t > 0, r = \infty, a = a_{sh}, P = P_0 \end{cases}.$$

Where P_0 is initial reservoir pore pressure (MPa).

To deformation field of solid body, its border condition may include two kinds, the first is border condition of displacement, $u=u$, $v=v_0$, the second is border condition of stress,

$$T_X = f,\ T_y = f_2 .$$

1.2 The Relation Model of Intensity Parameter and Pore Pressure

According to the principle of fluid mechanics, the difference of hydraulic pressure and chemical potential will change the pressure of rock pore, and derived from the equation of seeping equilibrium:

$$\frac{1}{r}\frac{\partial}{\partial r}(r\rho u_r) + \frac{\partial}{\partial t}(\phi\rho) = 0 . \tag{7}$$

Where u_r, ρ, φ is volumetric flow rate (cm^3/s), density (g/cm^3) and porosity respectively which put through haploid.

The relationship of mass flow and volume flow rate as follows:

$$\mu = \rho\mu_r . \tag{8}$$

Where μ is mass flow (g/s).

Combined (7) and (8):

$$\frac{1}{r}\frac{\partial}{\partial r}(ru) + \frac{\partial}{\partial t}(\phi\rho) = 0. \tag{9}$$

To use the definition of compressibility and assume it as constant, then derive the relation of pore pressure and density as follows:

$$\frac{\partial p}{\partial r} = \frac{1}{\rho C}\frac{\partial \rho}{\partial r} . \tag{10}$$

To establish the relationship of pore pressure and mass flow rate as follows:

$$\frac{1}{r}\frac{\partial(r\mu)}{\partial r} + \phi\rho C\frac{\partial P}{\partial t} = 0. \tag{11}$$

Where C and P is fluid compressibility and pore pressure (MPa) respectively.

The relation for mass flow rate and water content can be derived from the equation of mass balance as follows:

$$\frac{1}{r}\frac{\partial(ru)}{\partial r} = \frac{\partial w}{\partial t} . \tag{12}$$

Then you can get the relationship of water content and pore pressure as follows:

$$\frac{\partial w}{\partial t} + \phi\rho C\frac{\partial P}{\partial t} = 0 . \tag{13}$$

Where w is percentage of adsorbed water content (%).

Previous scholars have studied the relation of rock cohesion and water content and provided their model.[6]

The paper gets the relation for cohesion, angle of internal friction and water content of shale through in house laboratory investigation as follows:

$$\begin{cases} C_r = C_{r0} e^{k_1 w + b_1} \\ \varphi = \varphi_0 e^{k_2 w + b_2} \end{cases} . \qquad (14)$$

Where C_r is cohesion (MPa), φ is angle of internal friction (°), C_{r0} is cohesion for primary water content (MPa), φ_0 is angle of internal friction for primary water content (°), k_1, k_2, b_1, b_2 are coefficients.

Combined (13) and (14), then you can get the relation of pore pressure and rock cohesion and angle of internal friction.

Combined above coupling models and border conditions and use finite element method, then you can get the time-space domain's distribution for pore pressure of wellbore and rock stress and intensity parameters under multi-field contribution. According to regular intensity norm and computer critical pressure- caving pressure where near wall rock access to damage. The paper uses coulomb-mole law to computer, the resolution idea and process see blow.

2. THE FORECAST MODEL COMPUTER OF COLLAPSE CYCLE UNDER MULTI-FIELD

Based on the conductive model of pore pressure of multi-field coupling and rock intensity model that above established, the paper uses FEPG software to develop the relevant finite element computer program for collapse cycle forecast under multi-fields. The computer of coupling model equation is based on virtual displacement principle and on the base of coupling equation weakness and use the computer process of chart one to discriminate coupling equation group.

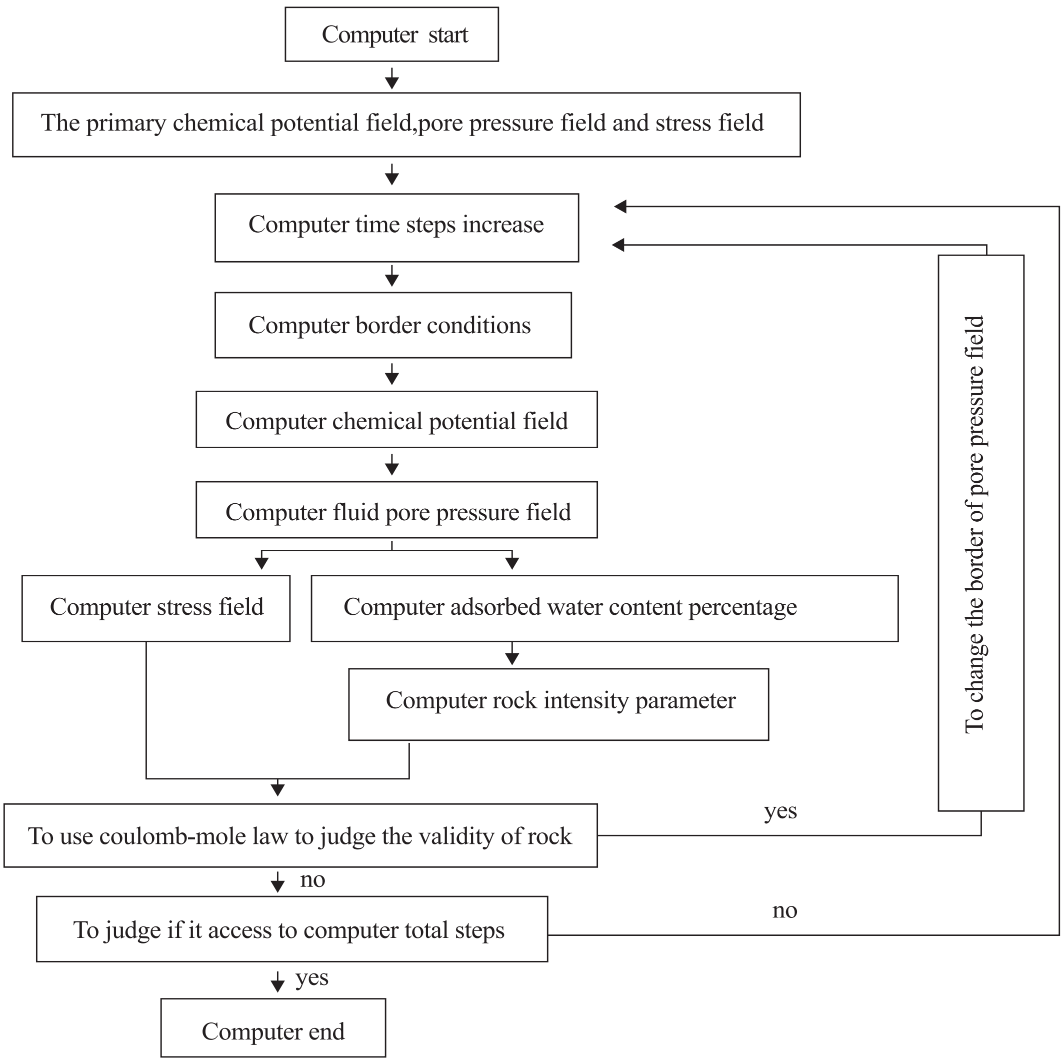

Figure 1
The Computer Process of Finite Element Software for Multi-Field Coupling Collapse Cycle Forecast

3. THE ANALYZE FOR MULTI-FIELD COUPLING COLLAPSE CYCLE

While drilling fluid contacting the formation, water molecule and ion will exchange continuously which their move closely related to the time domain and the space domain and the collapse pressure of borehole wall changes simultaneous. What follows in the passage we take a set of formation and drilling fluid parameters for example that it uses the software for multi-field collapse cycle forecast to simulation analysis the change law of pore pressure conductive, rock intensity and collapse cycle.

The analog computation use parameters as follow: minimal horizontal stress gradient is 0.017 MPa/m, maximum horizontal stress gradient is 0.021 MPa/m, vertical stress gradient is 0.026 MPa/m, and Poisson's ratio is 0.13, Biot coefficient is 0.8, initial formation pore pressure gradient is 0.0106 MPa/m, well depth is 2,500 m, porosity is 0.05, permeability is 6×10^{-9}mD, viscosity is 0.25cp, fluid compressibility is $8\times10^{-10}Pa^{-1}$, wellbore radius is 15cm, diffusion coefficient is $5\times10^{-10}Dm^2/s$, formation temperature is 300K.

3.1 The Analyze for Chemical Potential Impact on Pore Pressure Conduction

Figure 2 and Figure 3 given the change curve of pore pressure when drilling fluid activity is 0.9 and 1 respectively, where formation water activity is 0.95 and drilling fluid formula is 0.1%PHPA+2%ROH+0.2%SJ-1+3%PA-1+3%SPNH+0.3%MMH+20%KCl, core membrane efficiency measured from experiment is 30%. We can discover obviously from two charts that pore pressure around wellbore increase quickly at first and then up to stabilization. When the activity of drilling fluid under the activity of formation water, chemical action will remarkable slow down the increase tendency of pore pressure around wellbore that it in favor of the borehole wall's stabilization.

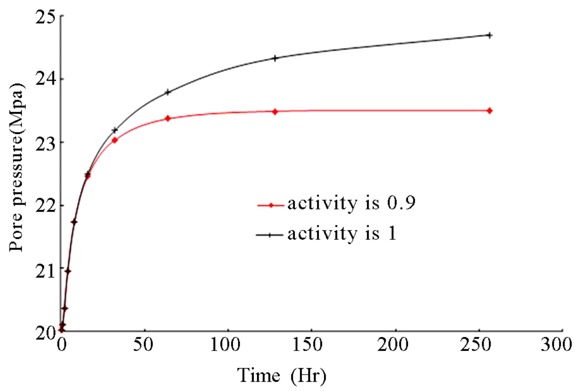

Figure 2
Pore Pressure Changes With Time When the Distance Is Equal to 1.1 Times Borehole Diameters

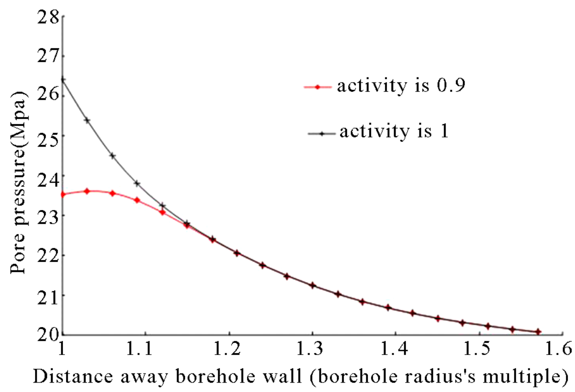

Figure 3
Pore Pressure Changes With Space (the Time of Conductivity Is 60h)

3.2 The Change Law of Rock Intensity Parameter Under Multi-Field's Action

As previously mentioned, the relation that cohesion and angle of internal friction of shale and water content general derived from experimental study. The experimental cores of this study come for from Karamay Oil Field of Xinjiang, we can obtain cohesion and angle of internal friction with different water content as list 1 and after matching and gain: k_1=-0.27919, k_2=-0.019, b_1=0.58, b_2=-0.034.

Table 1
Cohesion and Angle of Internal Friction With Different Water Content

Water content (%)	Cohesion (MPa)	Angle of internal friction (°)
2.47	34.8798381	21.40346785
3.38	27.0543027	20.65717999
4.04	22.5014704	20.13224902
5.07	16.8780668	19.33956424

Based on the computer for conductive model of pore pressure, the change of cohesion and angle of internal friction in the time domain and space can be obtained through simulation. As shown in the Figures 4 to 7, we can clearly see that the decrease of cohesion and angle of internal friction along with the increase of time and the increase of cohesion and angle of internal friction along with the increase of distance away wellbore. The use of drilling fluid with low activity can mitigate the decreasing trend of cohesion along with time at a certain extent under the combined action of chemical potential field and pore pressure field that it in favor of the borehole wall's stabilization.

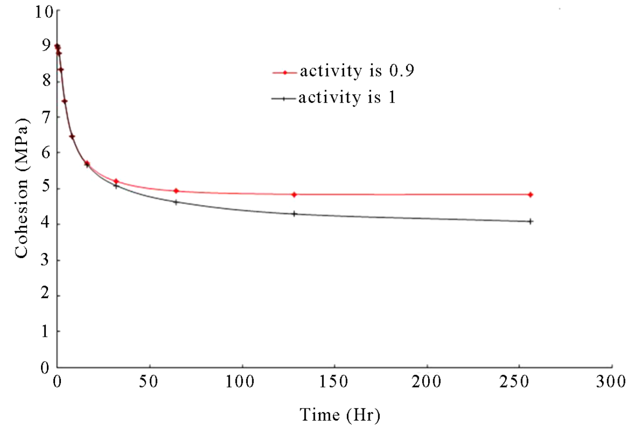

Figure 4
Cohesion Changes With Time When the Distance Is Equal to 1.1 Times Borehole Diameter

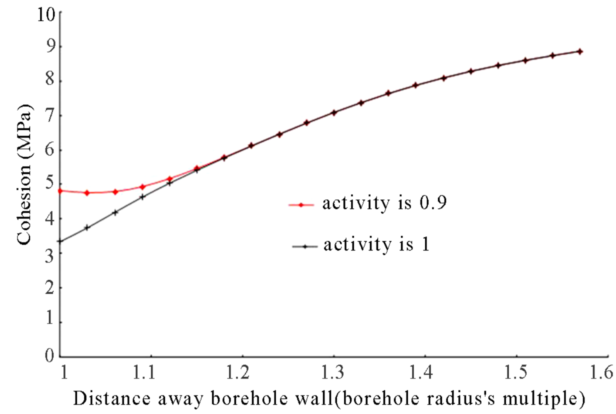

Figure 5
Cohesion Changes With Space (the Time of Conductivity Is 60h)

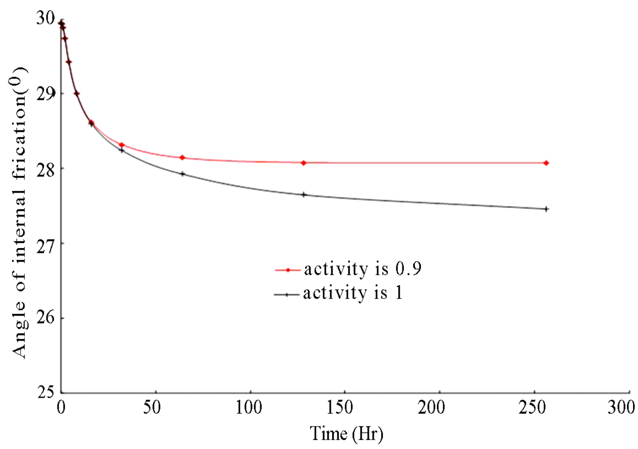

Figure 6
Angle of Internal Frication Changes With Time When The Distance Is Equal to 1.1 Times Borehole Diameters

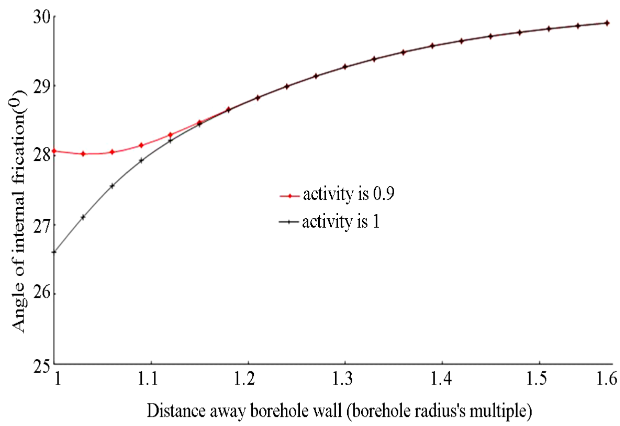

Figure 7
Angle of Internal Frication Changes With Space (the Time of Conductivity Is 60h)

3.3 The Forecast for Critical Collapse Pressure Under Multi-Field Coupling

With the change of pore pressure around borehole, rock intensity will change and its internal stress situation change at the same time. With certain drilling fluid density will can't meet the stability of borehole wall after some time, so we need to raise the density of drilling fluid to meet the requirement for the stability of borehole wall and adjust reasonably to use different density of drilling fluid during different time. Using the software of collapse pressure cycle to analog analysis above examples under multi-field coupling, the Figure 8 shows the critical collapse pressure and the density of drilling fluid with different time. It is very important for field drilling operation to comprehensive evaluation of collapse cycle from lithology and the performance of drilling fluid.

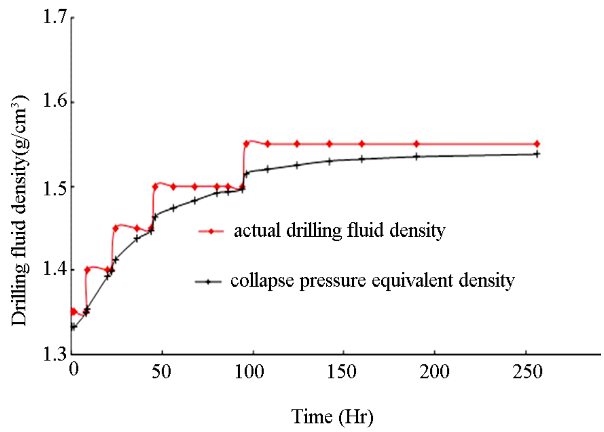

Figure 8
Collapse Pressure Equivalent Density Changes With Time

CONCLUSION

(a) To derive and establish the conductive model of pore pressure under coupling with chemical potential field, seeping field and stress field and the relation model of pore pressure and rock intensity parameter through experiments and theory deduction. The computer model for borehole wall collapse cycle of shale under multi-field can be created on their base and use the FEPG software to develop the relevant finite element program.

(b) The study show that chemical action can mitigate the rise tendency of pore pressure around wellbore and favor to maintain the stability of borehole wall when the activity of drilling fluid blows the activity of formation water.

(c) The low activity drilling fluid can mitigate the tendency of the increase of cohesion along with decrease of time under the combined action of chemical potential field and pore pressure field that favor stability of borehole wall.

(d) To evaluate the collapse cycle's size, we should consider from lithology and performance of drilling fluid and computer the critical collapse pressure of different time to optimize the density of drilling fluid which show great reference significance to maintain the stability of borehole wall during field drilling operation.

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